DEVELOPMENT OF AN ALGORITHM FOR MATERIAL SELECTION

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ABSTRACT

DEVELOPMENT OF AN ALGORITHM FOR MATERIAL SELECTION

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Material selection is one of the major points that should be taken into account seriously in the engineering design stage. Each material has various properties such as mechanical, thermal, electrical, physical, environmental, optical and biological properties. However, it is a well known fact that only a limited number of design engineers have a thorough knowledge on all these properties of a specific material, which is planned to be used in the manufacturing of the product. Therefore, the design engineer should be guided in selecting the most suitable material.

In the scope of this thesis, the aim was to develop an algorithm and a software package for material selection to help the design engineer in his decision making process. In the program, since steel is a widely used material in industry, it was selected as a material class among whole engineering materials, and a database covering all the necessary properties of various steels was constructed. These properties include chemical, mechanical, thermal, electrical and physical properties for steels. The database developed by using Microsoft Access also contains steels of 29 different steel standards and can be updated if the user wants.

The software package was developed for Windows environment by using Microsoft Visual Basic 6.0. In the program, steels can be searched for the list of suitable steels by entering application areas and properties such as chemical component, yield strength, heat capacity and electrical resistance. In addition to this, lists of steels can be created by selecting the appropriate name of the steel standards. Force and load calculations for various deformation processes such as forging, rolling, extrusion and drawing can also be carried out in the relevant modules within the program.

Key Words: Material Selection, Engineering Design, Software Package, Database, Steel, Steel Standards, Load Calculation, Deformation Process.

ÖZ

MALZEME SEÇİMİ İÇİN ALGORİTMA GELİŞTİRİLMESİ

Seyis, Önder

Yüksek Lisans, Metalurji ve Malzeme Mühendisliği Bölümü
Tez Yöneticisi : Prof. Dr. Haluk Atala
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Mühendislikteki tasarım işleminde, malzeme seçimi ciddi olarak ele alınması gereken noktalardan biridir. Her malzeme mekanik, elektriksel, termal, fiziksel, çevresel, optik ve biyolojik özellikler gibi çeşitli özelliklere sahiptir. Fakat, şu da iyi bilinen bir gerçektir ki ürünün üretiminde kullanılması planlanan spesifik malzemenin bütün bu özellikleri hakkında sınırlı sayıda tasarım mühendisi tam anlamıyla bilgiye sahiptir. Bu nedenle, tasarım mühendisi en uygun malzemeyi seçmede yönlendirilmelidir.

Bu tez kapsamında, amaç karar verme işleminde tasarım mühendisine yardım etmek için malzeme seçimi yapacak bir algoritma ve yazılım paketi geliştirmekti. Programda endüstride en çok kulanılan malzeme olmasından dolayı çelik, tüm mühendislik malzemeleri arasından malzeme sınıfı olarak seçilmiş, ve çeşitli çeliklerin tüm gerekli özelliklerini kapsayan bir veritabanı oluşturulmuştur. Bu özellikler, çeliklerin kimyasal, mekaniksel, termal, elektriksel ve fiziksel özelliklerini içermektedir. Ayrıca Microsoft Access kulanılarak geliştirilen veritabanı, 29 farklı çelik standartlarının çeliklerini kapsamaktadır ve kullanıcı istediğinde güncelleştirilebilir.

Yazılım paketi Microsoft Visual Basic 6.0 kulanılarak Windows ortamına uygun biçimde geliştirilmiştir. Programda, uygun çelikler listesi için çelikler, uygulama alanları ve kimyasal bileşimi, akma dayanımı, ısı kapasitesi, elektriksel direnci gibi özellikleri girilerek aranabilir. Buna ek olarak, uygun çelik standartlarının isimleri seçilerek istenilen çelik listeleri oluşturulabilir. Ayrıca program içindeki ilişkin modüllerde dövme, haddeleme, ekstrüzyon ve çekme gibi deformasyon işlemlerinin kuvvet ve yük hesaplamaları da gerçekleştirilebilir.

Anahtar Kelimeler: Malzeme Seçimi, Mühendislik Tasarımı, Yazılım Paketi, Veritabanı, Çelik, Çelik Standartları, Yük Hesabı, Deformasyon İşlemleri.

To the memory of my grandfather

MUSTAFA ÇALIKOĞLU

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CHAPTER 1

INTRODUCTION

Materials data are the basic requirement in engineering design. A material engineer should be aware of all possible alternative materials not to miss any opportunity in the design process. Tens of thousands of materials are available to engineers, and the number is increasing faster today than ever before. Each material has numerous mechanical, thermal, electrical, physical, environmental, optical, biological and other properties that are relevant to engineering design. No engineer can be familiar with more than a small subset of this ever-growing body of information. Although it is possible to narrow down these alternatives by using former experiences or some global charts and tables, it is still tedious and time consuming task to select the materials from handbooks or supplier catalogs.

Materials information can be classified according to the material family, the properties, the source of the data, or the data format. Many types of property data are functions of one or more variables. Therefore, it is obvious that a single database can not help solving every problem related to all kinds of materials. In order to obtain practical result, all the available material databases are concerned with a certain group of material. Grouping method changes due to the details of the information. In this study, taking into consideration the former experiences, problems and limitations encountered in engineering practice, a database and a data retrieval system is proposed for solving various problems in finding appropriate steels by searching through products of different countries. Steel is selected as the reference group since it is the most widely used material in engineering applications.

On the other hand, in manufacturing processes, materials are deformed to desired shape and size where optimum load should be applied during the deformation processes. Moreover, load calculations in the bulk deformation processes of steels need a strong interconnection between the database and the inference engine. In this respect, calculation of the optimum loads for major bulk deformation processes were included in the study.

As a result, in the scope of this study a software package is developed to assist a design engineer in selecting a suitable material for various applications. The database contains general, mechanical, physical and thermal properties of materials. In the first module, the user can view the properties of a specific material, which he may select among the material lists or search with its material designation or material number. In the second module, the user can calculate the required load for a specific material in a pre-defined bulk deformation process.

Database was created by Microsoft Access 97 and Microsoft Visual Basic 6.0 was used for the execution of algorithm for material selection and load calculation. Moreover, Mathcad 2001 is used for solving the load equations of bulk deformation processes explicitly. Program can be run on any IBM compatible machine and execution does not require Access or Visual Basic.

CHAPTER 2

THEORY

2.1. Engineering Materials

Materials have played a dominant role in the continued development of civilization and significant advances have been achieved with the development of new materials. The rapid increase in the variety of the manufactured materials in the last half century have played a major key in substutional technological progress. The most convinient way to study the properties and uses of engineering materials is to classify them into groups as shown in Figure 2.1 (Timings, 1998).

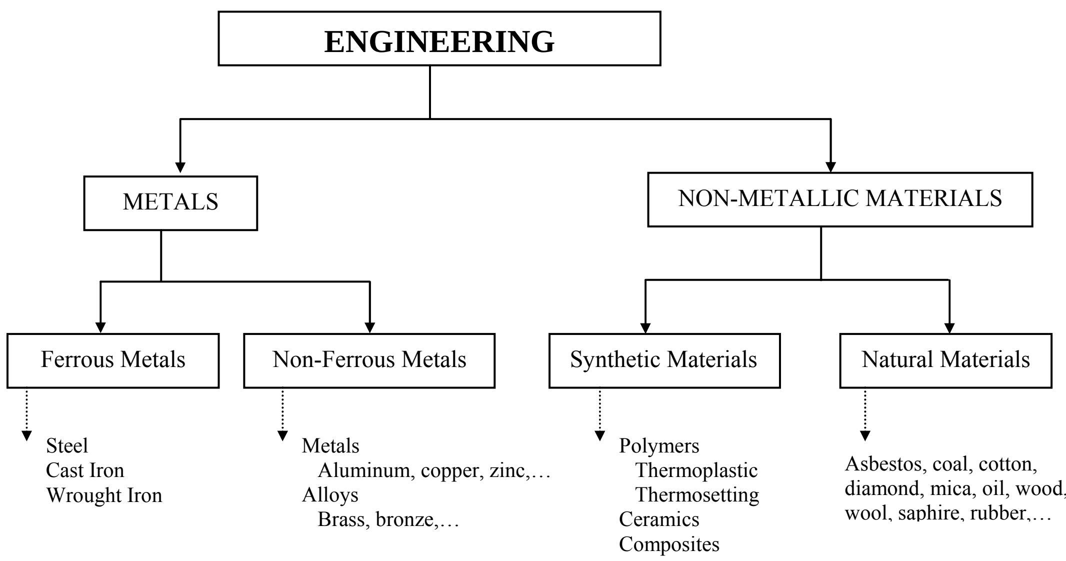

Figure 2.1 Classification of engineering materials

In Figure 2.1, some examples of material sub-groups are given besides the main engineering material families. The basic information related to the crucial material groups for design process will be given in the following sections.

2.1.1. Metals

Metals are inorganic substances composed of metallic elements including the broad majority of the elements in the periodic table. They have few valance electrons that are collectively shared by the atoms of the solid. This is referred as Metallic Bonding. As a result of this bonding, metals have a large number of neighboring atoms in their solid form and this provides the high density of metals. Moreover, the collective electronic nature of the atoms in the metals cause high electrical and thermal conductivity. The metallic bonding is also responsible for the high elastic stiffness of metals.

Most of the metals dissolve in each other to form an atomic solution or alloy. This solubility is often complete; that is, the elements dissolve in all portions in liquid states. The solubility in the solid state is usuallly more restricted. Materials engineers can explain the properties of metals with this feature of solid solubility.

Metals can be strengthened by alloying and by mechanical and heat treatment, but they can remain ductile, which accounts for their extensive use in structural applications. Metals are also not transparent to visible light; a polished metal surface has a bright appearance. Furthermore, metals are the least resistant to corrosion.

2.1.2. Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are frequently oxides, nitrides, and carbides (Callister, 2000). Chemical bonding in ceramics is different than in metals. As elements from the left side of the periodic table (electropositive elements) combine with elements from the right side of the table (electronegative elements), an ionic bond occurs. The ionic bond is due to the attraction between the negative and positive ions in the structure. Coordination number (the number of anion/cation near neigbors) of ionic solids are slightly less than those in metals, and this provides their lower densities. Ionic solids have lower electrical and thermal conductivities than metals in most cases. In the liquid state, ionic bounded materials often demonstrate respectable electrical conductivites due to the higher ionic mobility in liquid phase.

Some ceramics are covalent solids. Covalent bonding involves electron sharing that are localized. This results in low electrical conductivities and decrease in coordination number causing low density.

Many ionic solids include some degree of covalent bonding and the converse is true for covalent compounds. Therefore, some ceramics can be composed of partial covalent and partial ionic bonding. Materials of this nature are called polar covalent solids. Polar covalent solids usually display high melting points because of this mixed strong bonding.

Ceramics have often high elastic moduli, but they are brittle. Their strength in tension is too low with respect to their strength in compression that is 15 times greater. They are also stiff, hard and abrasion resistant so they are used as cutting tools in industry. Moreover, they are more resistant to high temperatures and corrosion.

2.1.3. Polymers

Polymers are composed of organic compounds that are chemically based on carbon, hydrojen, and other nonmetallic elements. Most polymeric materials consist of very large molecules which are in the form of long and flexible chains. The backbone of the chain is a string of carbon atoms bonded with strong covalent bonds to each other. The chain involves also side-bonding with various elements or radicals in which the bonds are weak Van Der Waals bonds in contrast to the strong intrachain strong covalent bonds. The dominant type of bond is covalent bond in polymers.

This results in low polymeric coordination number that acounts for their low densities. However, polymers' low densities are mainly due to the light atoms forming them. The localized nature of electrons in polymers renders them electrical and thermal insulators.

Polymers have very low elastic moduli meaning high elastic deflection. Moreover, the properties of the polymer strongly depend on temperature so that a polymer which is tough and flexible at 20^{o}C may be brittle at 5^{o}C. None of them have useful strength above 200^{o}C. Therefore; creep, a type of failure, is very critical for polymers. Polymers are also easy to shape so complicated parts used in industry can be formed from a polymer in a single operation. Furhermore, they are corrosion resistant and have low coefficients of friction.

Themoplastics such as polyvinyl chlorides (PVC) are polymers consisting of flexible and linear chains. They can be softened and reshaped by heating in many times. However, thermosettings, such as bakelite, epoxy, are composed of crosslinks between chains and are incapable of permanent deformation. Thermosettings are stronger as compared to thermoplastics because of their more dense and rigid networks. Elastomers are other types of polymers that may experience large and reversible elastic deformation (Pollack, 1981).

2.1.4. Composites

Composites are mixtures of two or more materials having significantly different characteristics. The development of the compound is due to the requirement of materials with unusual combinations of properties that can not be achieved by the conventional metals, ceramics and polymeric materials.

Most commercially important composites are polymer-based. The composites are made by adding a reinforcement over the thermoset polymer matrix during or prior to its setting. Glass, carbon and kevlar are common types of fibers used as reinforcement. The matrix acts as a glue, bonding the fibers, and also protects the reinforcement surfaces from degradation because reinforcements have generally low corrosion resistance.

Composites with metal and ceramic matrices are also available, but they are more expensive with respect to polymeric composites. Metals can be reinforced by ceramic particles or fibers and their strengths are increased, but at the expense of fracture toughness. In contrast, when metals reinforce the ceramic matrix, toughness is increased, but at the expense of strength. The increase in toughness can be satisfied with proper bonding with ceremic matrix and metalic reinforcements. Due to their high cost, metal and ceramic composites are not produced as a commercial product. However, since polymers have limited high-temperature property capacity, engineers must use metal and ceramic composites in high temperature applications.
Furthermore, composite components are expensive and relatively difficult to form and join. Therefore, engineers should use them only when added performance dominates the added cost.

2.2. Properties of Engineering Materials

Materials are selected and used as a result of a match between their properties and the needs ordered by the application. In this sense, the properties should be defined broadly and include fabricability.

The properties of materials are mainly determined by composition, internal structure and the result of the processing of a given composition. Therefore, types and amounts of various atoms and ions constituting the material are not the only factors that determine its property. In addition to those factors, the arrangements of the atoms or ions and various types of defects contribute to the properties of the material in a major way. The atom or ion arrangement and defect structures of the materials are determined by the processing of the material during the different stages of its manufacture. Thus, processing parameters control the structure of atoms or ions; this internal microstructure, along with composition, determines the properties of the material (ASM Handbook, 1997).

Although there is more than one effect in the determination of the material properties, some basic material characteristics (density, elastic modulus and to a lesser extent, thermal conductivity) are determined almost exclusively by chemical composition. These properties can be considered as microstructure insensitive. In contrast, microstructure sensitive properties such as the most of the mechanical properties (yield strength, fracture toughness, etc.) depend on microstructural features.

As a result of many effects explained above, the material properties constitute a large and complex list. The material properties can be summarised in the following table from general point of view.

Table 2.1 Material performance characteristics.

CHEMICAL PROPERTIES

- Position in electromotive series
- Corrosion and degradation
    - Atmosphere
    - Salt water
    - Acids
    - Hot gases
    - Ultraviolet
- Oxidation
- Thermal stability
- Biological stability
- Stress corrosion
- Hydrogen embrittlement
- Hydraulic Permeability

ELECTRICAL PROPERTIES

- Conductivity
- Resistance
- Dielectric constant
- Coercive force
- Hystresis

THERMAL PROPERTIES

- Conductivity
- Specific heat
- Coefficient of thermal expansion
- Emissivity
- Absorptivity
- Ablation rate
- Fire resistance

MECHANICAL PROPERTIES

- Hardness
- Modulus of Elasticity
    - Tension
    - Compression
- Poisson's ratio
- Stress-strain curve
- Yield strength
    - Tension
    - Compression
    - Shear
- Ultimate strength
    - Tension
    - Compression
    - Shear
- Fatigue properties
    - Smooth
    - Notched
    - Corrosion fatigue
    - Fretting
- Charpy transition temperature
- Fracture toughness
- High temperature behaviour
    - Creep
    - Stress rupture
- Damping properties
- Wear properties
- Cavitation
- Spalling
- Ballistic impact

PHYSICAL PROPERTIES

- Crystal structure
- Density
- Melting point
- Vapor pressure
- Viscosity
- Porosity
- Permeability
- Reflectivity
- Transperency
- Optical properties
- Dimensional stability

FABRICATION PROPERTIES

- Castability
- Heat treatability
- Hardenability
- Formability
- Machinability
- Weldability

NUCLEAR PROPERTIES

- Half-life
- Cross section
- Stability

The performance or functional characteristics of a material are expressed chiefly by physical, mechanical, thermal, electrical, magnetic, and optical properties. Material properties are the link between the basic structure and composition of the material and the service performance of the part. The goal of materials science is to learn how to control the various levels of structure of a material so as to predict and improve the properties of a material. Today the range of materials and properties available to the engineer is much larger and growing rapidly. This requires familiarity with a broader range of materials and properties, but it also introduces new opportunities for innovation in product development. An important role of the materials engineer is to assist the designer in making meaningful connections between the material properties and the performance of the part or system being designed.

Moreover, materials properties are not independent of each other (Sargent, 1991). There are certain interactions between some of them. For example hardness is directly related to the tensile strength and inversely related to the elongation. If certain hardness is required for the sake of design, then the elasticity of the material becomes limited. On the other hand, if details are considered, it can be said that there is no limit on the number of the materials properties. For example atomic structure or resistance to different chemicals, mechanical properties at different sizes, temperatures or tempering temperatures can be detailed as hundreds of different properties.

All of the material properties are not equally important for a specific design. Therefore, the values of the important properties for the design are usually printed into the documents. However, the degree of importance of the properties depends on the type of design application. For example, if a designer selects a stainless steel for a certain application, the corrosion properties of the materials will become the most important design parameters.

2.3. Design Process

The role of engineering design in a manufacturing firm is to transform relatively vague marketing goals into the specific information needed to manufacture a product or machine that will make a profit. This information is in the form of drawings, computer-aided design data, notes, instructions, and etc.

Designing a complex product or even relatively simple one with the requirements and considerations in mind is a tough and complex task. Therefore, finding creative and effective solutions to the many problems that are encountered through design is essential to competitive success. Creative problem solving is especially important early in the design process when conceptual alternatives are generated. Furthermore, a great deal of varied knowledge is needed in order to perform design competently and quickly. Thus, design is usually a team effort involving people from marketing, several branches of engineering, and manufacturing.

The total design model states that in any product development, the steps to be carried out include market investigation, product design specification, conceptual design, detail design, manufacture and sale (Pugh, 1991). A similar model was also developed and discussed (Pahl and Beitz, 1984) and is called the German Method by Prasad (Prasad, 1997a).

The goal of the first stage is to translate a marketing idea into engineering terms. The market investigation involves analyzing and clearly stating the problem. At this stage, the designer collects and writes down all the requirements and constraints. The target market of the product is delineated. Furthermore, safety considerations should be paramount.

At the concept level of design, essentially all materials and processes are considered rather broadly. The objective is to generate possible solutions, schemes, or methods to solve the problem. All different ideas are accepted and evaluated according to their merits. In this phase, all information and previous knowledge are put together in order that the proper decisions can be made. Specifications, which are developed for the product, are defined (Mangonon, 1999).

The embodiment design evaluates the two or three conceptual solutions or schemes selected in greater detail and makes a final choice of scheme or method to be used. The selection is done with considerable feedback to the conceptual design activity. The output of this stage should be rough drawings, specifications, and broad compliance to the needs and specifications of products.

At the detail or parametric design level, all the large number of small but important details to make or fabricate the product or component is considered. The quality of this work must be perfect; otherwise delays, higher costs, or failure may ensue. The output of this activity is a set of very detailed drawings and final specifications including tolerance, precision, and so on, to produce the product.

Pugh also developed a similar model for the total design process. In the conceptual design stage, Pugh has introduced a matrix evaluation chart called the Pugh alternative design selection process, in order to select the best concept. In this method, few concepts were developed and compared with an established concept called 'datum'. If the concepts are better than datum, positive scores are given, otherwise, negative scores. If the performance of the concepts is the same as datum, Ss is assigned. The concept with the highest difference between positives and negatives is taken as the best concept (Pugh, 1991).

At some stage in the process of converting a design idea into hardware, decision must be taken on the choice of material and the manufacturing route. These decisions should be taken at the earliest possible moment, as there are series of complex interactions between the three elements of materials, manufacturing and design (John, 1992).

2.4. Material Selection

The importance of materials selection in design has increased in recent years because the range of materials available to the engineer is much larger than ever before. This represents the opportunity for innovation in design by utilizing these materials in products that provide greater performance at lower cost. To achieve this requires a more rational process for materials selection.

Materials selection is a task normally carried out by design and materials engineers. The aim of materials selection is defined as the identification of materials, which after appropriate manufacturing operations, will have the dimensions, shape and properties necessary for the product or component to demonstrate its required function at the lowest cost (Gutteridge and Waterman, 1986). For the purpose of material selection, thousands of data would be needed to characterise all the grades of materials. Many selection systems are available to help design engineers to choose the most suitable materials. At the most basic level, design engineers could use tables of material properties in data books. However, data sheets are incomplete and once published, they are difficult to update.

Selecting the best material for a part involves more than selecting a material that has properties to provide the necessary performance in service; it is also connected with the processing of the material into the finished part. A poorly chosen material can add to manufacturing cost of a part and increase its price. Also, the properties of the material can be changed by processing (beneficially or detrimentally), and that may affect the service performance of the part.

Material selection is a complex process and it is very difficult to specialise in the selection sector. To choose the proper material for a specific process, the designer should avoid confinement of materials selection to materials that the designer is only familiar with. The designer utilizes also new materials and processes to enable innovation in design. The engineer improves product performance and eliminates material or service failure. Moreover, the designer solves processing difficulties and takes advantage of new processing techniques, reduces material and production costs, and anticipates or exploits a change in the availability of a material. The designer takes also the advantage of the introduction of a new product, or adjusts to a decline in the market. Furthermore, the designer accommodates a change in design for new and/or adverse environmental conditions.

Material selection is one of the most important activities for a product development process. In the modern design manufacturing environment such as newly-developed concurrent engineering methodology, material selection plays as important a role as other activities in the total design model such as market investigation, product design specification, component design, design analysis, manufacture and assembly as shown in Figure 2.2.

A material selection problem usually involves one of two situations. The first one is the selection of the materials and the processes for a new product or design. An original idea or working principle must be offered for development of the new product. Second one is the evaluation of alternative materials or manufacturing routes for an existing product or design. This situation usually is carried out to reduce cost, increase reliability, or improve performance. The process steps for both situations are different from each other.

Printed documents include several drawbacks as they are often outdated before reaching the bookshelves. It is very difficult to index them to find answers or to sort data in the manner of your choice. A computerized system, which provides access to materials data, is not necessarily a materials selection system, although access to data is essential to facilitate selection (White, 1995).

Cebon and Ashby developed a computerized materials selection system called Cambridge Materials Selector (CMS). The system uses materials selection charts, which are a way of displaying material property data through the use of optimization procedures. The selection process depends on implementing performance indices, a combination of material properties, which if maximized, optimizes performance.

The charts are developed to present the materials, and the performance indices, so that the most suitable selection of materials and shape can be carried out (Ashby, 1999, 1989 and, Cebon and Ashby, 1992,1996).

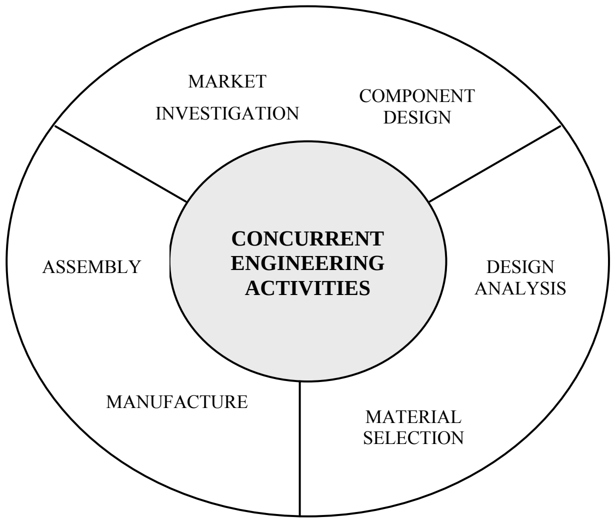

Figure 2.2 Importance of material selection in product development (Sapuan, 1998).

2.4.1. Relation between Materials Selection and Design Process

Materials selection plays an important role as important as design and manufacturing in the development of a product and that all these activities are interrelated (Charles, 1989).

Materials selection enters at every stage of the total design process. To attain the desired objective in the design process, it should typically go through certain stages, as mentioned before. Ashby developed a model describing the function of material selection in product design as shown in Figure 2.3. The materials required at each stage of design process differed greatly (Ashby, 1989).

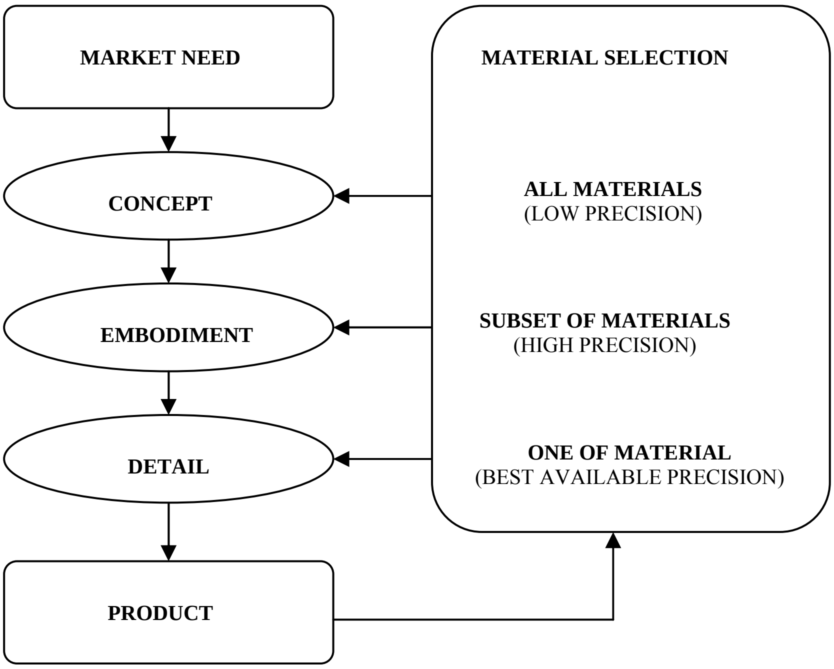

Figure 2.3 Design flow chart showing how materials selection enters the procedure (Ref. Ashby, 1989).

At the concept level of design, essentially all materials and processes are considered rather broadly. The designer requires approximate property values for the widest range of material. Therefore, the precision of property data needed is low. If an innovative choice of material is to be made, it should be at this stage because too many decisions have been made to allow for a radical change in the later stages of the design. During the embodiment design, the designer will have decided on a class of materials and processes. The material properties must be known to a greater level of precision. The data needed in this stage are found in more specialized handbooks and software, which deal with a single class of material. Finally, at the detail design, the decision will have narrowed to a single material and only a few manufacturing processes. Depending on how critical the part is, material properties may be required to a high level of precision. This precision is best found in the data sheets issued by the material producers.

Furthermore, a four-level approach to material selection in a more detailed approach to engineering design is developed. Level I based on critical material properties, and main group of the product is determined. In level II, type of manufacturing process is fixed. At the concept of level III, the narrow options to a broad category of material are carried out. Finally, the designers select a specific material according to a specific grade or specification in the level IV (Dixon and Poli, 1995).

From the studies given in the previous paragraphs, it can be concluded that the material and process selection is a progressive process of narrowing from a large universe of possibilities to a specific material and process selection.

2.4.2. Relation between Material Selection and Process Selection

Selection of material and manufacturing processes are placed in an early stage of the product design which accounts for 7% of the whole product cost while it is responsible for 65% of the potential decrease of the total cost (Hundal, 1992). The reason is that the design stage is decisive about the main cost constituents: material and manufacturing. It is important to develop designing aids that assist designers in the selection of materials and manufacturing processes (Perzyk and Meftah, 1998).

The selection of a material must be closely coupled with the selection of a manufacturing process. This is not an easy task since there are many processes that can produce the same part. The goal is to select the material and process that maximizes quality and minimizes the cost of the part.

In a general sense, the selection of the material determines a range of processes that can be used to process parts from the material. This range depends on certain material and process properties, and product considerations. The material melting point and deformation resistance and ductility are crucial for the applicability range of manufacturing processes. The first product consideration is the minimum and maximum overall size of the part. Shape of the product is the next factor to consider. The primary process is enough to produce the part as near to final shape as possible without requiring expensive secondary machining processes. Shape is often characterized by complexity. Complexity is correlated with lack of symmetry. In the most general sense, increasing complexity narrows the range of process and increase cost. Tolerance is the degree of deviation from ideal that is permitted in the dimensions of a part. Closely related to tolerance is surface finish. Each manufacturing process has the capability of producing a part with a certain range of tolerance and surface finish. Manufacturing cost increases exponentially with decreasing dimensional tolerance. Another process parameter is surface detail, the smallest radius of curvature at a corner that can be produced. Moreover, the number of parts required is another crucial consideration. For each process, there is a minimum batch size below which it is not economical to go because of tooling and equipment (ASM Handbook, 1997).

There are two approaches to determine material-process combination for a part. In the material first approach, the designer begins by selecting a material class and narrowing it down. Then manufacturing processes consistent with the selected material are considered and evaluated. With the process first approach, the designer begins by selecting the manufacturing process. Then materials consistent with the selected process are considered and evaluated. Both approaches end up at the same decision point. Most design and materials engineers use the materials first approach, where as manufacturing engineers gravitate towards other approach. No studies have been done to determine which leads to the best results (Dixon and Poli, 1995).

2.4.3. Knowledge-Base Systems

Information about engineering materials can be divided into two main categories, i.e. data and knowledge. Data is defined as the results of measurements, whereas knowledge represents the connections between items of data, the source of this knowledge, which contributes to an understanding of the results (Dodd and Fairfull, 1989).

In order to use a source of data effectively the user should have some knowledge base, which can be used to formulate an intelligent approach to the search and to provide a framework within which the data can be used. ‘Selection’ implies ‘decision’, and decisions can only be made against which would enable the data to be used in an intelligent way. Knowledge-base systems are software programs designed to capture and apply domain-specific knowledge and expertise in order to facilitate solving problems.

The knowledge-base system comprises expert knowledge capable of assisting the user in an interactive way to solve various problems or queries. Knowledge-base system is a computer system, which attempts to represent human knowledge or expertise in order to provide quick and easily accessible knowledge in a practical and useful way. Knowledge-base systems have the ability to accomplish cognitive tasks, which currently require a human expert. They can automate real time use of existing expert knowledge, explain it’s reasoning process and is readily extensible (Wu and Joseph 1990a, 1990b).

Languages can be used as a means to build knowledge-base system. They are means of capturing the knowledge for the design and development of a product. In addition to knowledge-base language, there are two types of languages that can be employed to capture life-cycle intent. These are geometry-based language and constraint-based language. Knowledge-based language provides ways to capture geometry and non-geometric attributes, and to write rules that describe the process to create the assembly. In addition to this, knowledge-based engineering deals with processing of knowledge. It is a process of implementing knowledge-base systems in which domain specific knowledge regarding a part or a process is stored together with other attributes (Prasad, 1997a).

Knowledge-base system for material selection enables the material selection task to be distributed among the talented concurrent engineering team members, in order to reduce the time for selecting the most suitable materials. Knowledge-base system of material selection comprises important tools in the forms of hardware and software.

In the knowledge-base system, advanced technology such as multimedia enables the users to communicate with the system interactively with interesting graphical user interface. The system could be used in conjunction with other important concurrent engineering techniques such as the Pugh selection method (Prasad, 1997b), FMECA, QFD and others.

It is reported that the area of computerized expert or knowledge-base systems can help analyze a complex situation and offer assistance to the user in solving the problem (Gubiotti, 1986). While this concept may not apply equally well to all problems facing an engineer or scientist, there are certain areas within material selection or data analysis that have been successfully improved using such techniques.

The knowledge-base system for material selection, in which the integration is made with the total design method, has been developed. This knowledge-base system also includes matrix evaluation method (Sapuan, 1998).

Finally, it can be concluded that the knowledge-base system is a very appropriate tool in material selection process. Some of the material databases could also be used as material selection systems, but as they are mainly developed for data storage, the material selection process using a material database is not very reliable. Therefore, attention should be given to the material selection process using a knowledge-base system.

2.5. Materials Data and Information

Only two generations ago the information needs of a materials engineer were rather simply served. This was because there was little intersubstitution among the major classes of materials and because the engineer was, most likely, a metallurgist with little concern for materials other than metals. There are over 100,000 different commercially avaliable materials in today's industry. Increasingly, in many applications, plastics, ceramics, and glasses compete directly with metals;

processing techniques once regarded as unique to a certain materials class are being adapted to other quite different classes. Although there are many scientific approaches to narrow down these alternative materials during selection, it is still a tedious task to choose the materials from printed documents for a specfic application (Farag, 1989). Thus, the scope of materials for which information is required has been greatly broadened.

In addition, the sheer volume of information has increased exponentially. There has been a general explosion in the primary journal publications, and another exponentially growing collection has developed in the report literature. Furthermore, an increasing proportion of materials data is not in hard-copy print form but in electronic formats, available on floppy disks, tapes, CD-ROMs, or on-line. Moreover, health, safety, and environmental issues require types of information unheard of a few decades ago for the application, storage, and disposal of materials. Worldwide sourcing of materials, multinational operations of many companies, and development of the use of the SI (the "metric system") place new demands on the searcher, compiler, and disseminator of materials information.

It is also important to emphasize that the materials information needs of engineers in industry are more demading and difficult to satisfy than those of the materials scientists. Engineers must not only possess the best existing value for the certain property, but they must also know the limits of uncertainty for the value in order to estimate the reliability of design. While materials scientists works with elemental metals or individual chemical compounds, engineers in industry are frequently interested in complex alloys, clads, and other composites whose properties and behavior must also be known or reliably estimated. Furthermore, many properties of commercial materials are not fixed values, as they depend on processing history, resulting structure and effect of external variables. In addition, engineers frequently require data that cannot be expressed in terms of a single property or combination of properties, but must be related to a performance test or service application.

Fewer sources of compiled and evaluated data supply the needs of industry as compared to scientists. Engineers in industry have less time available to search for answers to their questions or to compare their answers with other diverse sources. Furthermore, existing materials data compilations, both print and electronic, display a confusing variety of terminologies, test methods, property unit. The available data compilations may be from a publisher, from a materials supplier, or result from an in-house testing program. Approval of reliability of the information may be keyed to the individual editor, a professional association, or the data generator.

Table 2.2 Material information required during detail design (National Materials Advisory Board, 1995).

<u>Material identification</u>
- Material class (metal, plastic,…)
- Material subclass
- Material industry designation
- Material product form
- Material codition designation
- Material specification
- Material alternative names
- Material component designations

<u>Material production history</u>
- Manufacturability strengths and limitations
- Material compositions
- Material condition (fabrication)
- Material assembly technology
- Constitutive equations relating to properties

<u>Material properties and test procedures</u>
- Density
- Specific heat
- Coefficient of thermal expansion
- Thermal conductivity
- Tensile strength
- Yield strength
- Elongation
- Reduction of area
- Moduli of elasticity
- Stress-strain curve or equation
- Hardness
- Fatigue strength

<u>Temperature (elevated)</u>
- Tensile strength, yield strength
- Creep rates, rupture life at elevated temp.
- Relaxiation at elevated temp.
- Toughness

<u>Damage tolerance</u>
- Fracture toughness
- Fatigue crack growth rate
- Temperature effect

<u>Environmental stability</u>
- Toxicity
- Recyclability/disposal

<u>Material design properties</u>
- Tension
- Compression
- Shear
- Bearing
- Controlled strain fatigue life

<u>Processability information</u>
- Finishing characteristics
- Weldability/joinining technologies
- Suitability for forging, extrusion, and rolling
- Formability(finished product)
- Castability
- Repairability
- Flammability

<u>Joining technolgy applicable</u>
- Fusion
- Adhesive bonding
- Fasteners
- Welding parameters

<u>Finishing technology applicable</u>
- Impregnation
- Painting
- Stability of color

<u>Application history/experience</u>
- Successful uses
- Unsuccessful uses
- Applications to be avoided
- Failure analysis reports
- Maximum life service

<u>Availability</u>
- Sizes
- Forms

<u>Cost/cost factors</u>
- Raw material
- Finished product or require added processing
- Special finishing/protection
- Special tooling/tooling cost

<u>Quality control/assurance issues</u>
- Inspectability
- Repair
- Repeatability

Property data and information are needed at each stage of the design process. The needs for materials data changes as the design stages proceed. At the start of the design process, low-precision but all inclusive data are needed. At the end of the design process, data are needed for only a single material, but very precise data are required. These data are best found in the data sheets issued by materials producers. There is a very wide range of properties that may be needed, but in addition to these properties information including manufacturability, cost, experience base in use in other applications, and issues of quality assurance must be included. The material information in detail design is listed in Table 2.2.

In recent years, attention is given to the use of computer systems to store and process data regarding the properties of materials. It enables the designers to achieve large capacity and rapid retrieval from a computer database to provide easy access to the materials data.

2.5.1. References for Sources of Data

A persistent problem for seekers of materials information is the lack of adequate guides and directories. The insufficiencies of existing directories are composed of poor currency, narrowness of focus (by country, by material class, by format, etc.), and poor characterization of the reliability of the information contained.

Westbrook (1986), and Westbrook and Reynard (1993) developed a guide for overviews of materials information sources. It covers technical information sources: encyclopedias; dictionaries; numeric, graphical, and pictorial data sources; auxiliary information sources; the primary literature; reviews; and special topics. Moreover, Wawrousek et. al. (1989) presented a comprehensive materials information directory. It is an indexed catalogue of some 1250 different sources of data on the mechanical and physical properties of engineering materials. Each identified source was categorized by type such as computer readable, data center, printed handbook, etc. Many other useful guides to materials information sources are developed in various types of surveys.

Certain organizations are established to provide material information sources to engineers dealing with design process. They supply bibliographic material information sources as well as numeric or factual one. In addition to the organizations, the Internet is rapidly developing as a source of information on a vast array of topics. Clement (1995) and Renehan (1996) developed two general guides to science and technology on the Internet. Thomas (1996) and Meltsner (1995) were introduced databases to the Internet for materials scientists and engineers. PC software, and mathematical routines are typical examples of available general-interest applications on the Internet. Newsgroups such as “sci.engr.metallurgy” and “sci.materials” can provide free information on the existence of material information sources covering particular materials topics. Because such a vast quantity of information is available on the Internet, considerable time or specialized browsing software is needed to deal with it.

2.6. Material Databases

According to Prasad (1997a), materials are the common elements ordering parts in a product realization process. Nowadays, design engineers normally rely on the materials that they are familiar with. However, when design requirements exceed the constraints of such materials or exceed the constraints on material properties, concurrent engineering teams must consider alternative materials. With direct online access to a materials database, the concurrent engineering teams could select materials that are lighter, stronger and lower in cost. Assuming that the impact of such substitutions can be analysed or simulated, the teams could easily make an optimum selection of materials for the available processes, conserve materials for each process and thus, reduce material waste. Therefore, the usage of the databases is very crucial in the design process. The use of computer-aided tools allows the engineer to minimize the material selection information overload. A computerized materials search can accomplish in minutes what may take hours or days by a manual search.

Reynard emphasized the importance of the materials database and has criticized the attitude of some people who said that materials selection is not required by engineers or as a service from a computerized database. He suggested that the materials database should be presented 'in the best form suited to the needs of the users' such as by on line systems, mainframe systems, floppy disc for desktop use and CD-ROMS (Reynard, 1989).

Much materials information is structured in the material databases. It typically consists of databases or spread sheets with typical or allowable properties of materials. Other information is unstructured. It consists of electronic text, pdf or html files, photographs, tables, and/or graphs. The information may originate from reference or in-house sources. Reference data is provided by organizations such as ASM International, standards bodies (ISO, ASTM, AISI), Mil-Handbooks, material producers, and others. In-house data is data derived from corporate materials tests, or data collections built by company personal using other sources. Examples of structured reference data are databases provided by ASM in its Alloy Center; by Granta Design Ltd in its Material Universe database; Matweb; and others. Structured in-house data typically resides in the databases developed by materials engineers within a company. They often contain design (or "allowable") values of the properties of a list of preferred materials. The most comprehensive source of unstructured reference information is probably the ASM Handbooks, both print and online. Unstructured in-house information consists of reports, failure analyses, personal notebooks, and filling cabinets full of information collected over the years by material specialists in a corporation (Cebon and Ashby, 2003).

All materials property databases allow the user to search for a material match by comparing four or more property parameters, each of which can be specified as below, above, or within a stated range of values. Some databases have the ability to weigh the significance of the various properties. The most advanced databases allow the materials property data to be transmitted directly to a design software package, such as finite element analysis, so that the effect of changing material properties on the geometry and dimensions of a part design can be directly observed on the computer monitor. However, this capability is generally limited to a narrow homogeneous group of material.

Table 2.3 Examples of material databases and data centers according to their field

Field	**Database information**	**Country**
General	AEA Metals Databases (C)	U.S.A
	Cambridge Material Selector (C)	U.K
	CETIM-Centre Technique des Industries Mécaniques (C)	France
	DASMAT-Data sheet system of material (C)	Japan
	Engineering Science Data Unit (ESDU) (D)	U.K
	ICAM-RIMSE-Information Center on Advanced Materials (D)	China
	BAM-Information system on Measurement of Mechanical Quantities (D)	Germany
	Metals Infodisk (C)	U.S.A
	PERITUS (C)	U.K
	Binary Alloy Phase Diagrams (C)	U.S.A
	MAPP-Material Database from ASM (C)	U.S.A
	MATUS-Supplier's Data on a Full Spectrum of Materials (C)	U.K
	MATADOR (C)	Germany
	MSC/MVISION (C)	U.S.A
	TNO Metal Institute (D)	Netherlands
Ferrous Metals	American Iron and Steel Institute (AISI) (D)	U.S.A
	BCIRA-British Cast Iron Research Association (D)	U.K
	Stahlschlüssel (P/C)	Germany
	ENSTAL-Material Strength Database for Engineering Steels and Alloys (C)	Japan
	CASIS-Minitech Computerized Alloy Steel Information System (C)	Canada
	WDB-Werksstoffdatenbank (C)	Germany
	ISS-Iron Steel Society (D)	U.S.A
Nonferrous Metals	Aluminum Association (D)	U.S.A
	ITA-International Titanium Association (D)	U.S.A
	NiDI-Nickel Development Institute (D)	Canada
	Lead Industries Association (D)	U.K
Plastics	CAMPUS-A Database of Engineering Polymers (C)	Germany
	CETIM-ASTAR (C)	France
	ENGINPLAST (C)	France
	PLASTICS-International Plastic Selector (P/C)	U.S.A
	PLASCAMS-DB-Commercially Available Plastics and Elastomers(C)	U.K
	PLASTI-SERV(C)	U.S.A
	POLYMAT (C)	Germany
Ceramics and Glasses	ACDB-Advanced Ceramics Data Base (C)	China
	INTERGLAD (C)	Japan
	KERAMIK (D)	Germany
	NIST-Structural Ceramics Database (C)	Germany
	SG PROMAT (C)	France
	Ceramic Phase Diagrams (C)	U.S.A
Composites	ACM-Advanced Ceramic Composites (C)	Japan
	CETIM-FIMAC	France
	Database of Composite Materials for Future Industries (C)	Japan
High-temperature Materials	DIWA-Databank information system for materials behavior (C)	Germany
	HIGHTEMP (C)	Sweden
	HTMIAC-High Temperature Materials Information Analyses Center (D)	U.S.A
	HTM-DB-High Temperature Materials Data Bank (C)	Netherlands

The development of material databases has been reported by Harmer, Breuer, Baur, Michaeli, Ashby, and Cebon and Ashby. Material information sources are listed in Tables 2.3 to indicate current, authoritative and important databases. In selecting sources, emphasis was placed on sources containing substantial amounts of quantitative information on engineering properties of materials. Three different types of source are coded as C, computer readable; D, data center; and P, print.

Harmer (1997) reported that various database systems have been developed for plastics, elastomers and rubbers such as the Cambridge Materials Selector (CMS), CAMPUS, Selector II, Plaspec, CenBASE/Materials, Mat.DB, Plastics Design Library, Engineered Materials Abstracts, FUNDUS, Prospector Plus, Polymat, SPAO, Pro-Concept, Explorer, Platt's Polymerscan, Standards Infodisk, Pira Abstracts, Packaging Science and Technology Abstracts.

Computer-aided material pre-selection by uniform standards (CAMPUS) is a widely used materials database for plastics. A product similar to that of CAMPUS is a database concerned with the selection of long fiber reinforced plastics. This system is called FUNDUS and it allows the distribution of material information from the producer to the designer end-user. As such, it is of interest to all who work with sheet molding compound, bulk molding compound or glass-mat thermoplastic materials as reported by Baur (1994, 1995) and Michaeli et. al. (1995).

CAMPUS and FUNDUS have features, which allow the user to view all properties for any listed product, print the data for any products, search the database for products satisfying specific property requirements, select and view properties for comparison, and sort according to specific requirement in ascending or descending order.

Steel Property Database (SDB) including data processing system was developed and it was possible to select steels, throughout the chemical and mechanical properties. Computerization of different steel information was achieved by the developed database (Öcal, 1996).

Waterman et. al. (1992) studied the computerized materials property data systems for meeting the requirements of design, production and materials engineers. Computerized data and information on material are available in two forms. Firstly, there are on-line systems where the subscriber to the system could contact a central computer through a local terminal-modem telephone link and secondly, personal computer-based systems where the subscriber receives data on floppy discs and accesses these through a compatible personal computer.

Since each materials database has a complicated data structure and specific search functions, construction of a database needs much money and manpower and expertise of skilled researchers. Therefore many of these databases are constructed by governmental organizations or national research institutes, sometimes by their cooperation, in financial support of national funds. In addition, a great deal of effort is necessary for compilation and evaluation of different types and levels of data, which are diversified widely. Therefore it has been recognized that interlinking of databases in various organizations, international cooperation and standardization are very important for establishing and distributing databases.

In recent years, growing cooperation between information institutions and their integration makes the future development of databases and their usage more efficient. Since the beginning of 1998, Elsevier Science, which offers databases and electronic library products and publishes approximately 1200 scientific journals in all major scientific technical and medical disciplines, has acquired Beilstein Informationssysteme GmbH and entered into an exclusive license with the Beilstein Institute to market and support the Beilstein Database which will be updated and enhanced by this Institute in the future. Cooperative activities frequently take place within the framework of such organizations as the International Council of Scientific Unions and its Committee on Data for Science and Technology (CODATA) to improve the quality, reliability, processing, management and accessibility of data of importance to science (Fiala and Sestak, 2000).

2.6.1. Structure of Material Databases

Original source data in materials databases have many items, and they often can be represented in complicated data structure. In construction of database, these source data items are structured to a record, which is the information unit of a data file. Typical data items of materials databases are presented in Table 2.4 (Eriguchi and Shimura, 1990).

Table 2.4 Main data items of data in materials databases

Data item type	**Data items**
Material identifier	Compound code, compound name, chemical name, molecular formula, composition, material type, code (ASTM, DIN), common name, commercial name, species, producer
Property data	Molecular structure, physical property, mechanical properties, corrosion data, machinability, processability, phase diagrams, thermal property, electrical property, spectra, etc.
Auxiliary information	Compound class, synthesis, sample form, measurement condition, heat attribute, history, testing condition, welding, sampling location, mixing ratio, processing, producer, phase diagrams, photographs, comments, etc.
Reference information	Journal: name, issue (volume, number), publication year, author, organization, title of document, etc.

The materials database must store a large number of data items, which represent both property data and various auxiliary information, thus a unit record should be very large. Furthermore, each data item is correlated with the other items, so it is necessary to select an appropriate database structure among simple linear structure, multi dimensional relational structure, and network structure. Spectrum databases and chemical substance databases have relatively simple data structures, but databases for physical properties and mechanical properties have complex data structures corresponding to the relations within each data items.

The validity of the data in a database is an important issue. In order to increase the reliability and accuracy of the data in a computerized database; used sources, statistical basis of the data, status of the material, evaluation status, validation status, and certification status must be described. As the materials database includes standardized material specifications such as the material name, chemical composition, and production method, as well as standardized material properties such as numerical data, unit, test method and measuring parameters; it can be considered as a validated database.

Data types of materials databases are presented in simple textual data, numerical data, tables of data, or graphs. Textual data of character mode such as material names, key words, and author names are searchable with full-spelling, right-truncation, and string search techniques. Numerical data can be searched with range searching, above below, or within the limits specified.

2.6.2. Bibliographic Material Databases

Bibliographic databases have been around for many years, and in most cases their development has followed a similar course. A typical example is METADEX, the database covering the literature on ferrous and non-ferrous metals which is produced jointly by The Institute of Materials and ASM (American Society for Metals) International (Jackson, 1994).

Bibliographic databases give the references and sometimes these references may be supplied together. In general, the best way to achieve an accurate and economical research is to make use of controlled index terms (descriptors) rather than using simple free text. Many databases also offer subject categories which allow the user to carry out efficient and effective searches of broader topics.

Depending on the content of the database, the bibliographic databases can be classified. For example, there are numbers of long established 'heavy weight' databases. They are together with several more modestly sized general files, which have a very wide range in their coverage of technical and engineering subject matter. These databases contain substantial amounts of information about materials, most notably from the core journals and journals in related areas of physics and chemistry, but, because of their sheer size, care is needed to prevent search costs escalating to unacceptably high levels. Using these databases, it is relatively easy to retrieve reasonably satisfactory numbers of references on most standard or well documented materials themes, but it is also possible to miss minor topics which might only be covered in more specialized files.

Moreover, there are many databases whose area of coverage falls entirely within the province of materials science and technology. These include major and universal files such as METADEX, EMA and RAPRA Abstracts, and also files which are devoted exclusively to a large particular material or material type. Also within this category are the files dedicated to a particular aspect of materials engineering. When searching for information about materials, these databases are obviously of central importance. They cover the core journals and major conferences, as well as other types of literature such as patents and graphs. Since these specific databases are compiled by experts in the materials field, they can be relied on to pick up many of the smaller but valuable publications or those covering unusual or more controversial topics. Some of these databases are aimed at the pure scientist developing the materials; others take the more practical viewpoint of the engineer using them.

Information about materials can also be found in the many important databases, which limit their scope to a particular industry or area of technology. The advantage of using these files is that their contents are selected with the needs of that industry in mind and they often include papers published in sources not covered by other files. Much information can be found in the specialized materials databases. However, the searcher should keep in mind that papers retrieved from a materials science database will be written with the materials scientist in mind; papers retrieved from a file such as MEDLINE will generally be written in the language of medical professional, whose primary concern is the patient rather than the material.

Furthermore, specific databases include technical information, which is of use to the business person, or business information, which is of interest to the research scientist or engineer. They may contain information about the material industry; new products and production processes, trade and economics, markets, legislation, etc. Indeed, these databases can be used to supplement a batch of search results and provide a connection between these results and actual commercial concerns (Feldt, 1994).

Bibliographic databases may be on line or in CD-ROM. During the last decade, electronic bibliographic tools have been accessed by an increasing amount of users, many of whom might be classified as novices. During this same period, the cost of scientific journals has increased exponentially, forcing many university libraries to reduce the number of journal titles or substitute paper versions with those that can be accessed electronically, thus increasing the demand for Internet-based information access. This trend is also due to the ever-increasing availability of various reference information services (e.g., the Oxford English Dictionary, Encyclopedia Britannica, or various statistics covering national or other themes) together with several bibliographic databases (e.g., Inspec, Biosis, Springer LINK or the ISI Web of Science). In the latter case, in order to provide effective access, various modern indexing and abstracting services (such as MEDLINE, PsychINFO, Chemical abstracts) make use of some sort of human subject analysis and indexing, often invoking a controlled vocabulary (Savoy, 2004).

Some other bibliographic database examples can be listed as: CA (Chemical Abstracts) Search and INSPEC (Information Service in Physics, Electrotechnology and Control). Moreover, the world's largest and most comprehensive index of chemical literature, the CAS Abstracts File, now contains more than 18 million abstracts. During 1998, this file increased by 681008 new abstracts. Of these, 559009 were abstracts of papers (that appeared in some 14000 journals from 150 nations), 117815 patents (from 29 nations) and 4184 books related to chemistry (Fiala and Sestak, 2000).

2.6.3. Factual Material Databases

Bibliographic databases are designated as reference database because they provide orientations to the source documents. In the initial stage of design process for material selection, low precision material data is required. However, these are not proper databases for material design and manufacturing at this stage. The existence of the databases including certain material information directly is significant factor in the initial stage of design to provide effective and efficient searching of the information. For this purpose, factual databases are developed and they allow engineers to access directly to the source information that represents “fact”.

The available scientific and technological factual databases are much more likely to be used directly by designers and engineers involved in, for example, materials selection. The form of data related to engineering materials may be numeric, textual-numeric, full text, and graphic or image in these types of databases. In this study, this type of a database is developed.

To satisfy the extension of needs and importance of materials information systems, a variety of materials databases have been constructed as factual databases (Eriguchi and Shimura, 1990). In different literature sources they may be referred as “numerical databases”, “property databases” or “factual databases”.

Materials information in the factual databases does not contain a broad spectrum of information that is needed in the detailed design generally. Material types are composed of metals, refractories, superalloys, ceramics, glasses, composites, inorganic and organic compounds, plastics, semiconductors, woods, and others in the factual databases. These databases provide the information on materials properties such as mechanical properties, chemical properties, thermal, electrical, electronic, and other physical properties, corrosion, oxidation, and processability. However, usually mechanical and corrosion properties are well covered, with less extensive coverage of magnetic, electrical, and thermal properties. Since it is unlikely that any database will be sufficiently comprehensive for a specific user, it is vital that the system be designed so that users may easily add their own data and subsequently search, manipulate, and compare these values along with the entire collection of data.

In the area of enhanced electronic communications and the world-wide development of information systems, electronic publishing and the Internet offer powerful tools for the dissemination of all type of scientific information. However, because of the multitude of existing data of interest to materials science and technology and the variety of modes of presentation, computer-assisted extraction of numerical values of structural data is as difficult as before. As a consequence, the collection of these data, the assessment of their quality in specialized data centers, the publication of handbooks and other printed, the storage in data banks, and the dissemination of these data to end users (educational institutions and basic scientific and applied research centers), still remain tedious and expensive operations.

2.6.3.1. Construction of Factual Material Databases for Selection

Materials information is generated by a process that starts with individual test records, the results of measurements on a testing machine. Such tests are normally repeated many times, and the results are processed statistically to generate "allowable" (reference) values: minimum values of properties such as strength and modulus, which can be reliably used for design purposes. Measured property values for various temperatures, strain rates, and similar properties may then be combined to provide "functional" data, such as strength versus temperature. This process is very time consuming and very expensive, since many hundreds or even thousands of individual tests may be required to characterize just one property of the material. It is often a good idea to store the data generated by this process at three different levels (Cebon and Ashby, 2003).

First, the raw test data and all associated information about its pedigree (information about the material batch, the testing procedure, etc.) may be saved for quality assurance purposes, or to enable the possibility of further analysis. Second, the "reference data" is needed for design calculations. Note that it is important to be able to trace the source of the reference data. Therefore, it is highly advantageous for each record in the reference-data table to be linked to all of the raw-data table records that served to generate it.

Finally, another level of abstraction is required if materials information is to be used for optimal selection. Selection databases must satisfy a number of special requirements; otherwise, selection software that incorporates them will not yield optimal results. Therefore, it becomes necessary to process and collate the reference data in a variety of ways to generate selection data. The resulting database often contains "typical" values rather than "allowable" values, as a consequence of the wide variety of sources. It is helpful to link each record in the selection table to all relevant records in the reference table.

Certain standards for testing conditions are developed to obtain easier proper material data for selection databases. The utility of test data is not simply enhanced when standard tests are used. The test equipment has been calibrated using well-defined, certified reference materials. Moreover, standards for reporting test data have been fully met. Finally, terms used, descriptive of the material and the test, are recorded and defined. Without meeting the above conditions, it would be difficult to search a database or to properly merge or compare independent data sets. For this reason, certain organizations such as ASTM, ASM, ISO, etc. has been active in recent years developing standards for describing materials and recording test results and properties.

Problems of international standardization prevent a complete material database in the industry. However, it has been seen that databases including more specific data and certain groups of materials can also be practical and effective, if they are designed for specific purposes (Öcal, 1998).

2.7. Steel

2.7.1. Introduction

The study of steels is important because steels represent by far the most widely used metallic materials, primarily due to the fact that they can be manufactured relatively cheaply in large quantities to precise specifications. They also provide an extensive range of mechanical properties from moderate strength levels with excellent ductility and toughness, to very high strengths with adequate ductility. Therefore, steel is selected as the reference group for developing a database.

Steel is a metallic material. Since its basic component is iron, it is included in ferrous materials group. The ferrous materials with carbon content higher than 2% are categorized as cast irons and those with carbon content less than 2% as steels. (TS EN 10020, 2003). Carbon plays differing roles in affecting the constitution of the steel, as steels are heated and cooled (Hanson and Parr, 1965). Steel also includes some other elements such as manganese, phosphorus, sulphur, silicon, chromium, nickel, etc. in proper amount according the production purpose.

2.7.2. Classifications of Steels

Classification is the systematic arrangement or division of steels into groups. Steels are classified or grouped according to some common characteristics. The most common classification is by their composition and then by their strength. They are also classified by their final processing or finishing methods as well as by their sizes and shapes.

Classification by product form, such as bar, plate, sheet is very common within the steel industry because by identifying the form of a product, the manufacturer can identify the mill equipment required for producing it and thereby schedule the utilization of these facilities.

2.7.2.1.Classifications of Steels According to Composition

According to composition, the classification is broadly done with the carbon content and the alloy content, as shown in Table 2.5 (Mangonon, 1999). According to carbon content, steels are commonly classified as low carbon, medium carbon, and high carbon. According to the alloy content, they are plain carbon steels when no alloying element is added, except manganese which may be added up to 1.65%, silicon up to 0.60%, and copper up to 0.60%. Silicon and copper in the composition are not usually intentionally added but are the result of recycling of scrap iron. When other alloying elements are added, such as manganese up to 1.65%, nickel, chromium, and molybdenum, they are called low alloy steels when the total alloy content is less than 5%, and they are called high alloy steels when their alloy content is higher than 5%. In the latter category, the tool steels and the stainless steels exist. These steels have their own nomenclature. Tool steels are widely used for tools and dies. They are high quality steels and divided into groups such as; water hardening, shock resistant, cold work, hot work, high speed, and special purpose steels. Stainless steels are iron-chromium alloys that contain minimum of 10.5% chromium. They are subdivided into austenitic, ferritic, martensitic, precipitation hardening, and cast groups.

Table 2.5 Classification of steels according to composition

Carbon Content		**Alloy Content**	
Low Carbon	Less than 0.25%	Plain Carbon	No alloying element
Medium Carbon	0.25-0.55	Low Alloy	Total alloy content < 5%
High Carbon	Greater than 0.55%	High Alloy	Total alloy content > 5%

2.7.2.2. Classifications of Steels According to Strength

The classification of the steels according to strength starts with the properties of structural quality plain carbon steels that have low yield strengths generally less than 275 MPa. These are the most common materials used for construction. Another group is high strength structural steels. They have yield strengths generally between 275 MPa and 825 MPa, while ultra-high strength structural steels are those with extremely high yield strengths, with a minimum 1330 MPa. The ultrahigh strength steels are all quenched and tempered medium carbon, low-alloy steels or aged high-alloy steels and low carbon maraging steels, which are used primarily as aerospace and defense industry structural materials.

The high strength structural steels up to 550 MPa minimum yield strength may be achieved in the hot rolled condition with ferrite-pearlite or reduced pearlite microstructures. The steels may be either with low alloy additions as solid solution strengtheners that are called HSLA (high-strength, low alloy) steels, or with microalloy additions of niobium (Nb), vanadium (V), and titanium (Ti) that are called microalloyed HSLA steels. The latter are hot rolled with controlled temperatures and deformation, while the former are hot rolled with no controls. The HSLA steels have excellent strength and ductility as-rolled.

2.7.2.3. Classifications of Steels According to Product Shape

Typical product classification of flat hot-rolled carbon and low-alloy steels is done according to thickness and width. This is shown in Table 2.6 (Mangonon, 1999), which shows the ranges of thickness and width of flat hot-rolled bars, plates, strip, and sheet products. Beside the bars shown in Table 2.6, the term bar also includes rounds, squares, hexagons, and similar cross sections 9.52 mm and greater across; small angles, channels, tees, and other standard shapes less than 76 mm across; and concrete reinforcing bar, commonly called rebars.

In addition to the product forms in Table 2.6, there are also shape products that include structural shapes such as I-beam and special shapes. Structural shapes are flanged, are at least 76 mm or greater in cross-sectional dimension, and are used in structures such as bridges, buildings, ships, and railroad cars. Special shapes are those designed by users for specific applications.

Table 2.6 Product classification of flat-rolled carbon and low-alloy steel

Thickness (in.)	Specified Width (in.)					
	To 3.5	More than 3.5 to 6	More than 6 to 8	More than 8 to 12	More than 12 to 28	More than 28
0.230 and above	Bar[a]	Bar[a]	Bar[a]	Plate[a]	Plate[a]	Plate[a]
0.229 to 0.204	Bar[a]	Bar[a]	Strip	Strip	Sheet	Plate[a]
0.203 to 0.180	Strip	Strip	Strip	Strip	Sheet	Plate[a]
0.179 and below	Strip	Strip	Strip	Strip	Sheet[b]	Sheet[b]

[a] Subject to certain conditions, the dimensions are sold as carbon sheet or strip as well as bars or plate

[b]These product classifications for hot-rolled sheet are based on the median point of the minimum thickness ordered plus full published thickness tolerances

2.7.2.4. Classifications of Steels According to Finish Processing and Quality Descriptors

The finishing process classification signifies the last processing the steel has undergone. The most common, of course, are hot-rolled, cold-rolled, or cold-finished, annealed, normalized, quenched and tempered, and coating processes such as porcelain enameling, and electrolytic galvanizing (zinc coating). In addition to the finishing process, there are quality descriptors that indicate the suitability of products for certain applications or fabrication processes. The quality descriptors imply certain mechanical and physical attributes of the product that may be due to the control of one or more of the following factors during manufacture:

- degree of internal soundness
- relative uniformity of chemical composition
- relative freedom from surface imperfections
- number, size, shape, and distribution of non-metallic inclusion
- relative hardenability requirements

2.7.2.5. Classifications of Steels According to Application

This type of classification is widely used in steel standards. It can not be said that it is a systematic approach. One steel can be in different groups. But it is widely used in daily engineering practice. Some of these groups are given below (Dilme, 1991):

- General structural steels, are the steels used for construction purposes, such as bridges, buildings, ships, etc.
- Free cutting steels.
- Spring steels, are used for various types of spring manufacturing.
- Ball and roller bearing steels are used for bearings.
- Carbon tool steels.
- High speed steels.
- Valve steels, are tough steels which are used in valve manufacturing.
- Hot work tool steels are proper steels for hot forming.
- Cold work tool steels are used for cold formed products.
- Case hardening steels, are used for the applications in which harder surface is required than the core. Surface hardness is provided by carburizing.
- Nitriding steels, are similar to the case hardening steels.

2.7.2.6. Other Classification Approaches

Since steels are the most widely used materials in engineering, it can be observed that different grouping and standardization approaches in steel standards, mainly developed for commercial purposes. Some of these are:

- Classification by structure, such as austenitic, ferritic, martensitic, or fine grained.
- Classification by dominating alloy elements, such as chromium steels, chromium-nickel steels, aluminium-chromium steels, etc.
- Classification by specific applications such as steels for medical applications, shipbuilding, aircraft applications etc.
- Classification by quality such as ordinary steels, quality steels, high quality steels.

- Classification by deoxidation method such as killed, semi-killed, rimmed, nonaging, etc.
- Classification by steel furnace method such as basic oxygen furnace or electric furnace.

2.7.3. Designation of Steels

The selection of steels requires consultation on property information and supplier information on availability. If the designer is to make any sense out of handbook information, he should become familiar with the terms used to describe steels. “Grade”, “type” and “class” are terms used to classify steel products. Within the industry, they have very specific uses: grade is used to denote chemical composition; type is used to indicate deoxidation practice; and class is used to describe some other attribute, such as strength level or surface smoothness (Metals Handbook, 1978).

Designation is the specific identification of each grade, type or class of steel by a number, letter, symbol, name or suitable combination thereof unique to a particular steel. Chemical composition is by far the most widely used basis for designation, followed by mechanical properties. Many organizations establish their specific steel designations according to their methodology. Most of them were developed by limited interest associations such as the U.S. military, and their specifications are written with their specific interests in mind.

There are thousands of different steels available in the world. Although there are some international standards to designate these steels such as International Standardization Organization (ISO) or Euro-norm, steels are usually designated by producer country's standard designations and producer company's commercial names. Designation methods of certain standards will be given in the following sections to illustrate the methodology, which is used in practical applications.

2.7.3.1. Steel Designation in TS (Turkish Standards)

In Turkish Standards (TS), there should be one unique steel name for each steel. Two distinct identification methods are used for steel designation in the standard. The basic method is symbolic numbers, which are also called as "material numbers". However, if the steel can not be classified with this number, it can also be designated by material designations which will be referred as "standard designation". Turkish Standards related to steel designation are given in Table 2.7.

Table 2.7 Turkish standards related to steel designation

Number of Standard	**Name of Standard**
TS 1111	Steels and Iron - Carbon Materials Classification and Symbols
TS EN 10020	Definition and classification of grades of steel
TS EN 10027-1	Designation systems for steel-Part 2:Steel names, principal symbols
TS EN 10027-2	Designation systems for steel-Part 2:Steel numbers
TS EN 10079	Definition of steel products

TS EN 10027 sets out rules for designating steel, by means of symbolic letters and numbers to express application and principal characteristics, such as mechanical, physical, so as to provide an abbreviated identification of steel. This standard incorporates by dated or undated reference, provisions from other publications. TS EN 10027-2 sets out a numbering system, referred to as steel numbers, from the designation of steel grades. It deals with the structure of steel numbers. Such steel numbers are complementary to steel names set out in TS EN 10027-1. Moreover, TS EN 10079 explains the terms or suitable abbreviations for steel product form (see Table 2.8).

Table 2.8 Certain terms used for steel product forms in TS

Abbreviation	Meaning	Abbreviation	Meaning
FL	Flat products	FO	Forgings
B	Bars or sections	C	Castings
W	Wire	TS	Seamless tube
		TW	Welded tube

Steel numbers are allocated to steel grades according to specified characteristics which include (TS EN 10027-2, 2001):

- chemical composition
- characteristics as determined by standard test methods
- suitability for processing, such as cold forming
- suitability for specific applications, such as tyre cord wire

Differences in delivery requirements which do not affect the material characteristics; such as type of marking, surface appearance, dimensions, are not reasons to allocate a different standard number.

Material number is a seven-digit number, which is usually used with only first five. First digit is always 1 for steels including steel castings. Numbers 2 to 9 may be allocated to other materials. Second and third digits are the group numbers of the steels which are given in TS 1111 and TS EN 10027-2. The important group numbers of steels in TS are shown in Table 2.9. Fourth and fifth digits are lower kind numbers in this group and they are called sequential numbers. Sixth and seventh digits are additional numbers and generally they are not used. At present the sequential number consists of two digits. Increase in the number of digits should be necessary by reason of an increase in the number of steel grades to be considered, a sequential number of up to four digits is permitted. The structure of steel numbers is set out as follows:

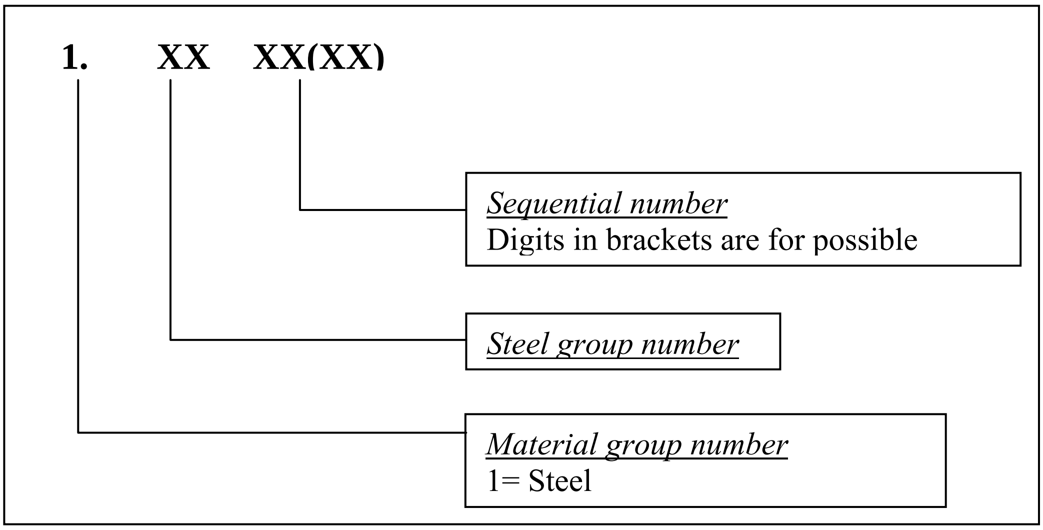

Figure 2.4 Designation of steel number used in TS.

Table 2.9 Meaning of group number in TS (TS EN 10027-2, 2001).

Steel Group			**Group Number**
Non-alloy steels			
	Base steels		00,90
	Quality steels		01,02,03,04,05,06,07,91,92,93 ,94,95,96,97
	Special steels		
		Steels with special physical properties	10
		Structural pressure vessel and engineering steels	11,12,13
		Tool steel	15,16,17,18
Alloy quality steels			
	Quality steels		08,09,98,99
	Special steels		
		Tool steel	20,21,22,23,24,25,26,27,28
		Miscellaneous steels	32,33,35,36,37,38,39
		Stainless and heat resisting steels	40,41,43,44,45,46,47,48,49
		Structural, pressure vessel and engineering steels	50,51,52,53,54,55,56,57,58,59 ,60,62,63,65,66,67,68,69,70, 71,72,73,75,76,77,79,80,81,82 ,84,85,87,88,89

For the purposes of material designation, steel names are classified into two main groups. Group 1 steels are designated according to their application and mechanical or physical properties. Group 2 steels are designated according to their chemical composition and further divided into 4 sub groups.

Symbols used for Group 1 steels are shown in Table 2.10. In addition to the symbols in the table, the steel designation is composed of specified principal symbols with respect to the group of the steel. Some of them are given in the following paragraphs.

Table 2.10. Demonstration of symbols of steels in Group 1 (TS EN 10027-1,1996).

Steel Group	**Symbol**
Structural steels	S
Steels for pressure purposes	P
Steels for linepipe strength	L
Steels for reinforcing concrete	B
Steels for prestressing concrete	Y
Steels for or in the form of rails	R
Cold rolled flat products of high strength steels for cold forming	H
Flat products for cold forming	D
Tinmill products	T
Electrical steels	M

In steels for reinforcing concrete, designation begins with symbol “B”. It is followed by a number being the characteristic yield strength in N/mm^2. Moreover, “Y” is the first symbol of designation for steels for prestressing concrete. It is followed by a number being the specified minimum tensile strength in N/mm^2. This designation type is also applied to steels in the form of rails after “R” letter.

The designation of flat products for cold forming starts with "D" and is followed by one of the following letters:

- C for cold rolled products
- D for hot rolled products for direct cold forming
- X for products the rolled condition of which is not specified

Group 2 steels have more complex steel designations as compared to Group 1 steels. For instance, in the Non-alloy steels (except free-cutting steels) with an average manganese content smaller than 1 %, the coding comprises the letter "C" and a number that is 100 times the specified average carbon percentage. However, for Non-alloy steels with an average manganese content greater than 1 %, non-alloy free-cutting steels and alloy steels (except high speed steels) where the content of every alloying element is smaller 5 %, the coding comprises the following symbols:

- a number being 100 x the specified average carbon percentage
- chemical symbols indicating the alloying elements that characterize the steel. The sequence of symbols shall be in decreasing order of the value of their content; where the values of contents are the same for two or more elements, the corresponding symbols shall be indicated in alphabetical order.
- numbers indicating the values of contents of alloying elements. Each number represents, respectively, the average percentage of the element indicated multiplied by the factors given in Table 2.11 and rounded to the nearest integer.

Table 2.11 Multiplication factors for alloying elements (TS EN 10027-1, 1996).

Alloying Elements	**Multiplication Factor**
Cr,Co,Mn,Ni,Si,W	4
Al,Be,Cu,Mo,Nb,Ta,Ti,V,Zr	10
P,S,N,Ce	100
B	1000

Alloy steels (except high speed steels) whose content by weight, of at least one alloying element, bigger than or equal to 5 % are also included in Group 2 steels. The coding is similar to that of the previous steel group, but the only difference is that the designation of this group starts with letter "X". The remaining of the code is composed of the same symbols with those in the previous group.

Designation of high-speed steels begins with the letters HS. The coding continues with numbers exhibiting the values of percentages of alloying elements indicated in respective order of tungsten (W), molybdenum (Mo), vanadium (V) and cobalt (Co). Each number represents the average percentage of the respective element rounded to the nearest integer; the numbers referring to the different elements shall be separated by hyphens.

Coding of steel casting is similar to that of group 1 and group 2 steels. Only difference is the initial symbol for steel castings. Where a steel is specified in the form of a steel casting, its steel name as specified above is preceded by the letter G.

2.7.3.2. Steel Designation in DIN (Deutsche Institut für Normung)

In the previous section, certain steel standards such as TS EN 10027-1, TS EN 10027-2 are used for steel designation. "EN" in the standard name means European Norm, and these types of standards may exist in any standard conforming European Standards. The contents of these standards are identical but the languages change according to country of the standard. The specified standard name is only added in front of "EN" part during preparation of these types of standards. For example, DIN EN 10079 and TS EN 10079 are the same standard with respect to their contents. DIN and TS are standards adhering to European Standards; therefore, methodology and designation of steels are similar in TS and DIN. Material numbers in these standards are almost the same. Same steel standards to explain steel designations, such as DIN EN 10027-1, also exist in the DIN standard.

Although both TS and DIN possess same steel standards to identify steels, small differences may exist in the designation of the steels. While TS 1111 is a standard that exists only in TS, DIN 17014 is developed to display the designation of steels in DIN standard specifically. Moreover, the number of the steels in DIN and TS are different from each other, and any steel developed in DIN cannot be present in TS standards.

2.7.3.3. Steel Designation in AISI and SAE

Specifications that relate to the properties and chemical compositions for steels have been developed by the American Iron and Steel Institute (AISI), the Society of Automotive Engineers (SAE), and the American Society for Testing and Materials (ASTM) in United States. The most common generic system for alloy designation used to be a system that had been in place for decades is AISI designation system. The system is developed by American Iron and Steel Institute, a division of a technical society. They published steel product manuals that reflected current steel mill alloys and practices. These publications served as the bible for what alloys are available from U.S. producers, product tolerances, available shapes, available tempers, and so on. In the mid 1990s the AISI stopped publishing their manuals on steel products. This function was turned over to the Iron and Steel Society, an organization formed by steel manufacturers. These manuals continue to show product forms and dimensions, but they do not consider the information in the manuals to constituent a specification. Other organizations use them for writing alloy specifications.

They developed a system that allows easy identification of the type or grade of steel, and sets specific limits on the allowable chemistry. The SAE also established a steel designation system similar to AISI system. Both standards have the same systems of numbers for various types of steel, with the exception that AISI numbers are preceded by a letter indicating the melting practice (Budinski and Budinski, 1999).

Table 2.12 AISI/SAE system of designation

Numerals and Digits	Type of Steel and Nominal Alloy Content
Carbon Steels	
10XX	Plain carbon (Mn 1.00% max)
11XX	Resulfurized
12XX	Resulfirized and rephosphorized
15XX	Plain carbon (max Mn range 1.00 to 1.65%)
Manganese Steels	
13XX	Mn 1.75%
Nickel Steels	
23XX	Ni 3.50%
25XX	Ni 5.00%
Nickel-Chromium Steels	
31XX	Ni 1.25%; Cr 0.65% and 0.80%
32XX	Ni 1.75%; Cr 1.07%
33XX	Ni 3.50%; Cr 1.50% and 1.57%
34XX	Ni 3.00%; Cr 0.77%
Molybdenum Steels	
40XX	Mo 0.20% and 0.25%
44XX	Mo 0.40% and 0.52%
Chromium-Molybdenum Steels	
41XX	Cr 0.50%, 0.80% and 0.95%; Mo 0.12%, 0.20%, 0.25% and 0.30%
Nickel-Chromium-Molybdenum Steels	
43XX	Ni 1.82%; Cr 0.50% and 0.80%; Mo 0.25%
43BVXX	Ni 1.82%; Cr 0.50%; Mo 0.12% and 0.25%; V 0.03% min
47XX	Ni 1.05%; Cr 0.45%; Mo 0.20% and 0.35%
81XX	Ni 0.30%; Cr 0.40%; Mo 0.12%
86XX	Ni 0.55%; Cr 0.50%; Mo 0.20%
87XX	Ni 0.55%; Cr 0.50%; Mo 0.25%
88XX	Ni 0.55%; Cr 0.50%; Mo 0.35%
93XX	Ni 3.25%; Cr 1.20%; Mo 0.12%
94XX	Ni 0.45%; Cr 0.40%; Mo 0.12%
97XX	Ni 0.55%; Cr 0.20%; Mo 0.20%
98XX	Ni 1.00%; Cr 0.80%; Mo 0.25%
Nickel-Molybdenum Steels	
46XX	Ni 0.85% and 1.82%; Mo 0.25% and 0.25%
48XX	Ni 3.50%; Mo 0.25%
Chromium Steels	
50XX	Cr 0.27%, 0.40%, 0.50% and 0.65%
51XX	Cr 0.80%, 0.87%, 0.92%, 0.95%, 1.00% and 1.05%
50XXX	Cr 0.50%; C 1.00% min
51XXX	Cr 1.02%; C 1.00% min
52XXX	Cr 1.45%; C 1.00% min
Chromium-Vanadium Steels	
61XX	Cr 0.60%, 0.80% and 0.95%; V 0.10% and 0.15% min
Tungsten-Chromium Steels	
72XX	W 1.75%; Cr 0.75%
Silicon-Manganese Steels	
92XX	Si 1.40% and 2.00%; Mn 0.65%, 0.82% and 0.85%; Cr 0.00 and 0.65 %
High-Strength Low-Alloy Steels	
9XX	Various SAE grades
Boron Steels	
XXBXX	B denotes boron steels
Leaded Steels	
XXLXX	L denotes leaded steels
XX in the last two digits indicates that carbon content (in hundredths of percent)	

The general classification of carbon and alloy steels is given in Table 2.12 for AISI and SAE. The system usually employs only four digits. In the system the first digit indicates the type of steel (the major alloying element). The second digit indicates the approximate percentage of the major alloying element (e.g. A 23XX nickel steel has approximately 3% nickel). The last two (or three in some cases) digits denote the carbon content in hundredths of a percent. For example, AISI/SAE 1018 steel is plain carbon grade (10XX), which contains an average carbon content of 0.18% (Thornton and Colangelo, 1985). In addition to the four (or five) digits, various letter prefixes and suffixes provide additional information on a particular steel (see Table 2.13).

Table 2.13 Letter prefixes and suffixes in AISI/SAE steel identification

Prefix	**Meaning**
A	Made in basic open hearth furnace, alloy
B	Made in acid Bessemer furnace, carbon
C	Made in basic open hearth furnace, carbon
D	Made in acid open hearth furnace, carbon
E	Made in electric furnace
X	Composition varies from normal limits
Suffix	**Meaning**
H	Steel meet certain hardenability requirements
Other Letters	**Meaning**
XXBXX	Steel with boron alloying element
XXLXX	Steel with lead additions to aid machinability

There were AISI/SAE systems for identifying other classes of steels, such as stainless steels and tool steels. These designation systems are different from that of carbon and alloy steels.

In AISI/SAE designation, the tool steel classification system is based on use characteristics. A prefix letter is used in alloy identification system to indicate category, and the specific alloy in a particular category is identified by one or two digits (see Table 2.14).

Table 2.14 Tool steel designation in AISI/SAE (Dallas, 1979).

Type of tool steel	**Prefix**	**Specific types**
Cold-work tool steels	W (water hardening)	W1, W2, W5
	O (oil hardening)	O1, O2, O6, O7
	A (medium alloy air hardening)	A2, A4, A6, A7, A8, A9, A10, A11
	D (high carbon, high chromium type)	D2, D3, D4, D5, D7
Shock resisting tool steels	S	S1, S2, S4, S5, S6, S7
Hot-work tool steels	H	H1-H19 chromium types
		H20-H39 tungsten types
		H40-H59 molybdenum types
High-speed tool steels	M (molybdenum type)	M1, M2, M3-1, M4, M6, M7, M10, M33, M34, M36, M41, M42, M46, M50
	T (tungsten type)	T1, T4, T5, T6, T8, T15
Mold steels	P	P6, P20, P21
Special purpose tool steels	L (low alloy type)	L2, L3, L6
	F (carbon-tungsten type)	F1, F2

Wrought stainless steels are commonly identified by the three-digit system that originated with AISI. The first digit indicates the classification by composition type (see Table 2.15). The last two digits in three-digit system have no significance to the stainless steel user. The PH stainless steels were originally identified by 600 series numbers, but in the late 1970s this identification was dropped in favor of UNS numbers.

Table 2.15 Stain stainless steels categorized by structure and chemical composition

Group	General properties	AISI/SAE	UNS No.
Chromium iron	Martensitics: Nonrusting tools and structural parts; Hardenable by heat treatment	403	S40300
		410	S41000
		414	S41400
		416	S41600
		420	S42010
		420F	S42020
		431	S43100
		440A	S44002
		440B	S44003
		440C	S44009
	Ferritic: Used for elevated temperature and nonrusting architectural parts; Nonhardenable	405	S40500
		409	S40900
		429	S42900
		430	S43000
		430F	43020
		436	S43600
		442	S44200
		446	S44600
Chromium-nickel	Austenitic: Used for chemical resistance; Hardenable by cold work	301	S30100
		302	S30200
		302B	S30215
		303	S30300
		303Se	S30323
		304	S30400
		304L	S30403
		304N	S30451
		304LN	S30453
		305	S30500
		309S	S30908
		310	S31000
		310S	S31008
		316LN	S31653
		317	S31700
		317L	S31703
		321	S32100
		347	S34700
		348	S34800
		384	S38400
Chromium-nickel-manganese		201	S20100
		202	S20200
		205	S20500
Precipitation hardening (PH)	Martensitic and semiaustenitic: Combination of chemical resistance and high strength; Hardenable by precipitation heat treatment	17-4	S17400
		17-7	S17700
		15-5	S15500
		13-8	S13800
Duplex	Austenite plus ferrite: Not normally by heat treatment	-	S32900
		-	S32550
		-	S32950

Source: Adapted from Stainless Steel Handbook, Allegheny Ludlum Steel Co.

2.7.3.4. Steel Designation in ASTM and UNS

American Society for Testing and Materials (ASTM) specifications are the most widely used in the United States. ASTM is an international technical society of over 30,000 members who write consensus standards on materials and testing methods. Steel specifications are written by a steel committee; cast irons are addressed by an iron casting subcommittee, and there are subcommittees that write specifications on most other metals. Specifications are published annually in bound volumes, and all 10,000+ specifications are available on CD-ROM. These specifications are available in most libraries around the world (Budinski and Budinski, 1999).

ASTM steels are designated using ASTM number and grade (if applicable). UNS (unified numbering system) numbers were developed by ASTM to identify metal alloys by common chemical composition, but this system is not a metal specification. It does not establish requirements for form, condition, property, or quality. Only specifications do this. AISI numbers are more widely used as compared to the ASTM specification numbers and the UNS numbers because they are easier to remember than the others. Another reason for this decision is that ASTM specifications are written for product forms. If you needed low-carbon steel for a shaft, designer would look up the specification for low-carbon steel bars and might arrive at ASTM A 36 as a suitable steel. If later the designer decides to save weight and use a tube instead of a solid bar, the same alloy would be specified as ASTM A 422 for welded tubing. If he wanted the tube galvanized, it would be specified as ASTM A 120. There may be 10 ASTM specifications that apply to your 1020 steel shaft, depending on product form and treatments. There are over 1000 specifications for steel alloys in various product forms. Fortunately, most of the ASTM alloy specifications consider that most people are familiar with the old AISI numbers. Therefore, many ASTM specifications have grade designations that use the AISI number. For example, the former AISI 1020 steel can be specified as ASTM A 29 grade 1020.

Table 2.16 ASTM specifications that incorporate AISI/SAE designations

A29	Carbon and alloy steel bars, hot rolled and cold finished, generic
A108	Standard-quality cold finished carbon steels bars
A295	High carbon-chromium ball roller bearing steel
A304	Alloy steel bars having hardenability requirements
A322	Hot rolled alloy steel bars
A331	Cold finished alloy steel bars
A434	Hot rolled or cold finished quenched and tempered alloy steel bars
A505	Hot rolled and cold rolled alloy steel sheet and strip, generic
A506	Regular-quality hot rolled and cold rolled alloy steel sheet and strip
A507	Drawing quality hot rolled and cold rolled alloy steel sheet and strip
A510	Carbon steel wire rods and coarse round wire, generic
A534	Carburizing steels for antifriction bearings
A535	Special-quality ball and roller bearing steel
A544	Scrapless nut quality carbon steel wire
A545	Cold heading quality carbon steel wire for machine screws
A546	Cold heading quality medium-high-carbon steel wire for hexagon-head bolts
A547	Cold heading quality alloy steel wire for hexagon head bolts
A548	Cold heading quality carbon steel wire for tapping or sheet metal screws
A549	Cold heading quality carbon steel wire for wood screws
A575	Merchant-quality hot rolled carbon steel bars
A576	Special-quality hot rolled carbon steel bars
A634	Aircraft-quality hot rolled and cold rolled alloy steel sheet and strip
A646	Premium-quality alloy steel blooms and billets for aircraft and aerospace forgings
A659	Commercial-quality hot rolled carbon steel sheet and strip
A680	Untempered spring quality cold rolled hard carbon steel strip
A682	Cold rolled spring quality carbon steel strip, generic
A684	Untempered spring quality cold rolled soft carbon steel strip
A689	Carbon and alloy steel bars for springs
A711	Carbon and alloy steel blooms, billets and slabs for forging
A713	High-carbon spring steel wire for heat treated components

Each ASTM specification covers a particular alloy or family of alloys. For example, ASTM A 36 covers carbon steels for structural applications. There are several grades in the specification, and to specify the use of one of these alloys, the grade designation would be included. The last two digits of an ASTM number are the year of the latest revision.

AISI/SAE designations for the compositions of carbon and alloy steels are normally incorporated into the ASTM specifications for bars, wires, and billets for forging. Some ASTM specifications for sheet products include AISI/SAE designations for composition. Table 2.16 includes a list of some of the ASTM specifications that incorporate AISI/SAE designations for compositions of the different grades of steel.

Several ASTM specifications, such as A 29, contain the general requirements common to each member of a broad family of steel products. Table 2.17 lists several of these generic specifications, which generally must be supplemented by another specification describing a specific mill form or intermediate fabricated product.

Table 2.17 Generic ASTM specifications

A6	Rolled steels structural plate, shapes, sheet pilling and bars, generic
A20	Steel plate for pressure vessels, generic
A29	Carbon and alloy steel bars, hot rolled and cold finished, generic
A505	Alloy steel sheet and strip, hot rolled and cold rolled, generic
A510	Carbon steel wire rod and course round wire, generic
A568	Carbon and HSLA, hot rolled and cold rolled steel sheet and hot rolled strip, generic
A646	Premium-quality alloy steel blooms and billets for aircraft and aerospace forgings
A711	Carbon and alloy steel blooms, billets and slabs for forging

The UNS provides a number to identify an alloy that is covered by specifications written by AISI or some other society or trade association. Where possible, the five-digit UNS number is preceded by a letter that indicates what metal system is involved: AXXXXX is used for aluminum alloys. The five digits often coincide in some fashion with the identification system that they are replacing. For instance, type 1020 steel is covered by UNS G10200. The first four digits come from the AISI/SAE system, and a 0 is added as the last digit. An outline of the entire Unified Numbering System is shown in Table 2.18.

For the designation of stainless steels, there are UNS numbers on all grades. The UNS numbers for stainless steels (see Table 2.15) usually consist of an S prefix, the AISI number, and two zeros. For example, The UNS number for AISI 316 stainless steel is S31600. There are also ASTM designations for stainless steel alloys, but some standards are written for specific types of service.

Table 2.18 Outline of the Unified Numbering System for metals.

UNS Number	**Alloy system**
Axxxxx	Aluminum and aluminum alloys
Cxxxxx	Copper and copper alloys
Exxxxx	Rare earth and rare element-like metals and alloys
Fxxxxx	Cast irons
Gxxxxx	Former AISI and SAE carbon alloy steels
Hxxxxx	Former AISI and SAE H-steels
Jxxxxx	Cast steels (except tool steels)
Kxxxxx	Miscellaneous steel and ferrous alloys
Lxxxxx	Low-melting metals and alloys
Mxxxxx	Miscellaneous nonferrous metals and alloys
Nxxxxx	Nickel and nickel alloys
Pxxxxx	Precious metals and alloys
Rxxxxx	Reactive and refractory metals and alloys
Sxxxxx	Heat and corrosion resistant (stainless steels)
Txxxxx	Tool steels, wrought and cast
Zxxxxx	Zinc and zinc alloys

2.7.3.5. Steel Designation in AFNOR, BS and Other Standards

AFNOR (France) steel designations are similar to the DIN designations as AFNOR includes many EN standards to demonstrate their steel designation and products. However, certain designation distinctions exist in AFNOR with respect to European steel standards demonstration. It uses the letter "A" instead of "St" in DIN. One other difference is the symbols of the alloying elements (e.g. "N" is used instead of "Ni").

BS (English) steel designation is based on a 6 digit numbering system. First three digit denotes the main group of the steel. 000-199 is for carbon steels, 200-240 for free cutting, 250-299 for spring, 300-499 for stainless and heat resistant, 500-999 for alloyed steels. Fourth digit is a letter such as A, H, M, S, designating special properties of the steel. Last two digit gives the hundred times of the carbon percentage. Moreover, material numbers and material designations are also used in the identification of steels in B.S., and similar to that in DIN standard. BS EN 10027-1 and BS EN 10027-2 were published in British Standard to display the steel designation that is used in European Standards.

JIS (Japan) is a standard having totally different steel designation, because standards, which are developed for steel identification and designation, are not similar to that of European Standards. Certain steel symbols used in JIS are shown in Table 2.19.

Investigation of steel designations in other standards (Wegst, 1998) shows that they use similar methodologies in designation, but the resultant designations are usually different. For example JIS (Japan), GOST (Russia), PN (Poland) standards have very different designations, whereas NBN (Belgium) and UNI (Italy) use similar designations to DIN because they obey European Standards.

Table 2.19 Certain steel designations in JIS

Symbol of class	Name of Class
S**C, S**CK	Carbon steels for machine structural use
SMn***H, SMnC***H, SCr***H, SCM***H, SNC***H, SNCM***H	Structural steels with specified hardenability bands
SNC***	Nickel chromium steels
SNCM***	Nickel chromium molybdenum steels
CCr***	Chromium steels
SCM***	Chromium molybdenum steels
SACM***	Aluminum chromium molybdenum steels

A complete formal representation of a steel must include the formal representation of the standard, number of related standard and steel designation or material number. For example, an alloyed tool steel in DIN Standards 17350 can be represented as DIN 17350 115CrV3 or DIN 17350 1.2210. During steel orders, related country standard acts as a technical specification. Therefore, steel orders, given by designation only, cannot be taken as a complete order (Tekin, 1992).

CHAPTER 3

PROGRAM DEVELOPMENT

3.1. Development of the Database

3.1.1. Introduction

The aim of the database developed in this study is to help in solving the conflict between data format of the printed sources in the literature and to meet data requirement of engineers. It stores the information of steels taken from printed sources and presents the information effectively to engineers working on design. Therefore, the database should possess a well designed data structure and data retrieval system.

First of all, the database is capable of working with computers having small memory to provide widespread usage of the database, because the requirement of complex systems decreases the usage of database. Storage of information into the database should be done properly to satisfy maximum compaction of the information.

The database should include information of steels that belong to different standards. This international steel information provides comparison of steels from different standards to the user. The most effective selection can be accomplished by using steels produced in various standards. This is because each country standard posseses special steels that are not present in other standards, and these steels may be the most suitable materials for any design process that is developed. In addtion to this, new types of steels are designed and produced day by day in the industry. Therefore, the database should be updated easily. User can enter steels that belong different standards and new steels that exist in the industry. The developed database will also supply steel information that engineers need in solving problems related to the design. Usage of the information stored in the database should not arise difficulties to engineers, and the steel information should be stored in simple form that can easily be evaluated by the user.

3.1.2. Data Concept of the System

Material properties can be stored in different ways into the databases. For instance, mechanical properties are loaded into datadase as numerical value, whereas remarks or notes about the mechanical properties are stored as textual form. Moreover, microstructure of the material has to be shown as a picture in the database and dependence of any material property to any parameter can be displayed as graphical presentation. Among these types of demonstrations of the material data, numerical and textual types are preferred in the database developed in the study because graphical and pictural demonstrations consume too much storage place and require long retrieval time. Therefore, to create a PC database application that is designed for thousands of materials, textual and numerical data storage types are the best. A numerical cell can be used to store any numerical property of the material in a single field and the value can be used in comparisons or calculations for numerical searching operations. However, a textual form can not be used in the numerical calculations. Any expression included in the textual field can be searched through the texts stored in the same types of fields, and these fields can also be sorted in alphabetical order.

Each material has numerous mechanical, thermal, physical and other properties that are relavant to engineering design. If the properties are tried to be stored in a database, hundreds of different fields will be required. Since the properties of the materials are given in a certain range in printed documents instead of a certain value, the size of the database becomes larger. For example, to store 20 different types of physical properties, 40 fields are required due to existance of maximum and minimum values. Moreover, dependence of some properties, especially mechanical properties, on material parameters such as size and thickness, and enviromental parameters such as temperature increases the number of the fields that are necessary for storage. Even if all the effects are considered and database is created properly, the excess increase in the number of the fields in the database will prevent the practical usage of the system due to existance of slow searching operations. In addition to this, the system does not become a user friendly system because many questions are asked to user about the parameters effecting the material property. User should possess adequate experience to answer the questions, and then he can use the system. Furthermore, some properties of materials are specifically designed for certain material groups and the system can exclude other material groups during searching operations due to lack of the property in the database.

To overcome the excess enlargement of the database, proper optimisation technique should be used for the variety of the information that is planned to be viewed to the user. Not only general information but also detailed information about material properties should be included in the database. The information stored in the database can be obtained from printed sources such as handbooks, reports or producer manuals, and databases provided by organizations such as ASM International. International designations and equivalents of materials should be obtained from different sources developed by various countries and so the system supplies international information to user. Moreover, properties that are more frequently used in design are tried to be selected instead of rarely used properties. Critical remarks about materials and major applications of materials should also be stored in the developed database and then user can obtain detailed information about the materials.

3.1.3. Engineering Material Used in the Database

Great progress has been made in the development of new engineering materials in the second part of the 20th century. Hundreds of thousands of materials are available to engineers, and the number is increasing faster today than ever before. The designer must select the material best suited to the specified task from this vast menu.

It can be recognised that engineering materials include virtually all metals and alloys, ceramics, glasses, plastics, elastomers, electrical semiconductors, concrete, composite materials, and many others. Although the polymer and composite industries grow rapidly and develop new materials today, metals are still the most generally employed engineering materials and the growth of their production (and especially that of steel) is considerably high. Moreover, steel represents an overwhelming portion of total metal production. There are thousands of different steels that are produced generally for various purposes with their different properties. Steel companies also try to develop new steels by various production techniques, such as combining various amount of alloying elements to offer unique properties. Due to existing many types of steel, it is very difficult to reach a specific kind of data about a steel or a group of steel.

Since steel has a broad range of applicability in the industry, it is chosen as the engineering material of the database developed in the study. To create an international database, steels are composed of 29 different steel standards, which belong to 24 different countries, in the database (see Table 3.1).

Table 3.1 Country and standard names in the database.

Standard Name	Country Name	Standard Name	Country Name
AFNOR-NF	France	MSZ	Hungary
AISI	USA	NBN	Belgium
AS/NZS	Australia	NS	Norway
ASTM	USA	ONORM	Austria
B.S.	England	OTH	Others
BDS	Bulgaria	PN	Poland
CSA	Canada	SAE	USA
CSN/STN	Czechia/Slovakia	SFS	Finland
DIN	Germany	SNV/VSM	Switzerland
EN	Euronorm	SS	Sweden
GB	China	STAS/SR	Rumania
GOST	Russia	TS	Turkey
ISO	International	UNE	Spain
JIS	Japan	UNI	Italy
		UNS	USA

3.1.4. Broad Range of Applicability of the Database

As it was stated that the selection of the correct material is a key step in the design process because an incorrectly chosen material can lead not only to failure but also to unnecessary cost. During the selection process, the information about the materials is an essential requirement. Therefore, the material data obtained from sources in the literature is mainly used to select the best material in the design. In addition to the design process, the material data can be used in different industrial areas such as repair, maintenance, and manufacturing.

Engineers, dealing with the design process, determine the most critical selection criteria, such as any property of steel during material selection facility. For example, if the steel part is used as a heat-exchanger tube, the primary function of the tube will be to transmit the heat and the heat conductivity will become the most critical property in the selection. If the designer obtain list that shows the heat conductivity values of steels, he can make primary elimination of steel from the list. Therefore, steels having special property values should be listed in the design process easily.

After selecting the best material in design, stock problems may exist. For instance, unless the most proper steel for the specified application is available in the stock, the closest available steel in the stock can be chosen for the application to obtain an economical selection. Steels are generally classified according to their similar properties, and engineers need steels in the same groups to observe the steels that resemble to each other. List of steels having same classification group is useful to engineers for this situation. In addition to the general comparison of steels, more detailed information such as elongation percentage, magnesium content, etc. can be selected and compared for steels in same group. Engineers provide steels that are closer to each other with the detailed searching.

Industrial machines are commonly composed of different parts. During maintenance and repair facilities, the identification of the parts is very critical. If the name of the steel part and its standard are known, it can be easily replaced by a new part. The identification of steel products should be done by production companies. However, the name of the steel, which is labelled on the part, can not be examined due to various reasons, such as erasing the name of the steel from the part. For this situation, some tests are applied to the part to attain certain information such as chemical composition. The obtained information is collected to identify the unknown steel. In such a case, engineer needs the list of the steels to make comparison between the collected values from the unexplored steel part and the theoretical values of steels in the literature. This comparison provides prediction of the steel name of the unknown part or replacement of the part with new steel that is similar to the unknown steel.

Special codes are created by different steel standards such as ASTM to identify steels. Each company, that produces steel parts, uses different types of codes. If any company deals with steel products importing from other countries, the engineers need to know the characteristics of codes of steels and equivalents of steels in its own standard. It is difficult to obtain equivalents of steels from the printed documents.

As a result of the examples that are given in the previous paragraphs, engineers need the list of steels in which comparison of certain steel properties are carried out, and equivalents and classification groups of steels are given. However, steels are listed in the order of their names in the printed documents. Therefore, preparation of the list from the printed documents takes along time. Decreasing of material selection time is very crucial in the design process. It can be achieved by transferring the material data from printed sources to the computer memory.

3.1.5. Problems Encountering in the Data Transfer from Printed Documents

Since storage of the information in the computer memory is different than that in the printed sources, some difficulties can be faced with during data transferring from printed sources to computer database. These difficulties are explained in the following paragraphs in detail.

Different designation codes were developed to identify steels by various steel standards. While identification of a steel in AISI standard can be done with only material designation (e.g. AISI 1040), not only material designation but also material number should be used to differentiate steel in DIN standard (e.g. DIN 140Cr3 or DIN 1.2008). The material designation is not a precise distinction method in DIN standard, because same designation can be used for different steels in the standard (e.g. DIN 100Cr6). Material number is used to eliminate this discord. The differences in the codes of steel standards result in a data-transferring problem during the development of the database. As only one field is enough to determine the codes of the steels in some standards such as ASTM and AISI, the steel codes should be stored into two distinct fields in other steel standards such as DIN and TS due to existence of two separate identification codes.

Certain properties of steels, especially mechanical, depend on the size of the specimen. The designation of this dependence in the database is very difficult because a lot of extra fields and rows should be necessary for only one steel. Moreover, the effect of temperature on the steel properties causes the same problem.

Different testing methods can be used to determine the properties of the steel in the various standards. The values can be transferred but they are not suitable in the searching operations. Therefore, certain testing method is chosen for the specified property during data transferring operation from printed sources. If the property value is calculated by any testing method, which is different from the selected method, its equivalent for the preferred testing method will be stored in the database by using conversion factors. This method becomes meaningless in the impact work because conversion factor between the testing methods is not designed for different impact testing methods.

Various units are used for same property in different printed sources. However, this problem can be eliminated by conversion of units to specified unit. Each property has a specified unit that is determined for this property in the database.

Another problem exists during transferring the classification groups of steels from printed sources in the different steel standards. The classification group names are different in each standard. Moreover, contents of the groups, which belong to different steel standards, show variety and any group in certain steel standard overlaps more than one group in other standards. Therefore, steels in definite standard cannot be placed to any group in other standard.

Although steel properties are generally given as numerical values, form of certain properties can be different. Ranking properties such as machinability, toughness, corrosion resistance, are illustrated as certain degrees instead of numerical values. However, demonstration of these degrees is dissimilar in various printed sources. For instance, some sources uses letters such as A, B, C for degrees, whereas some sources display degrees with numbers such as 1, 2, 3, 4. Creating a general range of degree that is dedicated for the steel property in the database can solve this problem.

Addition of a new field to the table is very critical for the database structure for the reason that it affects searching speed. Footnotes, special-notes can be easily used in the printed sources; where as usage of these formal texts in the database influences the main structure. Therefore, the information of the steel, which is taken from printed sources, has been chosen properly and then stored to the tables in the database to provide well-organized structure.

3.1.6. Content of the Database

3.1.6.1. Identification of the Material in the Database

The developed database is composed of steels provided by 29 different types of international steel standards. The standards have used different demonstration codes for the identification of steels. Therefore, it is difficult to store the steels having different types of demonstration techniques. To differentiate any steel in the database from the others, the following three different codes have been used:

- Standard Name
- Material Designation
- Material Number

The first item is the name of the steel standard that is provided by different countries. For example, DIN is a German steel standard that is widely used in the industry and includes hundreds of steel standard names such as DIN 17140-1, DIN EN 10083-3, etc. Certain countries can develop more than one steel standard such as ASTM and AISI/SAE that are steel standards established in United States. Same material designation can exist in different steel standards (e.g. 9S20 is a steel designation existing in both TS and DIN). Steels having same material designation in different standards show generally the similar behaviour. However, it is also possible to see some minor differences in this type of steels (e.g. C10 in DIN and UNI possess different sulphur and phosphorus contents). In addition to this, certain steels may exist in more than one standard name in the same steel standard. For instance, GX5CrNi19-10 steel appears in both DIN EN 10213-4 and DIN EN 10283 standard names in DIN steel standard. This type of steels belonging more than one standard name also shows similar properties except for insignificant differences.

Second term that is used to identify any steel in the database is the material designation. The development of the material designation is very complex because each designation gives some clues about steel such as chemical composition of the steel (e.g. steel having 0.09% carbon, and 0.23% sulphur, manganese, and lead content is shown by 9SMnPb23 material designation in DIN steel standard). The demonstration of the material designation includes certain rules depending on the steel standard. If an engineer knows the logic of the material designation developed by the steel standard, he can obtain some information about any steel from the material designation. Therefore, the arrangement of the material designation is developed by sophisticated organizations such as ASM international including a group of engineers having professional knowledge about steel.

Final term differentiating the steel is material number that exists in certain steel standards such as DIN, TS, etc. This is sometimes used to distinguish steels having the same material designation in the same steel standard. For instance, two steel have 100Cr6 material designation in DIN steel standard and one of them is displayed by 1.2067 and the other is shown by 1.3505 material numbers. However, demonstration of steel with its material number is not widely used as compared to material designation demonstration. Although a steel standard has material number designation for identification of steel, certain steels are developed without designing a material number in the same standard. These steels are only demonstrated by their material designations.

During the development of the database, an item number is defined for each steel to record the steel into the database. This item number retains a steel standard name, a material designation and a material number if exists. The steel is represented by its item number in all tables of the database.

Classification groups of the steels show differences according to steel standard. For example, while low carbon steel is a steel group name in the ASTM, this classification group is not designed in the DIN steel standard. Therefore, there are many types of classification groups for steels included in the database. To simplify the confusion, classification groups of certain steel standards are used and they are stored in a different table, in which each classification group is determined by a number. In addition to simplification, this eliminates the repetitions of entering the same classification group for different steels. Although certain number of classification group is loaded in the database, user can add new one to the database.

3.1.6.2. General Information about Properties in the Database

In this section, main groups of engineering material properties, such as mechanical properties, will be examined under database construction point of view in the following paragraphs.

Chemical Composition: Amount of alloying elements existing in the steel is very important because it affects steel properties, production techniques, application areas, price of steel, etc. There are many alloying elements that are added to steels, and the most widely used and critical of them are selected to view in the program. There are totally 18 alloying elements in the database with their maximum and minimum contents. Moreover, other elements are defined as others in another field and recorded as a textual form instead of a numerical form. While elements in the textual form can not be searched for numerical manipulations, 18 distinct alloying elements can be searched in numerical comparisons.

Physical Properties: Storage of physical properties of steels shows differences in the database. Density, specific electrical resistance and degree of shrinkage are stored in a numerical form. Since these properties are given in a certain range in the printed documents, two fields are reserved for the maximum and minimum values of each physical property. Magnetizability and weldability are stored as a boolean that is yes/no format in the database. Moreover, the physical property section includes toughness, corrosion resistance and cutting property of the steels. The values of these properties are especially located in the documents for tool steels. The values are not given as a numerical format, and certain degrees such as bad, average, good are used to determine the value of these physical properties. The degrees are stored in a numerical format to the database (e.g. value of '1' refers to degree of 'very bad'). All of the physical properties are in numerical searching operations except for magnetizabilty and weldability.

Thermal Properties: Thermal properties are stored as a numerical format and the values of them can be searched for numerical calculations and comparisons developed in the system. Thermal properties stored in the database are composed of thermal expansion coefficient, specific heat, thermal conductivity, melting point, maximum service temperature and minimum service temperature of steel. Two separate fields are reserved for each thermal property to represent the range of the physical property given in the literature. Moreover, thermal expansion coefficient depends on the surrounding temperature and different reference temperatures are used during the calculation of the thermal expansion coefficient of steels. The data are generally taken from the values at 20-100^{o}C to obtain comparable thermal expansion values in the database.

Heat Treatment Parameters: Heat treatments applied before, during and after production of steel effect the properties of steel, especially the mechanical properties. Therefore, proper heat treatments must be applied for steels to satisfy the desired mechanical property values. This is satisfied by using appropriate heat treatment parameters. The developed database includes heat treatment part that is composed of hot working temperature, soft annealing temperature, hardening temperature, normalizing temperature and stress-relieving temperature of steel. Duration time and cooling media parameters are also stored for some of the above properties. Furthermore, additionally two different separate fields are reserved for notes about considerations of heat treatments. One of them is related to general information about heat treatment and other comprises heat treatment notes for welding, if the steel is weldable. All heat treatment information in the database can be taken as presentation information and values in the fields can not be used in numerical searching operations.

Mechanical Properties: Mechanical properties stored in the database are composed of yield strength, tensile strength, young's modulus, bulk modulus, fracture toughness, endurance limit, hardness, percent elongation, Poisson's ratio, impact energy and percent reduction in area. Each mechanical property has two distinct fields to store its maximum and minimum value except for reduction in area.

Pre-treatments applied to the steel during its production stage strongly affect the mechanical properties. The dependence of the mechanical properties on the pre-treatments is designed in the condition part of the database. Each mechanical property of the steel is stored according to its condition name besides its original name. It means that mechanical properties of the same steel can be illustrated in different conditions in the database. For example, yield strength of AISI/SAE 1050 steel is between 325-405 MPa for annealed condition and 370-455 MPa for as-rolled condition, and both values can be stored in database under same steel name but different condition name. The condition of the steel sometimes is not specified in the documents for given mechanical properties. For this case, the condition name of the steel is stored as 'not specified' and this implies that any heat treatment or deformation process is not applied to the steel. Moreover, if desired condition name is not included in the database, user can add new condition names.

Mechanical properties are also dependent on the size of the specimen. This dependence is not shown in the database. Most widely used specimen size range in the industry is selected and all mechanical properties, taken from literature in this range, are stored in the database. For instance, 16-40 mm range is selected for strength properties and 10-150 mm range is preferred for impact values. The mechanical properties of steels become comparable by using the certain size ranges.

Some endurance limit and fracture toughness values in the database are estimated. These values, which are taken from literature, are very close to actual values and can be used in the numerical calculation operations. Elongation and reduction in area values are given as percentage, and the values stored in the database can not be higher than a hundred.

Hardness values of steel are calculated by different testing methods, such as Brinell Hardness Test, Rockwell Hardness Test, etc. The hardness numbers obtained from different testing methods can be converted into each other (e.g. Equivalence of 98 HRB (i.e. Rockwell Hardness number in B scale) is 228 HV (i.e. Vickers Hardness number)). During the storage of hardness values of steels, all hardness numbers calculated by various testing methods are converted to Vickers hardness number. Numerical comparison of hardness numbers for selection becomes possible with this conversion. Conversion errors are neglected in the hardness values. Impact energies of steels are also calculated by different methods, but the conversion between the testing methods is not feasible. The impact values are directly stored into the database without conversion between various testing methods. Since impact values obtained by different testing methods are in the same scale i.e. similar numbers are calculated by these methods, the impact energies are used in the numerical manipulations in the selection process.

The determination of the yield strength value depends on the material type. In steels, physical meaning of the yield strength is the value of applied tensile stress producing a permanent strain of 0.2%. The stress values at higher strains become critical for design. In the literature, yield strength values are obtained by various methods such as 0.2% off-set method depending on steel type. However, senses of yield strength are same in every method, and so the values can be compared to each other. Therefore, yield strength values can be used in numerical comparison operations in the system.

3.1.7. Database Development

The developed database contains general information about steel, mechanical, physical, thermal properties and heat treatment parameters of steels. Design of the database structure is carried out keeping the following issues in mind:

- Relational construction,
- Data retrieval,
- Data observing easiness,
- Minimization of repetitive data entrance and empty space,
- Minimization of number of primary keys and fields
- Flexibility
- Expandability
- Fast and direct access to the data

Microsoft Access 97 was used for creating the database, as it has been the most widely used database program in the computer-industry. The reason of selecting the version 97 is its good compatibility with Microsoft Visual Basic 6.0.

To maximize the data access speed, some tests with arbitrary data are carried out until the ultimate form of database is obtained. During these trials, it has been seen that increase in the number of fields in a single table diminishes the speed of the search operation and using minimum number of indexed fields enhance the speed of the search considerably. Furthermore, instead of using higher number of tables, usage of foreign keys to connect two tables, increases the search speed. Therefore, the final form of the database includes optimum number of tables and fields to accomplish maximum process speed. There are totally 12 tables in the database. The tables can be divided into 3 main groups;

- Identification tables,
- Property tables,
- Explanation tables.

Data connection between the property tables such as general property and mechanical property tables is constructed by 6 or 7 digit number called "ITEM NUMBER" that is used as primary key if exists in the tables. In addition to the item number, different primary keys are used in the database, especially in the explanation tables such as condition name table. The primary key in the tables is to maintain high selection speed. However, more than one primary key namely item number and condition name are used in mechanical property table. For the tables with one primary key, one to one relation is established during searching. One to many relation is constructed for the tables with two primary keys and general index table. Each item number represents one steel designation and one material number in the database.

The relationships between data cause logical construction of tables in the database. From this point of view, all the physical tables containing the item number as the primary key field, can be described as one logical table. Other logical tables are data explanation tables, and mechanical property table having 2 primary keys.

Numerous abbreviations and codes are designed for saving space and avoiding repetitive data entrance. They are utilized in whole property and explanation tables, and the meanings of the codes are clarified in the design view part of the tables. User can easily comprehend the meanings of the abbreviations used in the fields of the tables. By this method, content of the tables in the database are kept shorter and data-searching time is diminished.

During data recording system, each entry is checked to prevent existences of the registered data more than one time in the database. The checking is done according to country standard, material designation and material number for each steel in the general identification table. If duplication of recording of the same steel appears in the table, it will result in unnecessary extension of the database and cause illogical output files in the selection processes. Each entry in the database is differentiated by a unique item number, which is designed by the administrator.

Since some properties of steels are given in a range in the literature, maximum and minimum values should be used for these type of properties. Therefore, as the numbers of fields in the tables increase, the process speed decreases. Although usage of minimum and maximum values in the tables creates an enhance in data searching time, the extra fields coming from maximum and minimum values are necessary to obtain exactly reliable property data.

3.1.8. Data Structure

Physical data structure of the database is given in Figure 3.1. Streaks between the tables demonstrate the relational connections. More than one lines may appear in the tables such as mechmain table shown in the figure. This indicates higher traffic over the mechmain table with respect to the tables possessing only one line.

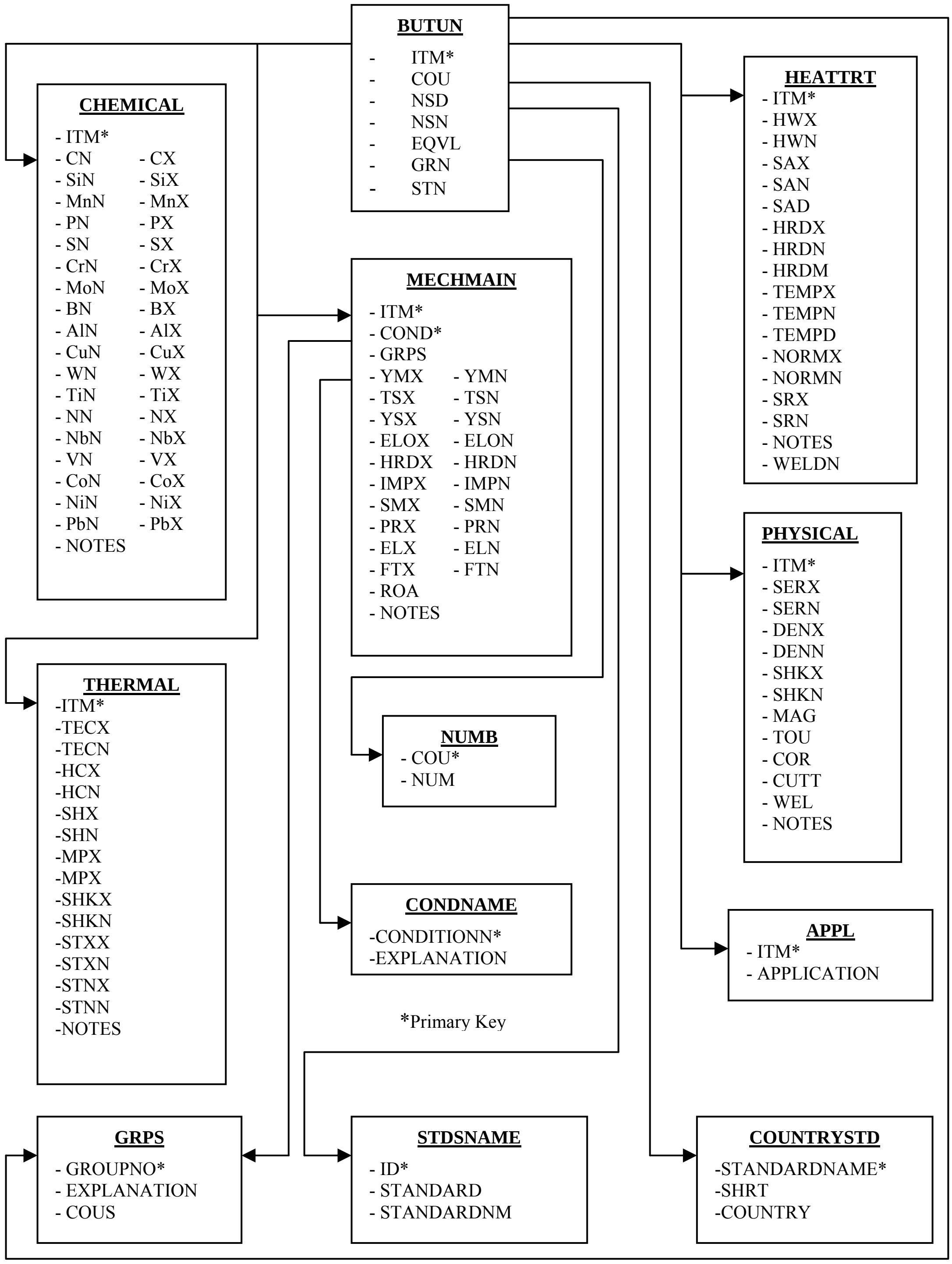

Figure 3.1 Physical structure of database.

General index table (BUTUN) is the fundamental index of the database. Description of the steel in the database is accomplished in this table. Basic information such as standard name, group of the steel about steel is also present in the table. First field is item number (ITM), which is unique for each steel. Second field is dedicated for the country or standard name (COU) of the steel. Abbreviation or symbol of the steel standard is typed in the field. Explanations of the symbols are stored in the country standard table (COUNTRYSTD). National standard designation field (NSD) is a text type field, so a letter or a number can be entered in the field. National material number field (NSN) stores the material numbers of the steels consisting of 6 character and second character of the material number must be equal to "." (i.e. 1.4000) and it must begin with 1 to indicate steel engineering material group. Since some of the steel standards such as AISI define their steel with only the material designation, "-" is used for the national material number cell. Equivalent of steel is stored in the equivalence fields (EQVL). GRN represents the group number of steel field, which is in numerical format. Explanation of the number is given in the GPRS table. Steel standard number field (STN) is also number data type and it can be stored by entering a certain number to the field. Exact standard number and its explanation can be obtained from the STDSNAME table.

Property tables have similar connections in the database. Each steel is stored by an item number and the number is stored in ITM field of the property tables. Abbreviations and explanations of property tables are given below;

- Chemical property table (CHEM)
- Mechanical property table (MECHMAIN)
- Physical property table (PHYSICAL)
- Thermal property table (THERMAL)

Mechanical property table (MECHMAIN) includes two primary key fields, namely ITM (item number) and COND (condition of steel). By using second primary key (COND), each steel can be stored several times with different conditions. Conditions such as “annealed” are stored with codes, and their explanations are assigned in COND table. Heat treatment data is stored in a separate table HEATTRT. The table is composed of 17 fields and connected to other tables with item number (ITM). Structure of other property tables such as physical property, chemical composition tables is similar to that of HEATTRT. They include one primary key and numerous information fields.

In addition to the developed database, another database is constructed for hardness unit conversion system. It is composed of only one table and the conversion of hardness values, which are obtained by different testing methods, are stored in the fields of the table separately. This table is used in the conversion module of the program. Hardness values expressed by any hardness test can be converted to those attained by other hardness tests.

3.1.9. Operations in the Database

After the storage of the information of steel in the database, values and texts should be shown to user by developing an algorithm in computer. The system must be user friendly and certain operations should be done in the database to provide the connection between the information and the user. The operations are planned to provide effective and quick data flow in the database. All operations developed in the system are explained in the following paragraphs in details.

First of all, the information about the steels in the database must be demonstrated to the user properly. The data are directly taken from database without any variation and displayed to the user by transferring it to the screen. General information, material name, standard name, mechanical properties, heat treatment parameters, thermal properties, chemical compositions and physical properties of the steel should be demonstrated in an effective visualization on the screen.

Numerical values that belong to same field in the tables can also be compared to each other and specified values determined by the user. This comparison is very important for selection of the proper steel in the design process. Selection criteria are developed by the user and shortlist of steels obeying the criteria is constructed in the system. During extracting of the lists, the numerical values in the database are compared to the criterion limits. Mechanical properties, chemical compositions, thermal properties and physical properties in the database can be searched by this method. In selection of proper steels according to the criteria, criterion statements are always combined with 'and' command. 'Or' command is not used due to the lack of combination in its meaning.

Moreover, the strength values in the mechanical properties part of the database can be taken and substituted into certain formulae developed in the process section of the program. After certain calculations in the formulae, user can observe the obtained value such as minimum required load. The values in the database are joined in the calculations developed by the system in this part.

In addition to numerical values in the database, the information in textual form can also be searched in the system. Any expression that is determined by user can be seeking in the textual data such as steel applications. Furthermore, the information in the textual format can be sorted in the alphabetical order. This is very crucial arrangement. If excess numbers of steel are listed in the system, user can easily find the desired steel in the list of the steels given in alphabetical order.

New values can be added to the database in the existed format and the values stored into the database can be deleted from the database. During enlargement of the database, the added values must be in the format, which is identical to the developed format in the system.

3.2. Package Developed

3.2.1. Introduction

The package, which has been developed in this study, aims to help the user to observe the properties of the selected steel, to list the steel obeying the specified criteria determined by the user and to calculate the critical loads for bulk deformation processes. The properties presented by the program are composed of chemical composition, physical properties, mechanical properties, thermal properties and heat treatment parameters of the steels. User can define a maximum and a minimum value for any property included in the database and then view the steels of which property values are between the specified minimum and maximum value. Moreover, user can select any steel from the database and calculate the minimum required and maximum applicable load for 13 different bulk deformation processes as entering the process parameters to the program.

This program requires Microsoft Windows as the operating system because it is developed in Microsoft Visual Basic programming language as mentioned before. Final version of the visual basic namely, Microsoft Visual Basic 6.0 is used due to its advantages with respect to other versions.

3.2.2. Modules in the Program

The package consists of five main modules. These are namely:

1. Property Displaying Module
2. Search Module
3. Selection Module
4. Process Module
5. Update Module

In addition to above modules, “About”, “Exit” and “Unit Conversion” facilities are carried out in the system. “Exit” option is used to close the program. “Unit Conversion” section is designed to provide conversion between metric (SI) units and U.S conventional units. The conversion section supplies more effective usage of the other modules in the system, such as selection module. “About” option gives information about the designers of the program and their connection addresses can be obtained from this section. The system also includes several sub-programs that are carried out under main modules of the system. All sections in the program can be summarized in the operation diagram of the system (Figure 3.2). The main modules that are given above are explained in the following sections in details.

3.2.2.1. Property Displaying Module

Steels are demonstrated by two different types of codes in the program. These codes are “Material Designation” and “Material Number”.

The demonstration of the steel depends on its steel standard. Some of the standards such as ASTM, AISI, and GOST display their steel by only material designation. Some of the standards such as DIN, TS, and UNI display their steel with material designation and material number at the same time, only material number or only material designation.

Material designation gives some hints about steels such as chemical composition and type of classification. For example, 1040 is a numerical designation of any steel in the material designation of AISI-SAE standard. In the designation, the last two digits determine its carbon content and 1040 steel has 0,40% carbon content due to XX40 designation. Moreover, the first two digits display its classification group and 10XX designation in the AISI-SAE standard replies Plain Carbon steels. Similar interaction between the material designation and general information of steel exists in other types of steel standards.

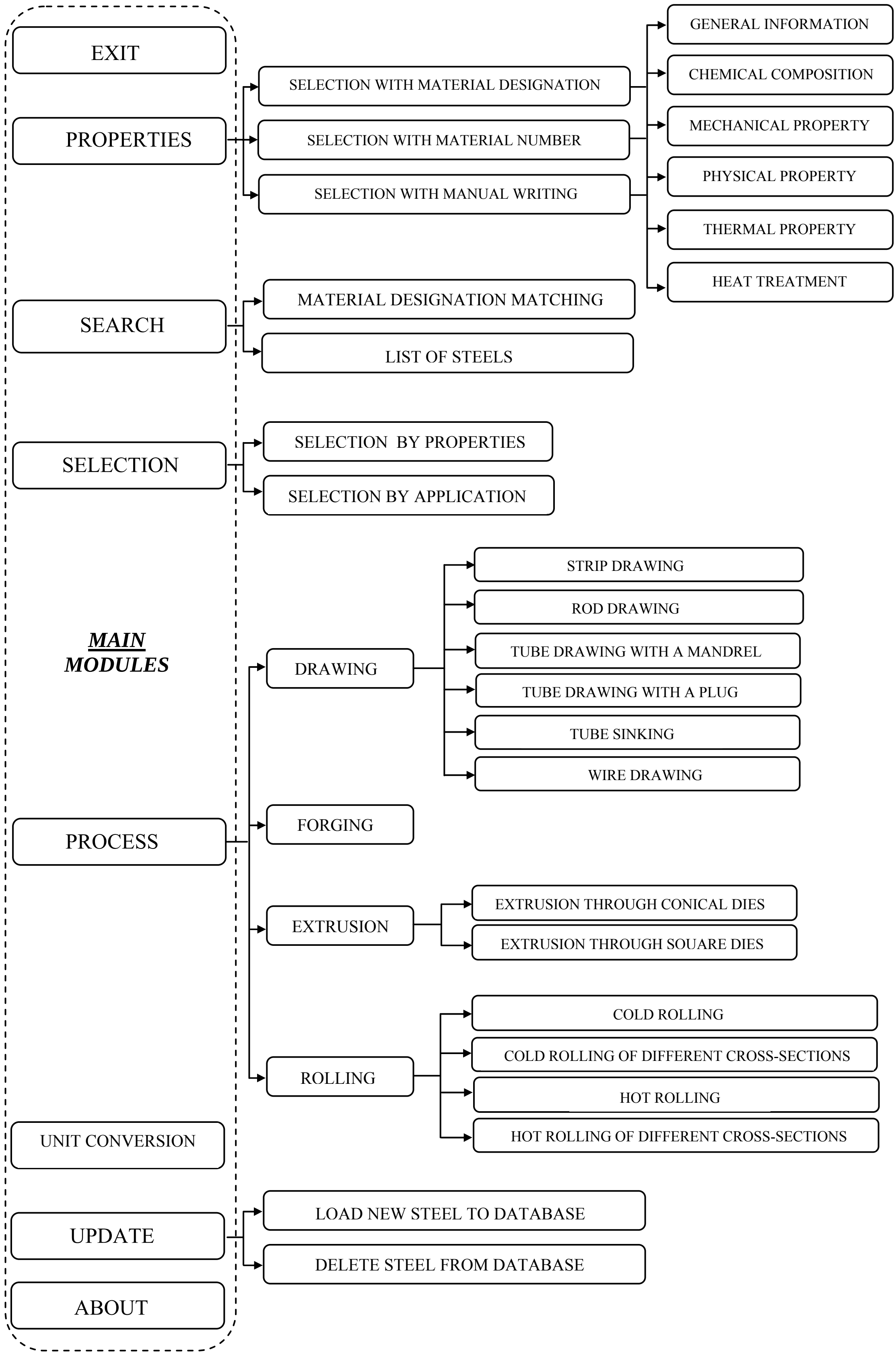

Figure 3.2 Operation diagram of the program

Material Number demonstration carries out only in the certain types of steel standards. If the same material number designation of steel exists in different steel standard, the steels belonging different steel standards show generally similar properties. However, since each standard includes different numbers of steels, any material number can exist in certain steel standard while not occurring in the other standard. This depends on the extent of the steel standard. DIN standard supplies most broad range of material number demonstration with respect to other standards. Material number of the steel includes seven characters (e.g. 1.4323). The number must begin with ‘1’ to designate steel group and then continues with ‘.’ character. The last four characters are composed of four-digit number. As the new steel is added to the standard, new material number is designed for the new steel and the standard enlarges. Moreover, some steels existing in the standard can be taken out from the steel standard and this material number is eliminated. Therefore, the demonstration of material number for steel changes continuously.

To display the properties of the steel the program should learn the steel standard, material designation and material number if exists from the user. Therefore, user has to know the general information of the steel to observe its properties. However, the material designation and material number are complex codes and it is difficult to memorize these codes. Program provides list of steels to user to satisfy easier observation of steels. Any steel standard or classification group can be selected and listed to the screen, and then desired steel can be chosen and the properties of steel will be able to be observed. With these steel lists, there is no need to know exact name of the steel and user not having any information about steel demonstration can use the program easily. More professional part is also developed in the program to demonstrate the properties of the steel. User can write the exact material designation or material number to the form. However, this part necessitates more professional knowledge about steel standards and demonstration.

In some steel standards, it is possible to see the same material designation for different steels. For example, DIN-100Cr6 implies two steels having different material numbers in DIN steel standards. The developed program warns the user that the material designation is belonged to two different steels and they are distinguished by their material numbers. Then, user can select the steel he wants.

User can observe general properties, chemical composition, mechanical properties, physical properties, heat treatment parameters and thermal properties about specified steel. General properties part includes identification details such as material number, material designation, standard name and country of the steel. Some industrial applications of the identified steel are also shown in the general properties. Chemical composition section is composed of 18 different types of elements (C, Si, Mn, P, S, Cr, Mo, Ni, V, Al, Cu, W, Ti, N, Nb, B, Pb and Co).

Mechanical properties part consists of yield strength, tensile strength, young's modulus, bulk modulus, fracture toughness, endurance limit, hardness, elongation, Poisson's ratio and reduction of area. Mechanical properties of materials strongly depend pre-treatments such as heat treatments carried out during or/and after the production of steels. Therefore, same steel shows different mechanical property values due to different pre-treatments. Mechanical properties of steel for various pre-treatments such as as-rolled, annealed are also shown in the program.

Physical properties part is composed of density, specific electrical resistance and degree of shrinkage of the steel. In addition to above properties, information about cutting property, toughness degree, corrosion resistance, magnetizability, weldability are also given in the physical properties part.

Thermal properties part includes thermal expansion coefficient, specific heat, thermal conductivity, melting point, maximum service temperature and minimum service temperature of steel. Heat treatment parameters in the program are hot working temperature, soft annealing temperature, hardening temperature, normalizing temperature and stress-relieving temperature of steel. There are also two types of notes in the part. One of them is related to general information about heat treatment and other includes heat treatment notes for welding if the steel is weldable.

3.2.2.2. Search Module

Typing of Material designations for steel sometimes becomes very difficult as it is mentioned in the previous section. Engineer should enter exactly correct material designation to identify any steel in the standard. Whether the letter in the designation is upper case or not is critical to determine the steel designation. The arrangement of the characters has to be exactly same with the original material designation; otherwise the designation can imply another steel in the standard or become meaningless.

The developed system in the study provides a user-friendly program to engineers. With this respect, lists of steels are constructed in the program as mentioned before. In addition to this, material designation matching part is developed in the system to solve the typing errors in the material designation. User can search any part of designation in the program. For example, if user remembers only “mn” part of the material designation that is 100MnCrW4, he can search all material designations including “mn” expression in the database. The system constructs the list of the steels having desired expression in their designation.

More than one expression in the material designation can be searched in the system. For instance, “mo” and “ni” terms can be inspected at the same time and then the program detect certain steels, such as 56NiCrMoV7, in the database, and construct the list of the steel. Finally, user can select the steel that he searches from the database.

To develop the list of the steels that belong to certain steel standard name, classification group and standard number is very useful for engineers dealing with the design process. Classification groups developed in the steel standards are composed of steels that are used in similar applications. This is true for also standard number. For example, the steels having 1.0425 and 1.0473 material numbers are in the DIN EN 10083-2 steel standard number, and both of them are used in the production of pressure vessels. Therefore, if any engineer obtains the steels in the same standard number or classification group of the steel standard, he can compare alternative materials with the original material used in the production easily.

The system develops the lists of the steels with respect to their classification groups and standard numbers in the steel standard. Each standard in the database can be grouped according to its standard number and classification group. The developed lists can also be sorted by material designation or number in the system.

3.2.2.3. Selection Module

Selection module is developed to determine the proper steels according to specified criterion defined by user. The selection procedure is divided into two methods given below:

1- Selection by Properties
2- Selection by Application

In the selection by properties part; mechanical properties, chemical compositions, physical properties and thermal properties are defined as the selection criterion. Any property given in the module can be chosen and desired limit values can be determined to develop the selection criterion. More than one criterion can be developed in the program. These criteria can belong to different type of properties.

To define the limit values of the criterion, there are two different methods exist in the program. The first one is the selection by nominal value and deviation percentage. In this method, an exact value for the specified property is determined and then the deviation percentage is given for the exact value. For example, if the user defines the exact value as 100 units and the deviation percentage 50 % for specified property, the program search the steels having between 50 and 150 units for the property. The second one is the selection by maximum and minimum values. User determines the limit values directly by entering a maximum and a minimum value into the program.

The developed package demonstrates logical limit values for the properties given in the selection part. This is very essential due to create meaningful selection criteria. If user does not have enough knowledge about the values of the specified properties, the limit values displayed by the program can help him to determine proper selection criteria for the design. Moreover, if user enters an illogical limit value for the specified property, the program will warn about this limit value.

Most of the mechanical, physical and thermal properties, and all chemical composition data are stored in a certain range with a minimum and maximum value in the database. During selection operation, this range is always considered and all steels having an intersection, which is equal to or greater than zero with the user defined range, are taken as acceptable steels. Therefore, the range of the property of selected steel does not have to cover the whole range of the selection criteria determined by the user. Certain intersection between these ranges is enough to be a selected steel.

Sensitivity of the limit values is very essential in the selection process. While some properties are in the range between 500 and 1000 (e.g. tensile strength values for the steels are between 500 and 2500 MPa.), others such as chemical contents of the elements in the steel especially are in the range between 0 to 1. Therefore, the limit values may have certain decimal places during determination of selection criterion. The decimal places in the limit values are evaluated in the developed program, list of proper steels are created according to the limit values possessing decimal places.

In the selection by application section, the program can list the steel having specified industrial application. User can enter the name of application such as “gear”, “tool”, “ship building”, “pressure vessel”, “spring”, or any other specific expression to choose proper steel for desired application. After determining the application, steels possessing desired application are listed and demonstrated to the user.

List of steels obeying the specified criteria determined by user in both selection by properties and selection by application sections are created. It is also possible to observe the properties of the selected steel in the selection parts directly. Therefore, there is no need to return to displaying property module of the program.

3.2.2.4. Process Module

Process module is used to calculate minimum required load and maximum applicable load for bulk deformation processes. These processes are listed in the following:

- Extrusion
    - Extrusion through conical dies
    - Extrusion through square dies
- Rolling
    - Cold rolling
    - Cold rolling for different cross-section
    - Hot rolling
    - Hot rolling for different cross-section
- Drawing
    - Rod drawing
    - Strip drawing
    - Tube drawing with mandrel
    - Tube drawing with plug
    - Tube sinking
    - Wire drawing
- Forging

In the program, special parts are created for each bulk deformation process given above. List of steels is designed according to steel standard name and classification group of steel in each part of the process module. User can easily select any steel from the list.

Calculation of the critical loads is done by formula, which is developed by engineers specialized in the stress analyses. The formulae are composed of the bulk deformation process parameters and certain mechanical properties of steels. The properties of the selected steel are substituted into the formulae from the mechanical property table of the database automatically by only detecting the steel in the list. The process parameters in the formulae should be determined by the user. Therefore, certain input boxes are placed on the form of each process module for the parameters and user can enter the proper values for the parameters.

The number and type of the process parameters in each part of the process module depend on the type of the bulk deformation process. Moreover, some process parts provide more than one method to calculate the critical load for the process. For example, the loads can be calculated for frictional and frictionless condition in the rod drawing bulk deformation process part.

During development of the load calculation formulae, certain assumptions were done and some process parameters must be in a certain range that is defined by engineers. The program gives also information about the critical values of the process parameters to the user. If user enters an illogical value for the process parameters, the program will warn him about the incorrect value.

The stress analyses and the formulae, which are used for each bulk deformation process in the program, are investigated in the following sections in details.

3.2.2.4.1. Stress analyses in Extrusion

The extrusion of cylindrical billets is investigated as the extrusion process. A proper solution for the extrusion of cylindrical billets requires involved numerical analysis even when friction and work hardening are disregarded. However, in practical point of view, solutions based on the consideration of equilibrium should provide fairly realistic estimates of the extrusion load. Chakrabarty (1987) states that by the kinematic theorem of limit analysis, any imaginary velocity field that satisfies the incompressibility condition and the prescribed boundary conditions supplies an overestimate on the extrusion pressure. Then, by using upper bound solution, the extrusion pressure can be evaluated for the extrusion of cylindrical billets. Shape of die can be conical or square for extrusion. The developed stresses for the two die shapes should be examined separately.

Pressure calculation for square dies:

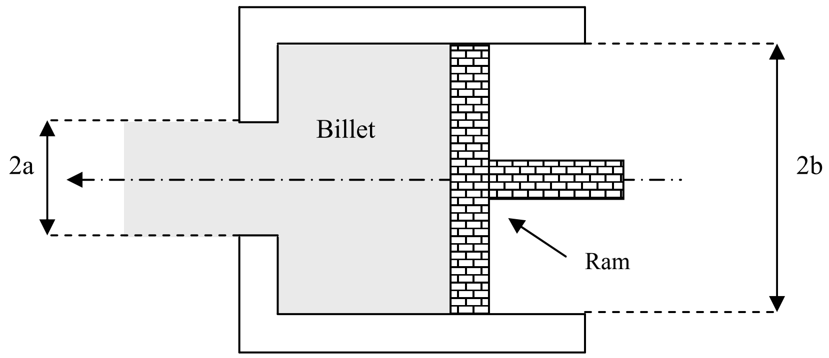

Figure 3.3 Schematic view of extrusion of cylindrical through square die.

The schematic view of the extrusion of cylindrical billets through square dies is shown in Figure 3.3 and the extrusion pressure can be expressed by:

$$p_e = \frac{Y}{\sqrt{3}}(e+f) \tag{3.1}$$

where

$$e = 2\ln\frac{b}{a} + \left(1 - \frac{a^2}{b^2}\right)\left[\frac{a}{c}\ln\left(\frac{c}{2a} + \sqrt{1 + \frac{c^2}{4a_2}}\right) + \frac{1}{2}\sqrt{1 + \frac{c^2}{4a_2}} - 1\right] \tag{3.2}$$

and

$$f = \frac{2ac}{b^2}\left[m + \left(1 - 2m + 2m^2\right)\frac{2}{3a}\left(\frac{b^3 - a^3}{b^2 - a^2}\right)\right] + \left(1 - \frac{a^2}{b^2}\right)\left(\frac{2b-a}{c} + \frac{c}{a}\right) \tag{3.3}$$

p_e	: extrusion pressure (MPa)
Y	: uniaxial yield strength of the workpiece (MPa)
a	: half of final height of the workpiece (mm)
b	: half of initial height of the workpiece (mm)
e, f, m, c	: constants in the equation

m and *c* can be calculated from the following equations:

$$m = \frac{1}{2}\left[1 - \frac{3a}{4}\left(\frac{b^2 - a^2}{b^3 - a^3}\right)\right] \tag{3.4}$$

$$\frac{c^2}{a^2}\left[1 + \frac{2ma^2}{b^2} + \frac{8m^2 a}{3b^2}\left(\frac{b^3 - a^3}{b^2 - a^2}\right)\right] = \left(1 - \frac{a^2}{b^2}\right)\left[\frac{2b}{a} - 1 + \ln\left(\frac{c}{2a} + \sqrt{1 + \frac{c^2}{4a^2}}\right) - \frac{c}{2a}\sqrt{1 + \frac{c^2}{4a^2}}\right] \tag{3.5}$$

The last two terms in rectangular brackets on the right-hand side of Equation 3.5 may be neglected for easier calculation of c. For sufficiently small reductions in area, this formula gives good results.

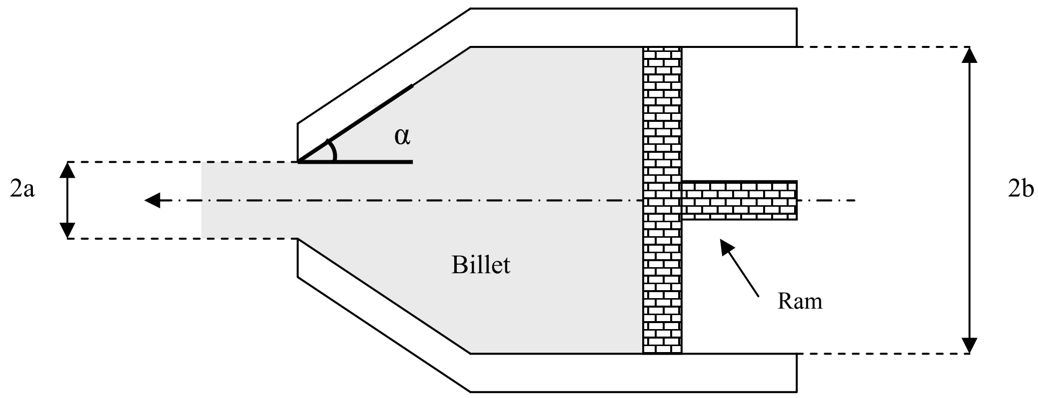

Figure 3.4 Schematic view of extrusion of cylindrical through conical die.

Pressure calculation for conical dies: An upper-bound analysis is also developed for the extrusion of cylindrical billets through conical dies (see Figure 3.4) and the extrusion pressure can be expressed by:

$$p_e = \frac{Y}{\sqrt{3}}(e+f) \qquad (3.6)$$

where

$$e = 2\ln\frac{b}{a} + \left(1-\frac{a^2}{b^2}\right)\left[\frac{a}{c}\ln\left(\frac{c}{2a}+\sqrt{1+\frac{c^2}{4a_2}}\right)+\frac{1}{2}\sqrt{1+\frac{c^2}{4a_2}}-1\right] \qquad (3.7)$$

and

$$f = \frac{2ac}{b^2}\left[1+\frac{2}{3a}\left(\frac{b^3-a^3}{b^2-a^2}\right)\right]+\left(1-\frac{a^2}{b^2}\right)\left[\frac{a^2+c^2}{2ac}+\left(\frac{b-a}{c}\right)\cos ec^2\alpha-3\cot\alpha\right]$$

(3.8)

p_e	: extrusion pressure (MPa)
Y	: uniaxial yield strength of the workpiece (MPa)
a	: half of final height of the workpiece (mm)
b	: half of initial height of the workpiece (mm)
e, f, c	: constants in the equation

The ratio c/a can be obtained by the following formula given in Equation 3.9:

$$\frac{c^2}{a^2}\left[1+\frac{4a}{3}\left(\frac{b^3-a^3}{b^4-a^4}\right)\right]=\left(\frac{b^2-a^2}{b^2+a^2}\right)\left[1+\left(\frac{b}{a}-1\right)\cos ec\alpha^2+\ln\left(\frac{c}{2a}+\sqrt{1+\frac{c^2}{4a^2}}\right)-\frac{c}{2a}\sqrt{1+\frac{c^2}{4a^2}}\right]$$

(3.9)

The last two terms in the rectangular brackets of Equation 3.9 possess a negligible effect on the solution of c/a ratio. For large reductions in area, this formula is usually used by substituting $\alpha = \pi/2$ instead of the previous formula for extrusion cylindrical billets through square dies and gives more accurate results Chakrabarty (2000).

3.2.2.4.2. Stress analyses in Rolling

The analyses of rolling are developed for hot rolling and cold rolling processes separately in the program.

Hot Rolling: There are many formulae to determine the roll separating force in hot rolling. Equation 3.10 for calculation of roll force has been derived by Ekelund and is very suitable formula for practical uses (Wusatowski, 1969).

$$P = b_m \sqrt{R(h_1 - h_2)} \left[1 + \frac{1.6 f \sqrt{R(h_1 - h_2)} - 1.2(h_1 - h_2)}{h_1 + h_2} \right] \left(K_f + \frac{2\eta \upsilon_m \sqrt{\frac{h_1 - h_2}{R}}}{h_1 + h_2} \right) \quad (3.10)$$

P : roll force (kg)

h_1 : initial height of stock (mm)

h_2 : final height of stock (mm)

b_m : mean width of rolled stock (mm)

f : coefficient of friction

- for cast iron and rough steel rolls, $f = 1.05 - 0.0005t$
- for chilled and smooth steel rolls, $f = 0.8\ (1.05 - 0.0005t)$
- for ground steel rolls, $f = 0.55(1.05 - 0.0005t)$

t : rolling temperature (^oC)

K_f : yield stress (kg/mm^2)

η : coefficient of plasticity of rolled stock ($kg.sec/mm^2$) (starting from 800^oC)

$\eta = 0.01\ (14 - 0.01\ t)$

v_m : mean rolling speed in the pass (mm/sec)

Formula given in Equation 3.10 is valid for speed up to 7 m/sec. When rolling speed is higher, the following correction coefficient c is used for the calculation of η:

v(m/sec)	*c*
up to 6	1.0
6-10	0.8
10-15	0.65
15-20	0.6

In these cases the corrected value of $\eta' = c.\eta$ should be substituted for η in Ekelund's formula.

Equation 3.10 is valid for sheet, strip and flats. When rolling in passes, instead of h_1 and h_2, mean heights of the pass are used. Furthermore, the Ekuland formula for calculation of resistance to deformation of the rolled stock is based upon the assumption that internal friction decrease in direct proportion to the increase of the temperature. According to Ekelund's formula the yield stress would be equal to zero, if the rolling temperature were to increase up to 1400°C, i.e. the rolled stock would begin to melt, which is obviously illogical. However despite disadvantages, the Ekelund formula gives results very closely approximating to the true ones. Therefore, this formula is suitable for calculation of load in hot rolling.

Cold Rolling: It is more difficult to calculate roll forces in cold rolling than in hot rolling, due to work-hardening of the rolled stock. The projected length of arc of contact for deformed rolls is increased at both ends in comparison with the value for undeformed rolls due to roll flattening. This causes the changing of resistance to deformation of roll stock. Ford gave a formula stated in Equation 3.11, for flattened radius R, assuming the roll to be still of cylindrical form in the flattened place, but of greater diameter (Wusatowski, 1969).

$$R' = R\left(1 + \frac{2cP}{b_m\left(h_1 - h_2\right)}\right) \tag{3.11}$$

where

R : radius of undeformed rolled (mm)

R' : radius of deformed rolled (mm)

P : total roll force (kg)

h_1 : initial height of stock (mm)

h_2 : final height of stock (mm)

b_m : mean width of rolled stock (mm)

c : coefficient equal to $1.06*10^{-4}$ mm^2/kg for steel rolls

$2.06*10^{-4}$ mm^2/kg for cast-iron rolls

The formula given in Equation 3.10 derived by Ekelund for calculation of roll force in hot rolling has been simplified by Bland and Ford (1948) and transformed for cold rolling into the following form (Wusatowski, 1952):

$$P = b_m K_f \sqrt{R'(h_1 - h_2)}\left[1 + \frac{1.6 f \sqrt{R'(h_1 - h_2)} - 1.2(h_1 - h_2)}{h_1 + h_2}\right] \quad (3.12)$$

where

P : roll force (kg)

h_1 : initial height of stock (mm)

h_2 : final height of stock (mm)

b_m : mean width of rolled stock (mm)

f : coefficient of friction

K_f : yield stress (kg/mm^2)

R' : radius of deformed rolled (mm)

In the formula given in Equation 3.12, the results of calculation depend considerably on roll flattening; the influence of roll peripheral speed is not taken into account. Therefore, the calculated values of roll force are almost equal to or slightly less than measured values for the first passes, i.e. for small rolling speed.

For rolling of non-rectangular sections such as bars, shapes, rails, etc., an additional term, the mean height of stock, is introduced besides h_1, h_2. The mean height of stock is expressed as (Wusatowski and Wusatowski, 1952):

$$h_m = m \times h_{\max} \tag{3.13}$$

where

h_m : mean height of section (mm)

h_{max} : maximum height of section (mm)

m : a coefficient, determined for respective types of sections

To apply the above equation stated in Equation 3.13, values of m given in the Table 3.2 may be used.

Table 3.2 Mean height of the pass h_m for different pass forms.

Type of pass	Coefficient, m	Remarks
Gothic	0.55-0.6	
Square with rounded edges	0.97-0.99	Flat position
Square with sharp edges	0.51	
Diamond with sharp edges	0.51	
Square with rounded edges	0.56-0.58	Diagonal position
Flat oval	0.67-0.65	
Elliptic oval	0.785-0.82	Entering into oval
Rounded oval	0.80-0.94	Comes out square
Pyramid oval	0.55-0.88	
Hexagon	0.75	Diagonal position
Round	0.785	

3.2.2.4.3. Stress Analyses in Drawing

There are totally six drawing processes that are investigated in the system. The stress analyses are given for all of the drawing processes in the following paragraphs.

Wire drawing: Wires of small diameter are produced by successive drawing through dies so that its cross-section is progressively reduced to the specified size (see Figure 3.5). By combined action of the applied longitudinal pull and the pressure developed between the wire and the die, the material can be shaped plastically.

A useful expression for the mean drawing stress, including friction and redundant work, may be obtained on the assumption of homogeneous deformation, no back-pull effect and non-strain hardening material. By adopting the extrusion pressure formula developed by Lambert and Kobayashi (1969) to wire drawing process, the mean drawing stress with friction may written as follows:

$$t = Y\left\{1+\left(1-0.5\ln\frac{1}{1-R}\right)\mu\cot\alpha\right\}\left\{0.5\sin\alpha+\left(0.91+0.12\sin^2\alpha\right)\ln\frac{1}{1-R}\right\} \tag{3.14}$$

where

- t : mean die pressure (MPa)
- Y : uniaxial yield stress of material (MPa)
- R : reduction in area
  - $R = 1 - (a/b)^2$
  - a : final radius of wire (mm)
  - b : initial radius of wire (mm)
- α : semicone-die angle (degree)
- μ : coefficient of friction between die and wire

This formula stated in Equation 3.14 gives proper results that is found to be in good agreement for $\alpha < 30^{o}$.

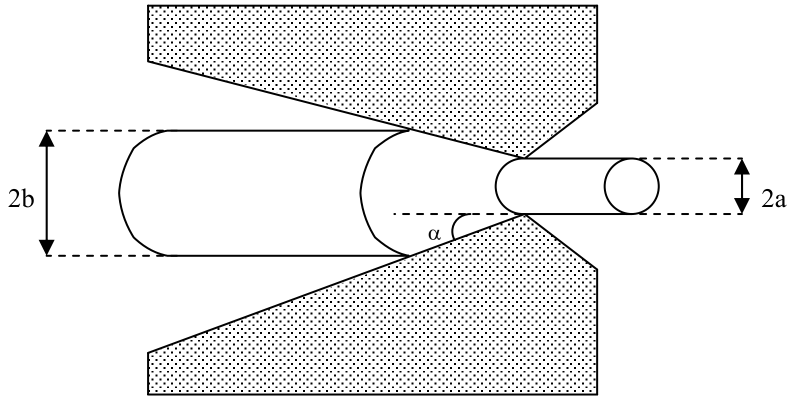

Figure 3.5 Schematic view of wire drawing.

Rod Drawing: Rod drawing and wire drawing processes are similar to each other. The main distinction between them is the size of the sample to be drawn. In general, the term wire implies to small diameter products less than 5 mm that may be drawn rapidly on multiple-die machines. Therefore, the stresses existing in the rod drawing can be calculated by formulae different than that used in the wire drawing.

The stresses developed in the cylindrical-rod drawing, with a conical die, are investigated, and for homogeneous deformation the drawing stress can be given as (Hoffman and Sachs, 1953):

$$\sigma = Y\left(\frac{1+B}{B}\right)\left[1-(1-r)^{B}\right] \tag{3.15}$$

where

σ	: rod drawing stress (MPa)
Y	: uniaxial yield stress of material (MPa)
r	: reduction in area

$$r = 1-\left(\frac{D_a}{D_b}\right)^2$$

D_a	: final diameter of rod (mm)
D_b	: initial diameter of rod (mm)

B : a constant or variable

$$B = \mu \cot \alpha$$

μ : friction coefficient between rod and die

α : semi-cone angle of die (degree)

It is assumed that strain hardening, redundant work and back-pull effects are not considered during analyses and also friction coefficient is taken as constant along all die surfaces.

If the coefficient of friction is zero, the parameter B becomes zero and Equation 3.15 can not be used. Therefore, another formula should be developed for frictionless condition to calculate drawing stress. It can be given as:

$$\sigma = Y \ln\left(\frac{1}{1-r}\right) \tag{3.16}$$

where

σ : rod drawing stress (MPa)

Y : uniaxial yield stress of material (MPa)

r : reduction in area

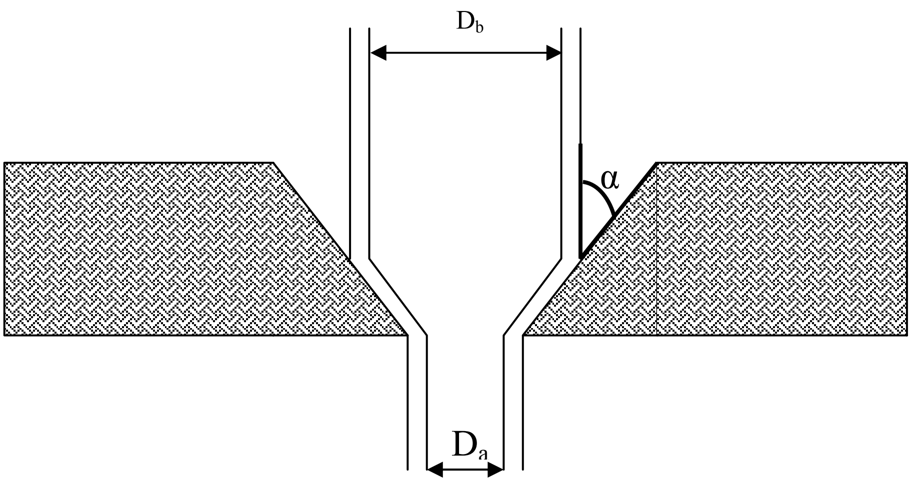

Figure 3.6 Schematic view of tube sinking.

It can be noticed that Equation 3.16 is independent of the die angle. This means the dies are equally well curved, provided that there is perfect lubrication.

Tube Sinking: Tube sinking consists in drawing a tube through a die such that its external diameter is reduced with no internal support for the tube (Figure 3.6). During deformation, there are several stresses acting on the tube. They are tensile stress, parallel to the die face, compressive stress due to contact with the die and the compressive hoop stress (Johnson and Mellor, 1973).

The stresses involved in the process have been analysed by Sachs and Baldwin (1946) on the assumption that the wall thickness of the tube remains constant. The analyses is similar to the analyses in wire drawing except that there is a more complex stress system in tube sinking. If the material can be taken as non-strain hardening, the tube sinking stress is given in Equation 3.17 as follows:

$$\sigma = 1.1Y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{D_a}{D_b}\right)^B\right] \tag{3.17}$$

where

- σ : tube sinking stress (MPa)
- Y : uniaxial yield stress of material (MPa)
- B : a constant or variable
  - $B = \mu \cot \alpha$
  - μ : friction coefficient between tube and die
  - α : semi-cone angle of die (degree)
- D_a : final diameter of tube (mm)
- D_b : initial diameter of tube (mm)

The above formula was developed under the plane-strain condition. Under most practical conditions, the wall thickness is slightly increased by sinking, but this does not seriously affect the calculated stress.

Tube Drawing with a plug and a mandrel: The major part of the deformation in tube drawing with a plug or mandrel carries out as a reduction in wall thickness. Due to existence of the plug and the mandrel in the inside of the tube, a small reduction in the diameter of the tube occurs. Therefore, there is no hoop strain during the deformation and the analyses of the processes can be based on the plane-strain condition. Under the condition, Sachs et. al. (1944) analysed the stresses in the processes.

In plug drawing (Figure 3.7), the frictional drag acts in the backward direction on both inside and outside of the tube. For tube drawing, the draw stress can be expressed by (Dieter, 1988):

$$\sigma = S \frac{1 + B}{B} \left[1 - \left(\frac{h_a}{h_b} \right)^B \right] \qquad (3.18)$$

where

σ : draw stress (MPa)

S : yield stress of the material in plane strain condition (MPa)

$$Y = \frac{\sqrt{3}}{2} S$$

Y : uniaxial yield strength of material (MPa)

B : a constant or variable

$$B = \frac{\mu_1 + \mu_2}{\tan\alpha - \tan\beta}$$

μ_1 : coefficient of friction between tube and die wall

μ_2 : coefficient of friction between tube and plug

α : semi-cone angle of die (degree) (α is equal to 0 for cylindrical plugs)

β : semi-cone angle of plug (degree)

h_a : final wall thickness of tube (mm)

h_b : initial wall thickness of tube (mm)

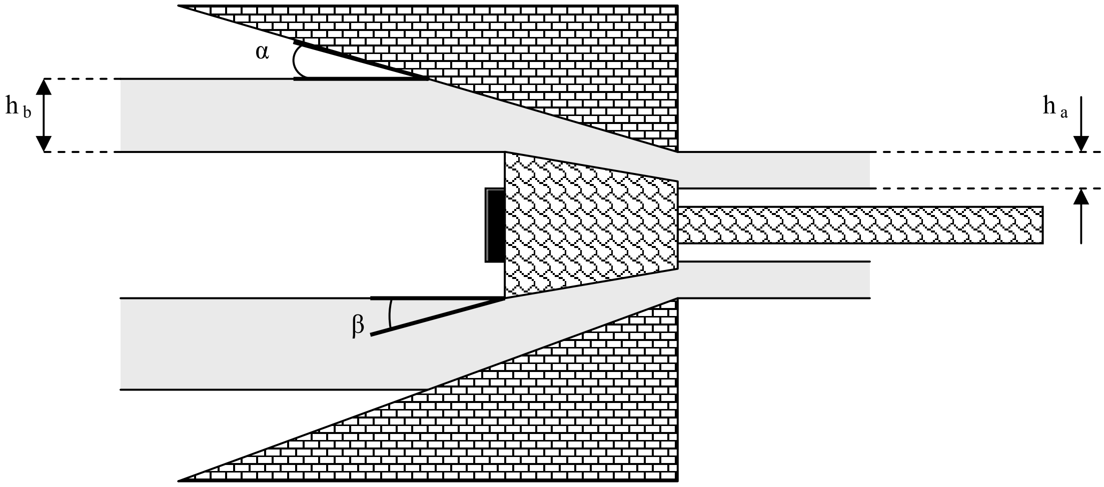

Figure 3.7 Schematic view of tube drawing with a plug.

For tube drawing with a mandrel (Figure 3.8), the same formula given in Equation 3.18 can be used for the calculation of the draw stress. However, when the mandrel is drawn forward with the tube, the relative motion on the inside of the tube is reversed due to the elongation of the tube. Therefore, the direction of the frictional force between mandrel and tube is opposite to that between tube and die. The parameter *B* is changed to:

$$B = \frac{\mu_1 - \mu_2}{\tan\alpha - \tan\beta} \tag{3.19}$$

where

μ_1	: coefficient of friction between tube and die wall
μ_2	: coefficient of friction between tube and mandrel
α	: semi-cone angle of die (degree)
β	: semi-cone angle of mandrel (degree)

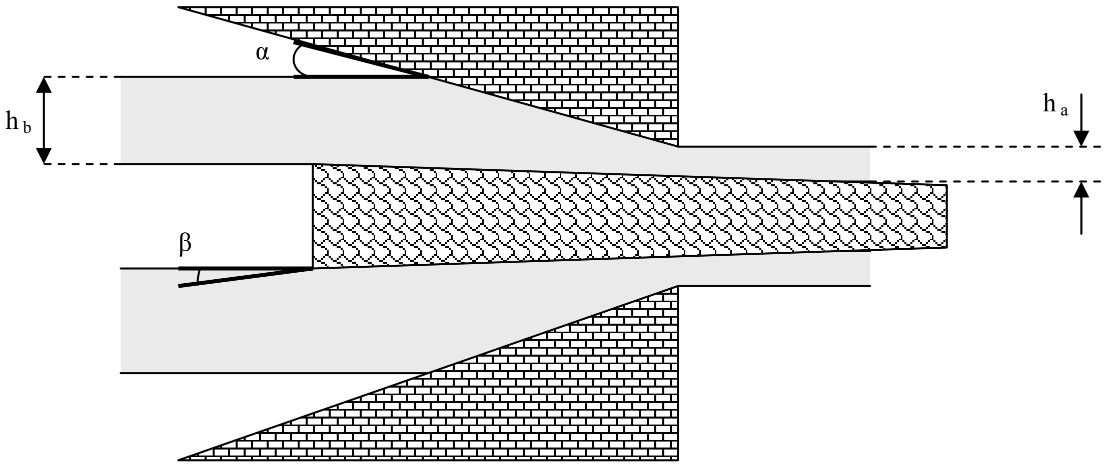

Figure 3.8 Schematic view of tube drawing with a mandrel.

If $\mu_1 = \mu_2$, B will be equal to zero. Under the condition, the deformation can be considered as homogeneous and the draw stress is given as (Rowe, 1977):

$$\sigma = S \ln \frac{h_b}{h_a} \tag{3.20}$$

where

σ : draw stress (MPa)

S : yield stress of the material in plane strain condition (MPa)

h_a : final wall thickness of tube (mm)

h_b : initial wall thickness of tube (mm)

Strip Drawing: The strip drawing is a drawing process where the stresses acting on the strip are similar to those existing previous drawing processes. Under the plane strain condition, the stress developed in drawing of wide, flat strip with wedge-shaped dies (Figure 3.9) can be given as in Equation 3.21 by Sachs (1934):

$$\sigma = S \frac{1+B}{B} \left[1 - \left(\frac{h_a}{h_b} \right)^B \right] \tag{3.21}$$

where

σ : draw stress (MPa)

S : yield stress of material in plane strain condition (MPa)

$$Y = \frac{\sqrt{3}}{2} S$$

Y : uniaxial yield strength of material (MPa)

B : a constant or variable

$$B = \mu \cot \alpha$$

μ : friction coefficient between tube and die

α : semi-cone angle of die (degree)

h_a : final height of strip (mm)

h_b : initial height of strip (mm)

The drawn material is considered as non-strain hardening and back-pull effect is neglected during the development of the formula.

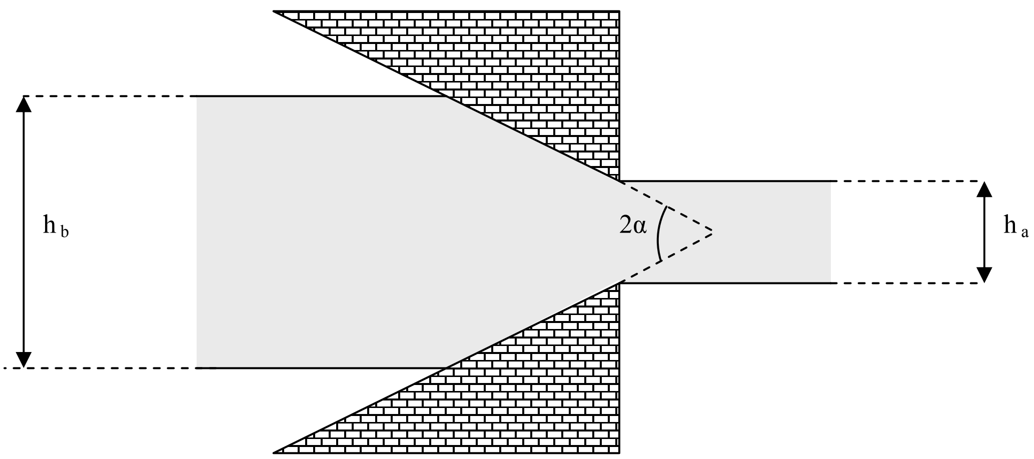

Figure 3.9 Schematic view of drawing of flat strip with wedge-shaped dies.

3.2.2.4.4. Stress analyses in Forging

The compression of short cylinders between a pair of overlapping parallel dies (Figure 3.10) can be considered as a simple forging process. It is investigated in forging section of the program. The stress analyses of the process was developed by Siebel (1923) and Bishop (1958). During the analyses, the coefficient of friction between the cylinder and the dies is assumed constant, and the stresses are under plane-strain condition.

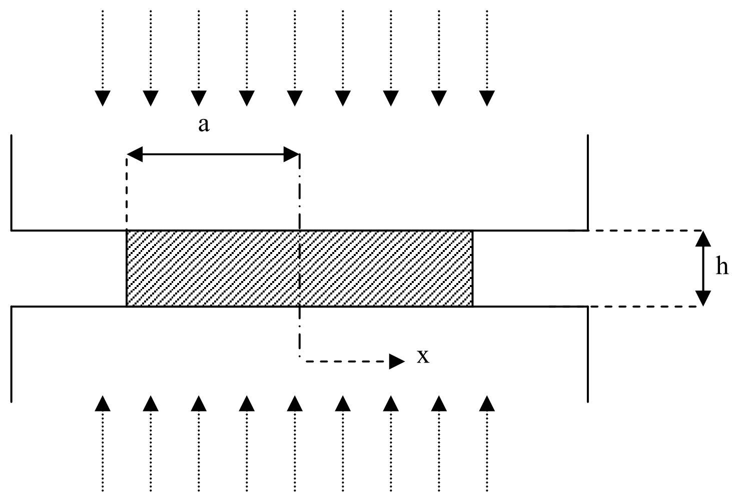

Figure 3.10 Schematic view of compression of short cylinders between parallel dies.

Depending on the magnitude of the friction on the surfaces, the stresses can be calculated for high and low friction condition separately.

Low friction condition: The presence of the friction causes an imbalance of the force along the x-direction (see Figure 3.10) and the forging pressure depending on the distance from the center of the cylinder can be given in Equation 3.22 as follows:

$$q = S \exp\left[2\mu(a - x)/h\right] \qquad (3.22)$$

where

q : the forging pressure (MPa)

S : yield stress of material in plane strain condition (MPa)

$$Y = \frac{\sqrt{3}}{2} S$$

Y : uniaxial yield strength of material (MPa)

μ : coefficient of friction between cylinder and die

a : radius of cylinder (mm)

h : height of the cylinder (mm)

x : distance from center of the cylinder along x-axes (mm)

For large a/h ratio values, there can be two different situations along x-axes:

If $\mu q < Y/\sqrt{3} \Rightarrow$ Sliding friction condition

If $\mu q \geq Y/\sqrt{3} \Rightarrow$ Sticking friction condition

The value of μq with different x values should be calculated and compare with the value of $Y/\sqrt{3}$ to determine the condition of the given processes.

If the maximum value of μq is smaller than the value of $Y/\sqrt{3}$ in the process, complete sliding friction condition will be satisfied. For the condition, the mean forging stress (q′) can be taken as:

$$q' = S\frac{h^2}{2\mu^2 a^2}\left\{\exp\left(\frac{2\mu a}{h}\right) - 1 - \left(\frac{2\mu a}{h}\right)\right\} \qquad (3.23)$$

where

S : yield stress of material in plane strain condition (MPa)

μ : coefficient of friction between cylinder and die

a : radius of cylinder (mm)

h : height of the cylinder (mm)

As the vertical forging pressure increases inwards, the magnitude of the frictional stress μq will also increase, but when it reaches a value to $Y/\sqrt{3}$, no further increase is possible. Then the central region will be governed by the sticking friction condition. Thus, the situation of the process becomes the combination of sliding and sticking friction condition. For this condition, the mean forging stress (q') can be taken as:

$$q' = S\left[\frac{h^2}{2\mu^2 a^2}\left(\frac{1}{2\mu}+\frac{r_o}{h}-1\right)-\frac{h}{\mu a}+\frac{r_o^{\,2}}{a^2}\left(\frac{1}{2\mu}+\frac{r_o}{3h}\right)\right] \qquad (3.24)$$

where

r_o	: critical distance from the center of the cylinder at which sliding condition transforms to sticking condition (mm)
S	: yield stress of material in plane strain condition (MPa)
μ	: coefficient of friction between cylinder and die
a	: radius of cylinder (mm)
h	: height of the cylinder (mm)

High friction condition: In high friction condition, the value of μq is equal to or bigger than the value of $Y/\sqrt{3}$ for all possible values of x. Therefore, complete sticking friction condition is satisfied and the mean forging stress can be given as:

$$q' = S\left(\frac{a}{2h}+1\right) \qquad (3.25)$$

where

q'	: mean forging pressure (MPa)
S	: yield stress of material in plane strain condition (MPa)
a	: radius of cylinder (mm)
h	: height of the cylinder (mm)

3.2.2.4.5. Load Calculation

In the stress analyses of processes that are given in the previous sections, stress formulae are sometimes developed instead of load formulae. However, the load calculation can be carried out easily by giving the relation between load and stress parameters.

$$Load = Stress \; x \; Cross\text{-}Sectional \; Area \qquad (3.26)$$

By using above relation between stress and load, the stress formulae can be easily converted into the load formulae. Cross-sectional area, which the load is applied to, changes for each bulk deformation process in the system.

Moreover, the unit of the loads to be calculated in the program is kilo newton (kN), and the stress values that are obtained from database are in the unit of mega pascal (MPa). For this reason, the units of the process parameters are designed to provide the specified load unit.

3.2.2.5. Update Module

Existing update facility in the database is very significant to provide loading current information to the system or deleting useless information from the system. Otherwise, the program is going to lose its efficient applicability after a certain period. In the program developed in the study, update facility allows the user to enter a new record and delete any existing record in the database.

User can load his own private steel records into the database. This section provides the user to add new information into all property tables of the database, namely mechanical property table, chemical composition table, physical property table, heat treatment table and thermal property table. In addition to property tables, application and general information tables can be used for storing operation.

Countries, standard names, classification groups, and standard numbers in the database are listed in the update section. User can select any of them from the lists. Classification group or standard number of the new steel may not be in the lists of the update section. For this situation, user can add new classification group or standard number to the database.

Logical data input is very crucial during adding a new steel into the database. In this respect, some values, such as item number of the new steel (i.e. it is used as primary key in the property tables), are given automatically by the system. Furthermore, values of properties must be in a certain range for steels. For instance, density of steels has to be between 7,5 and 8,5 g/cm^3. If user wants to enter a value, which is out of specified range for steels, the data of the steel will be incorrect. Searching operations, which are carried out in the program, give illogical list of steels due to errors in the new data edited by user. To eliminate the problem, the system developed an error mechanism against illogical data input. As user is entering illogical values to database, the mechanism works automatically and warns him about incorrect value. The system also displays the correct ranges of the values for certain properties of steels in the update module.

CHAPTER 4

DISCUSSION

The most important part of the engineering design process is the selection of suitable material for a specific application. The engineer should have enough knowledge of materials or possess a powerful tool in hand to assist him in order to select the most appropriate material for the application in question. In this respect, this study includes a steel property database and a computer program for both material selection and required load calculations for bulk deformation processes of steels.

The developed steel database in the scope of this study is not a complete reference for steels but supplies many advantages to user as compared to the printed data in the literature. First of all, user can reach any information of a steel in the database in a very short time by using the program. If a designer selects a suitable material for specific application, minimisation of time spending on reaching the information of the material is of primary importance. Identification data and equivalents of steels in different standard systems can be obtained easily since steel database contains 24 different types of country of steels and their equivalents between each other. Furthermore, calculation of required load for 13 different bulk deformation processes provides fundamental combined information between the process and the material. Moreover, update part of the program supplies enlargement of the steel database and usage of the new steels in the program.

On the other hand, some limiting factors existed during the construction of steel database which are going to be explained in the following paragraphs.

The information of steels was taken from the literature, but data designation methods were different for various standards. Miscellaneous test methods are used to calculate the properties of materials for different steel standards; therefore, the values of properties to be obtained from different methods cannot be inserted directly to the database. Conversion factors between these testing methods were used. Turkish Standard Institute (TSE) catalogues are the most proper source for the general knowledge of steels produced in our country besides specific commercial steel catalogues including special steels. There are inconsistencies in the information of various printed sources of the steels, but they can be neglected due to small differences.

Steel properties, especially mechanical properties, strongly depend on the size and geometry of the specimen used in materials testing condition. Different types of steel standards measure the mechanical properties of the steels in various sizes. Due to existence of metallurgical effects related to the size of the materials, the mechanical properties of the same steel show differences for miscellaneous steel standards. Therefore, a certain size range must be defined for each mechanical property, and the system designates the properties of steels with the specified size ranges. This provides presence of numerical comparison in material property values for searching process developed in the program logically.

Furthermore, it is difficult to categorise different standard steels in a certain group because the steel standards perform different classification group names for the same steels. If the system uses dissimilar categorisation methods improved by various standards, excess classification groups will be present in the database. This prevents observation of similar steels in different standards. To eliminate the problem, the program determines specified classification group names according to Stahlschlüssel and AISI/SAE standard. New group names can also be added to the database in the update module.

Constructing more specific databases can decrease some of the difficulties and limitations on these types of studies. For development of more detailed computerised information sources, steels may be divided into groups such as stainless steels, tool steels, structural steels etc. This type of programs was constructed by the companies in the industry and satisfies more specific information about the steel but the database includes particular steel groups and does not provide a general inspection for whole groups in the material selection process. Therefore, the programs are only suitable to users having specific expertise.

The existence of the cost values in the database is very crucial to obtain a commercial program. However, it is very difficult to find the exact price of the steels belonging to different countries. In addition, the charge of the same steel changes day by day because of the diversity in the supply and demand in the steel industry. The fluctuations in the price of the steels complicate the development of cost module in the database.

In the process section, bulk deformation processes can be examined with more elaborate methods in the program. This satisfies more precise load values to the user. These types of programs are present in the industry to determine each value of stress at any point of the process by using finite element or boundary value methods. However, the programs are developed by a group of design engineers specialised in the stress analyses area and the stress calculation period is too long for practical usage. There is no need to use these complicated programs in the initial stages of the design process. In this respect, fundamental methods should be used in the program for load calculations in order to avoid complexity and reduce computation time.

During the development of the program, various literature sources and standards were used. Nevertheless, it is not possible to guarantee that, the steel in the database will confirm a perfect agreement with the steel in hand or in the market, due to existence of many factors on the steel property, such as variations in the microstructures of the steel.

In addition to the database, software package developed in the program provides various practical information about steels to a user dealing with design process in a user-friendly environment. First of all, there is no need to spend a lot of time to detect the values of the properties of certain steels by using this program. Moreover, the user can list the steels that conform with the limitation criteria defined by the user. Lists of steels can also be created by choosing the desired name of the steel standards and classification groups. The designer can determine the minimum required load and maximum applicable load for the bulk deformation processes included in the program. Furthermore, all of the evaluations and determinations can be achieved in a very short time by using the high speed of computer processor.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

Computerisation of material and process information is a milestone for progress of material and manufacturing process selection. Due to the high capacity of the computers, engineers accomplish these selections more precisely and effectively. Moreover, computer applications during these processes minimize the total design time, which is spent for development of any industrial product. This study provides a methodology in this area with an example on searching of steels, most widely used engineering materials in industry.

Unfortunately material databases are not extensively used in Turkish industry. Nonetheless, in many countries, companies generally use these kind of computerised systems. Despite a broad range of applicability of the programs, the information of the algorithms of the programs is kept as concealed for competition purposes. The programs are commonly developed for special purposes of the company. There are also large numbers of material databases or computer programs related to material selection and load calculation studies having been carried on by governmental and international working groups.

The developed program in the scope of this thesis will help the user in steel selection by generating a shortlist at the beginning, and by providing detailed information and determining the required loads for various types of bulk deformation processes in further decisions. Moreover, the generated program serves as an expeditious reference in immediate conditions.

For future work on the same subject the following modifications can be improved and applied on the program and algorithm.

Mechanical properties depend of the size of the material. Therefore, effect of the size of the steels on mechanical properties can be shown in the program. This provides more precise investigation of steel properties and complicated numerical comparison of the properties in the searching module of the program. The program can present various size ranges to user, and one of them can be defined during the searching operations.

Product shapes, relative prices, producer company names, telephones and addresses can be added to the program, so user can learn the production place or the shape of any steel in the database. Interaction between the user and the steel company is extremely crucial during the processing and the usage of the steel product. More detailed information such as corrosion properties, amount of stock, etc. can easily be reached by providing direct contact with steel production company.

Graphical representation can be added to accomplish more effective visual demonstration of the program. For example, hardness values at different depth from surface of the steel can be shown in the graph by obtaining the hardenability data of the steels from literature. This helps in investigation the relation between given material properties and the parameters affecting it efficiently.

The database created in this thesis provides general information that is used in the initial stages of the material selection process. More specialised program including more detailed information can be developed for specific types of steels such as stainless steel. User can obtain much more information about the particular type of steel and can make more precise selection. Since detailed information of material is required in the last stages of the design process, the developed database comprising additional precise data assists the final decision of the engineering material for any industrial product.

Instead of specializing the material used in the database, the developed database can be extended by adding other types of material such as non-ferrous materials, polymers, ceramics and composites. In addition to steels, other classes of engineering materials have been widely used in the industry for several decades. Moreover, steel standards, which are not present in the current database, can be appended. This provides a broad range of material spectrum for selection process to the user.

In process module of the program, totally 13 bulk deformation processes are presented to user. This number can be increased, and certain machining processes or other types of bulk deformation processes can be inserted to the process section of the system. Then user can calculate the critical loads for higher number of manufacturing processes, and can decide whether the material is appropriate for process family or not.

The algorithm of the developed program can be adopted as WebPages to obtain world-wide usage of the program. Practice of computer programs for material selection in the Internet starts to widen day by day, and any user on the other side of the globe becomes capable of using the program by connecting to the Internet.

The computerised material selection programs can be integrated to networks and combined with larger computer systems. In such a surrounding, selection may be initiated from a point that includes all engineering materials used in today's industry. By elimination methods, alternative materials can be reduced and by dropping alternatives more precise information should be provided. Finally, the most proper material can be selected for the product to be used in the industry.

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APPENDIX A

USER MANUAL

A.1. Minimum System Requirements

- Windows 98 or higher versions
- P-III or higher microprocessor
- At least 64 MB of memory (128 MB recommended)
- 3.2 MB of free hard disk space for program files
- MS Access 97 or higher (for editing database files, optional)

A.2. Installation

Program runs under Windows 98 and higher versions. In order to install the program insert the installation CD into the CD-ROM and run from “SETUP.EXE” or wait for Auto-run. The setup program will ask you to select the destination directory and installation options, installs files to your hard disk and will create a program group and an icon for the program.

In order to edit the material database independent of the program, you should have MS Access 97 or higher installed on your system.

A.3. Main Window of the Program

When the program is executed the main window (Figure A.1.) that covers the whole screen appears. There are two methods to reach the main-programs in the system. First one is the menu editor bar at the top of the main menu. It includes “exit”, “properties”, ”search”, ”selection”, “process”, “conversion”, “update” and “help” tabs. User can observe the sub-groups of these parts by clicking the menu editor. Second one is the command buttons on the main window. They are composed of "properties", "selection", "process", "update" and "search". By similarly clicking the buttons, the sub-groups can be seen. The main window of the program is designed to be as user-friendly as possible. Moreover, the addition of some images on the screen supplies aesthetics to the overall program view. Main sections of the programs are explained in the following parts.

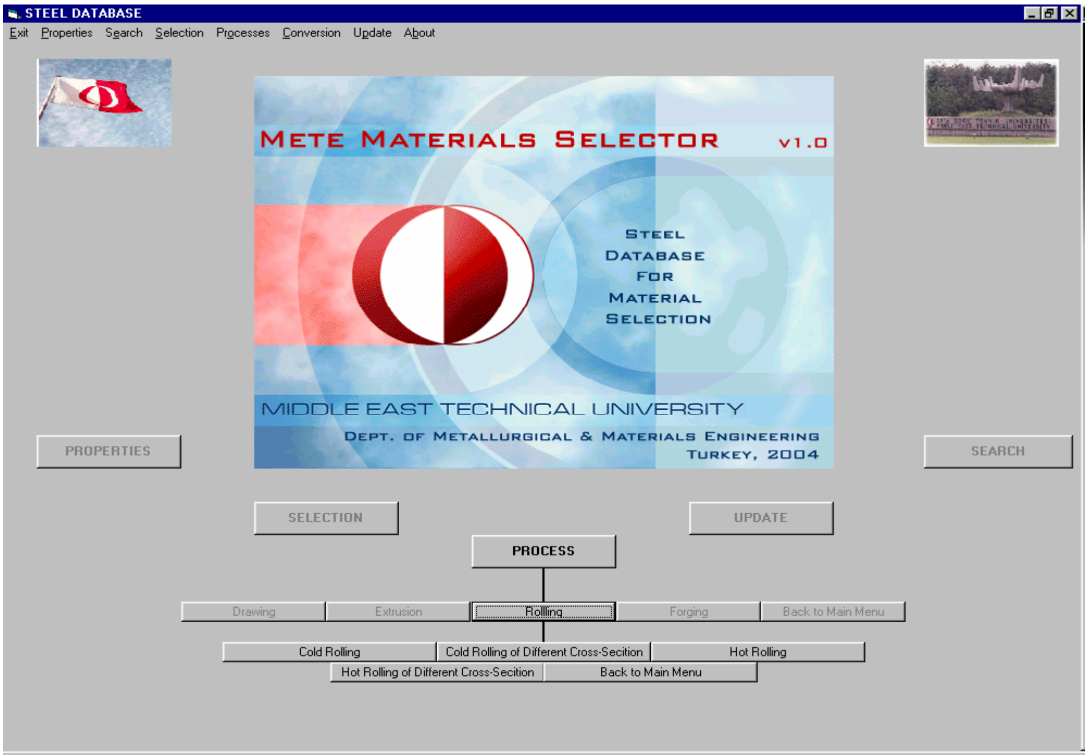


Figure A.1 Window of the main menu of the program

A.3.1. Properties

One of the main sections of the system is "Properties" section. It is used to observe all properties of steel that are available in the database. There exist three types of main demonstration sections in the system.

First one is “Selection with Material Designation” where materials are classified with respect to steel designation. Origin or standard of steels can be selected from a combo box and steel belonging to the standard (or country) would be seen in the list. Moreover, user can choose classification group of steels by arranging classification group check box.

Second tab is “Selection with Material Number” whose working principle is similar to “Selection with Material Designation”. Only difference between them is the type of demonstration. Steels are listed with respect to material number in “Selection with Material Number” section whereas in the previous section steels are displayed in the list with their material designation. Both forms are shown in Figure A.2 and Figure A.3.

Last sub-section of the “Properties” option is “Material Selection with Manual Writing” (Figure A.4). To identify the steel, user should select the country or standard to which steels have been added previously, and then enter the standard designation or material number of steels. Check boxes above “Material Name” text box must be compatible to expression that is written in the form. For instance, if user wants to write any steel designation to “Material Name” text box, the value of “Material Designation” check box must be true. Moreover, user should be careful about material designation as writing any text to “Material Name”. Since the “Material Name” text box is case sensitive, entering of uppercase letter instead of lowercase letter may cause a change in the steel name. Therefore, this sub-group requires higher professional knowledge about material numbers and designations as compared to the previous sections, and thus is suitable for advanced users.

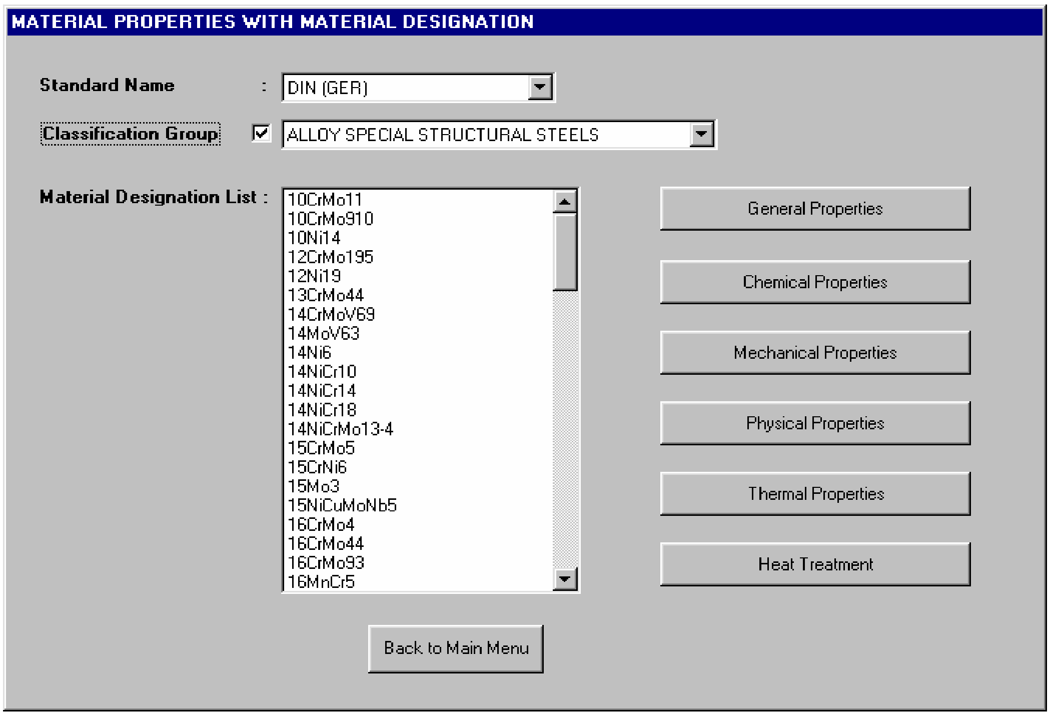


Figure A.2 Material properties with material designation window.

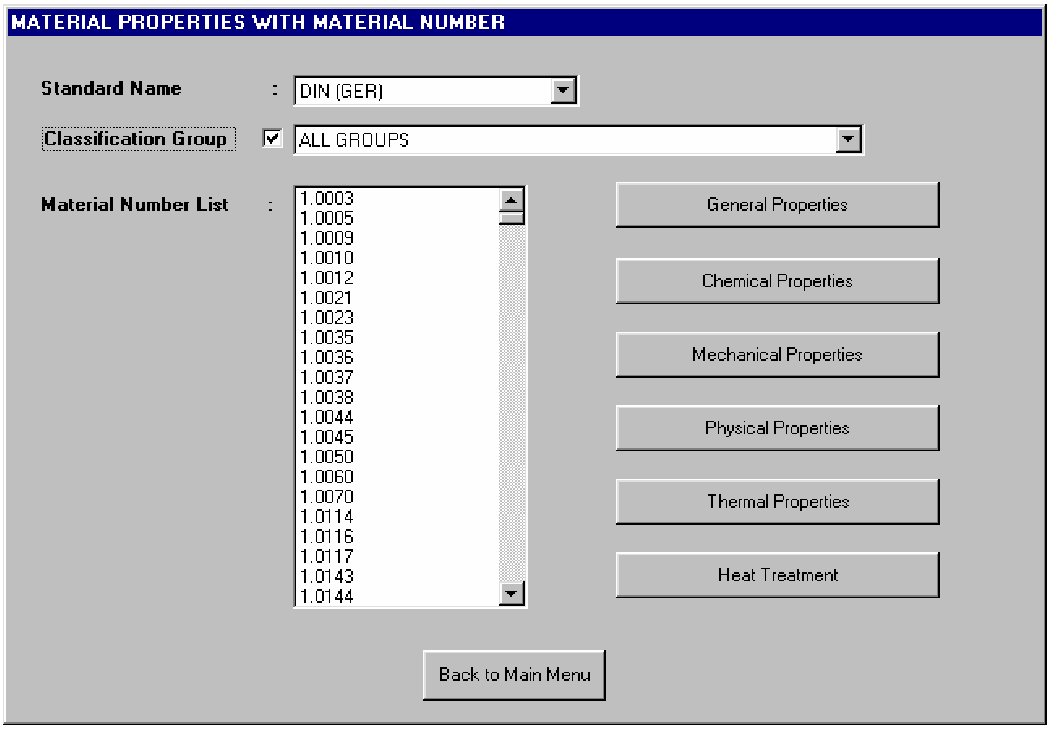


Figure A.3 Material properties with material number window.

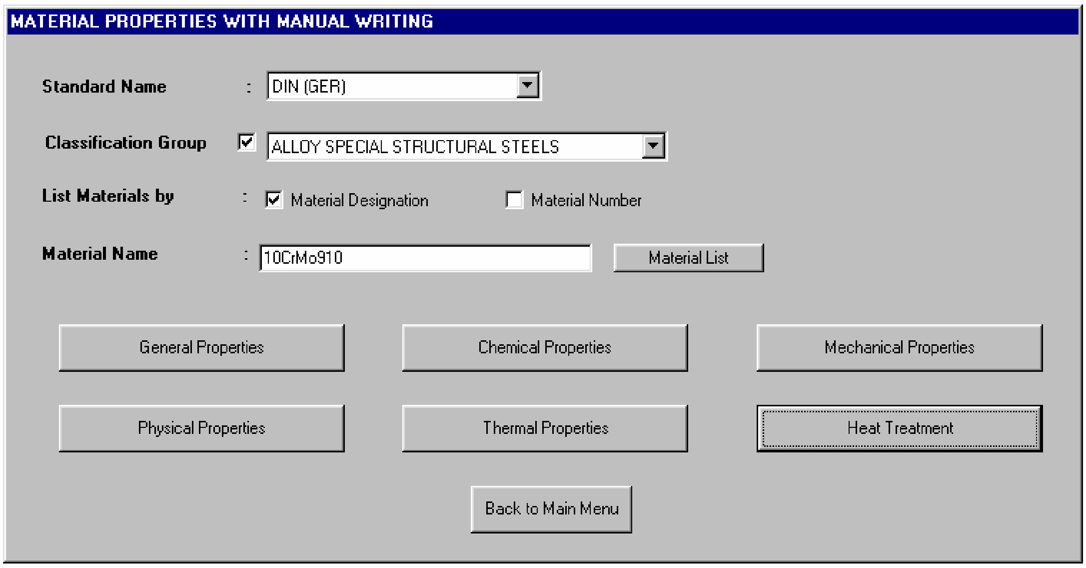


Figure A.4 Material properties with manual writing window.

User can observe general information, chemical compositions, mechanical, physical and thermal properties, and heat treatment parameters of selected steels. All sections are explained in the following paragraphs in detail.

To observe the general information of a steel user must press “General Properties” button. The section gives identification details such as producing country, standard number, application and group of steel. Furthermore, if there are equivalences of selected steel in the database, these equivalences are also listed to a combo box in the form. User can also see explanation of the steel standard name by bringing mouse icon on standard number label, and a text including the standard name appears on the screen. This form is shown in Figure A.5.

Chemical composition form includes 18 elements (C, Si, Mn, P, S, Cr, Mo, Ni, V, Al, Cu, W, Ti, N, Nb, B, Pb and Co). User can activate the form by pressing “Chemical Properties” button. In addition, only elements to be included in the steel are shown in the form, that is if steel does not include an arbitrary element, its amount will not be shown in the chemical composition form (Figure A.6).

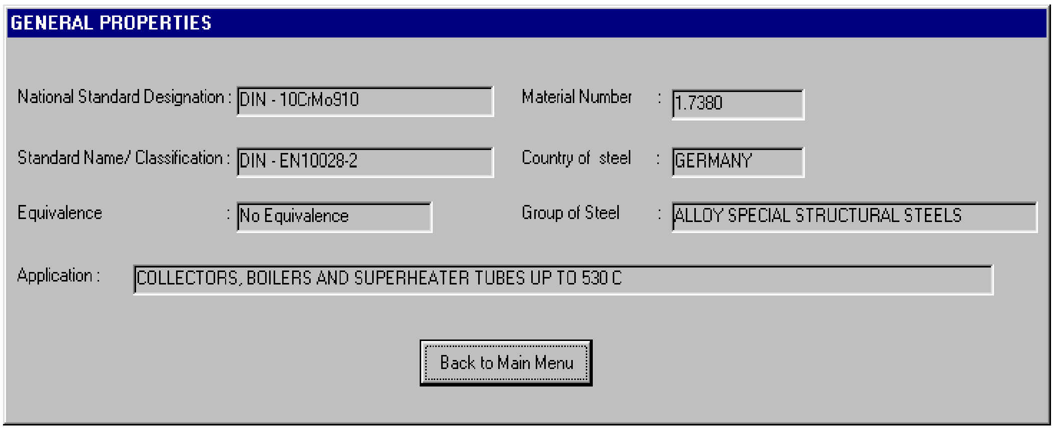


Figure A.5 General properties window.

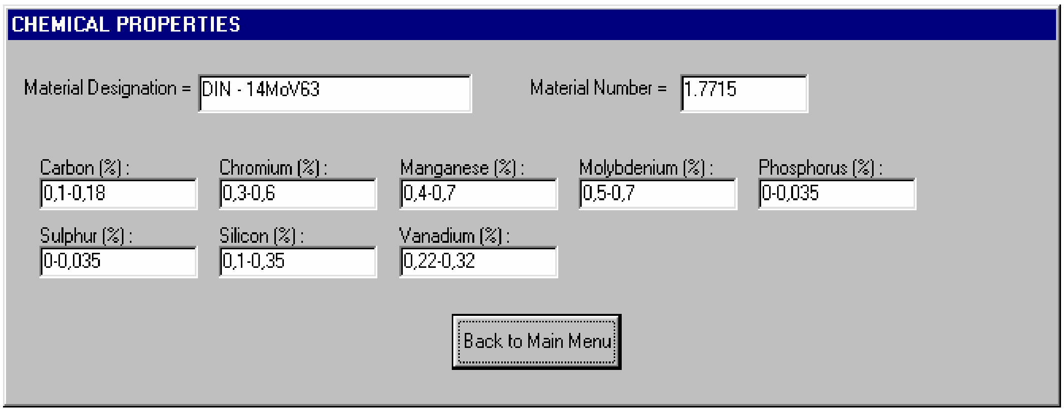


Figure A.6 Chemical composition form.

Mechanical properties form (Figure A.7) provides tensile strength, yield strength, young's modulus, bulk modulus, fracture toughness, endurance limit, hardness, elongation, poisson's ratio and reduction of area information. There is also a combo box on the form. It is used to change the condition of the steel. As changing the condition of the steel, values of mechanical properties varies on the form with respect to the new condition of the steel. Furthermore, there is a remark label in the form and necessary notes related to mechanical properties of steel can be seen on the label.

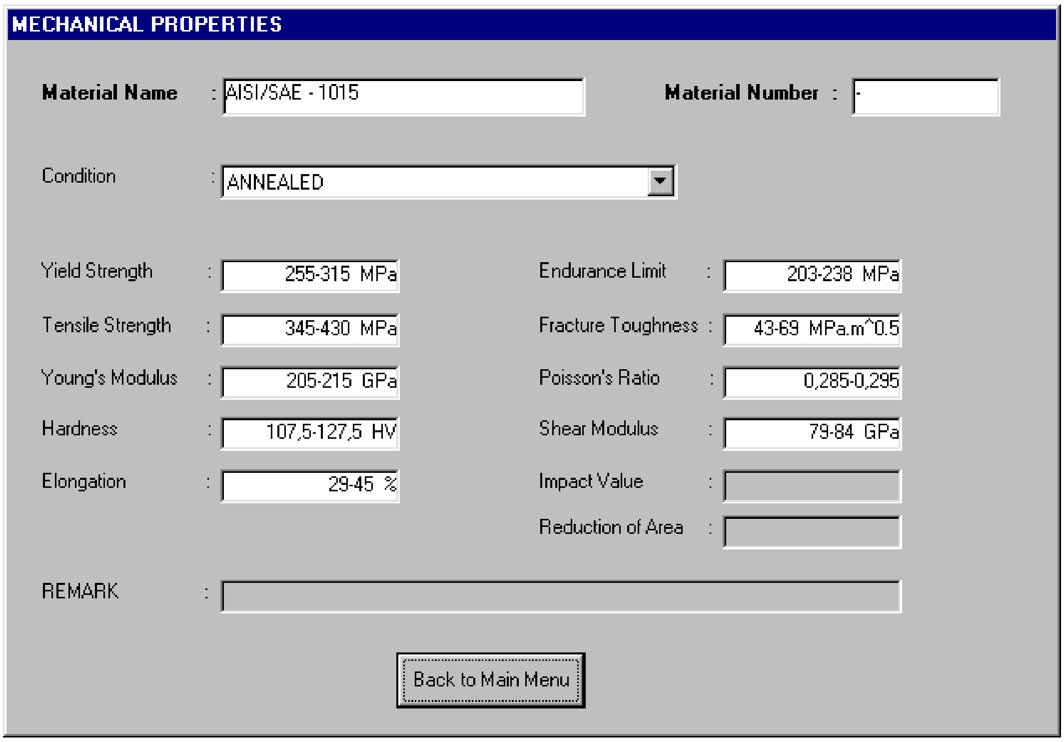


Figure A.7 Mechanical properties window.

To enter physical properties form user should press the "Physical Properties" button. Physical properties part is composed of density, specific electrical resistance and degree of shrinkage of steels. User can learn whether steel is magnetisable and weldable or not by looking to the value of check boxes in the form. Moreover, cutting property, corrosion resistance and toughness degree of steels are shown in the physical properties form (Figure A.8).

"Thermal Properties" part includes thermal expansion coefficient, specific heat, thermal conductivity, melting point, maximum and minimum service temperature of steel. User can observe the thermal properties of steel by pressing "Thermal Properties" button in the main forms. This form can also be seen in Figure A.9.

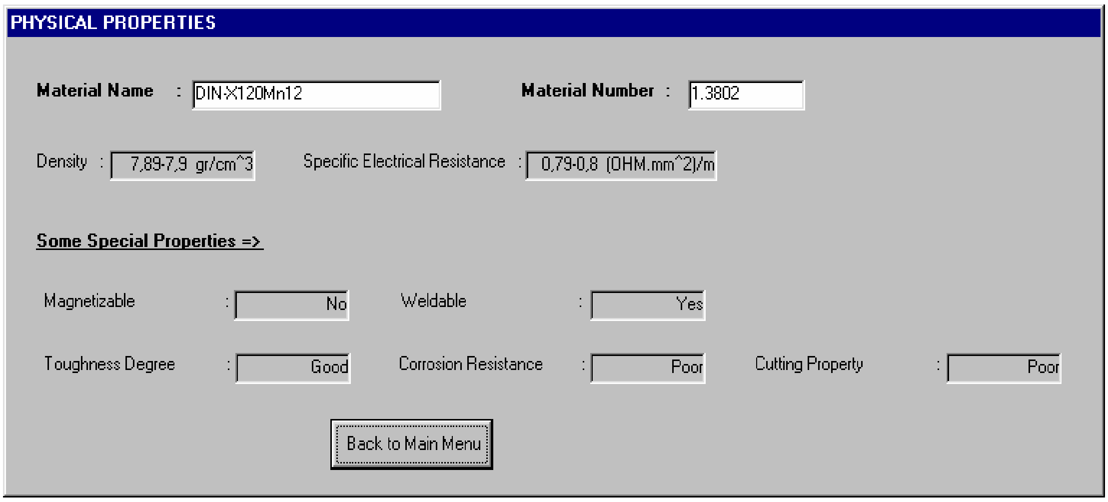


Figure A.8 Physical properties window.

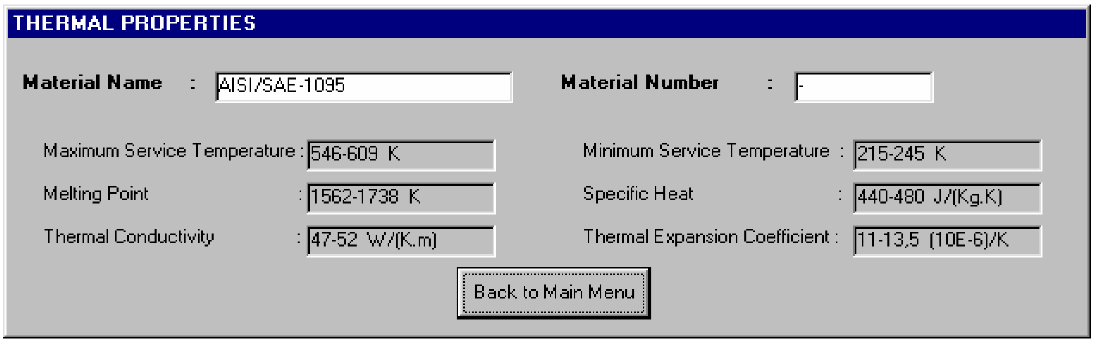


Figure A.9 Thermal properties window.

Heat treatment parameters of steels can be experienced by selecting “Heat Treatment” button. This form consists of hot working temperature, soft annealing temperature, hardening temperature, normalizing temperature and stress-relieving temperature of steels. Certain information about the temperatures given above, such as duration and media, can also be given in the form. Furthermore, there are two types of notes in the form. One of them is related to general information about heat treatment and other item includes heat treatment notes for welding if the steel is weldable. The heat treatment form is given in Figure A.10.

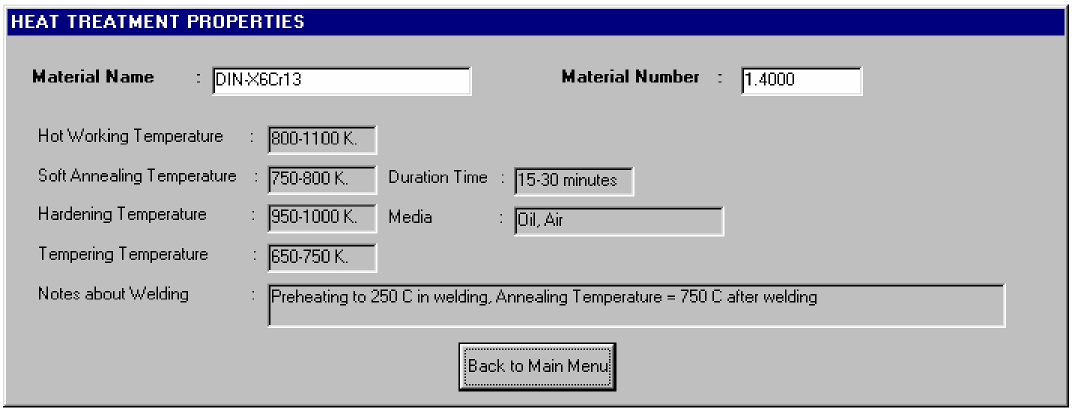


Figure A.10 Heat treatment window.

A.3.2. Search

Any steel with its designation can be searched and list of steels can be constructed in the "search" main-section of the program. Sub-groups of this section can be loaded by the "search" part of the menu editor and the "search" button on the form.

The material designation is developed by steel standards and each character in the material designation implies a logical sense in the standards. The arrangement of the characters in the designations is significant to specify any steel in the standard. Material designations for steel is sometimes very complex expressions such as X45CoCrWV555, 100MnCrW4, etc. Therefore, it is difficult to memorize all characters in the material designation exactly. The aim of the development of "material designation matching" module in the program is to eliminate the problems existing due to typing errors in material designations. The certain expression that is remembered or known in the material designation can be searched in this part.

There are three situations in the combo box of the "material designation matching" window (Figure A.11). These situations are designed to provide different searching methods in the system. In the first one, "at the beginning of the expression" namely, the written expression is searched at the beginning of the material designation. The material designations starting with the specified expression are listed with their standard names, countries and material numbers. This is satisfied by clicking "match" button in the form. If the situation is "in the designation", the determined expression will be searched inside of the material designations. Final situation is "combined statement" in the form. More than one situation can be searched in the material designation of the steels. User should add Boolean operator, i.e. "+" sign, between the expressions to be investigated (see Figure A.11). In addition to this, there are not any empty spaces between the plus sign and the expressions.

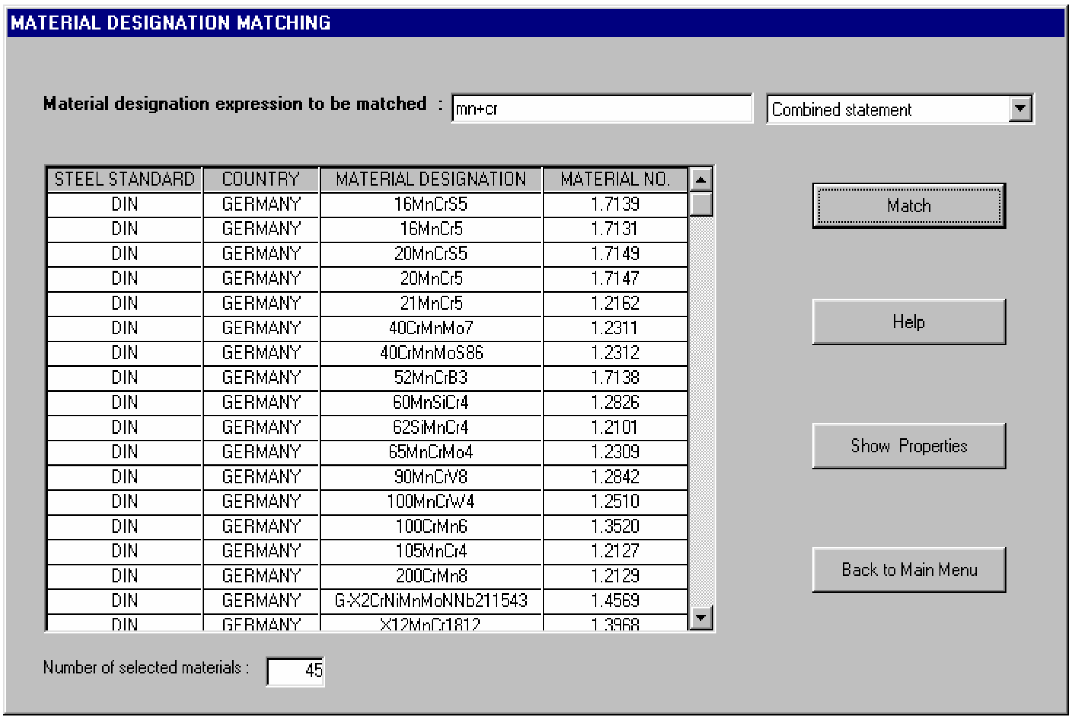


Figure A.11 Material designation matching window.

After developing the list of steels having desired material designation, any steel can be picked from the list, and its properties can be observed by clicking "show properties" button. Moreover, the number of the steel in the developed list can be seen on the form. The "help" button is designed to explain the situations in the combo box.

"Search" part of the program includes also "list of steels" module (Figure A.12). This module provides certain lists of steels to users. There are three different types of options in the module. First one prepares lists of all steels in a country or standard (e.g. German steels, ASTM steels). Lists are constructed only by selecting any steel standard or country from "country/standard name" combo box. Second one lists the steels according to their standards or countries and classification groups (e.g. low alloy steels in AISI/SAE, bearing steels in DIN). The "country/standard name" and "classification group" combo boxes are arranged to construct the lists. Final option develops list of steels in a certain standard number of a country or standard name (e.g. AS/NSZ 1594, DIN EN 10028-2). The expression in the "country/standard name" and "standard number" combo boxes are used to obtain the steel lists.

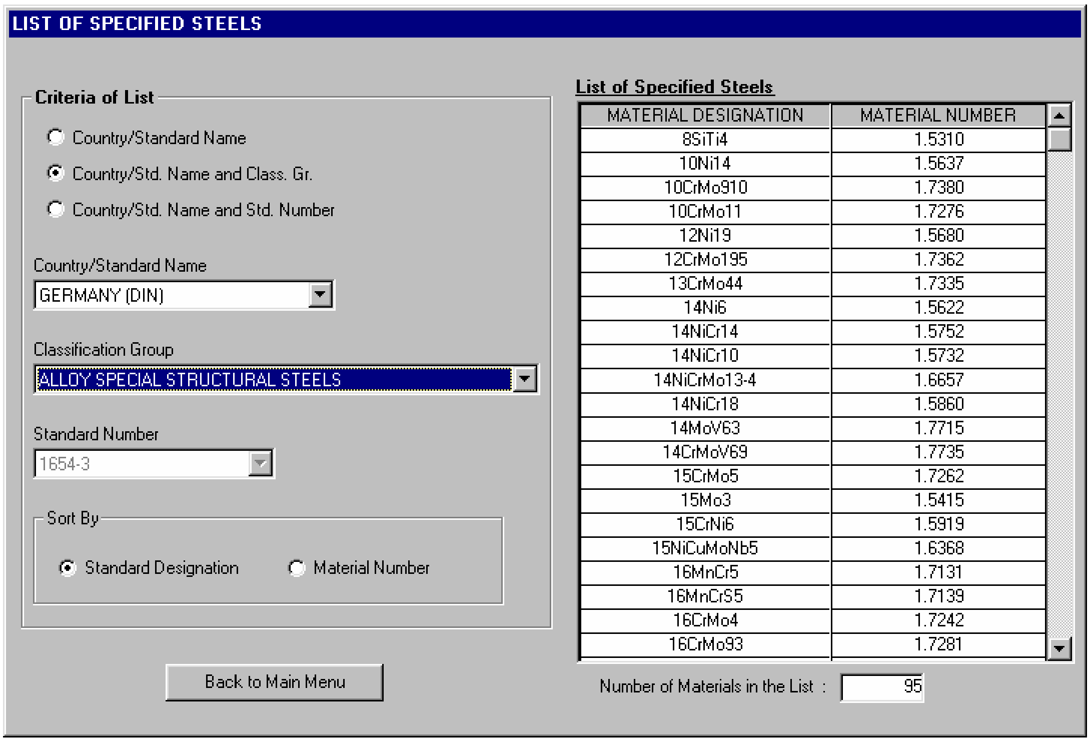


Figure A.12 List of steels window.

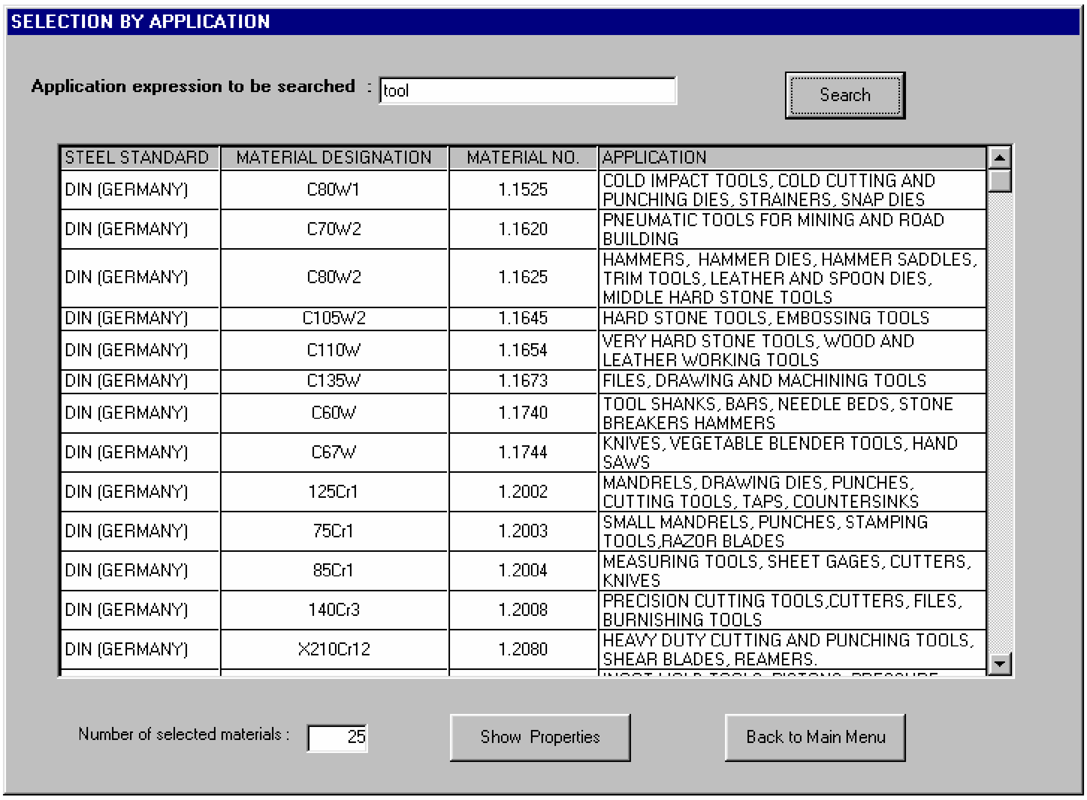
The combo boxes in the form become automatically enabled or disabled by selecting the desired options from the form. List of steels includes material designation and material number. The sort type of the list can be arranged by user, and material designation or material number can be selected as parameters to be sorted in the list. Moreover, the number of the steel in the list can be observed on the screen.

A.3.3. Selection

“Selection” part is composed of “Selection by Properties” and “Selection by Application”. Both parts are used to choose the proper steel from the database according to selection criteria. The selection procedures are different in each part of the selection section.

In “selection by application section”, user is capable of entering the name of application such as “gear”, “tool”, “ship building”, “pressure vessel”, “spring”, or any other specific expression to choose proper steel for desired application. After pressing “search” button, steels possessing specified application are listed. Number of steels in the list can also be observed in the form. Furthermore, there is no need to exit from “selection by properties” part to observe the properties of the selected steel in the list. “Show properties” button is designed for this aim and user can see any properties of the steel in the list. In order to design a general list user can enter “*” as the searching expression to investigate all available data on steel applications table. The selection by application form is shown in Figure A.13.

Second sub-section of the selection part is “selection by properties”. The selection can be done by defining mechanical properties, physical properties, thermal properties and chemical compositions. “Type of property” frame is constructed in the form, and desired property can be selected in the frame. A combo box is also designed to determine the properties that are used in the selection. There are two types of selection criterion in the form. First one is selection by nominal value and deviation percentage. Selection process can be started after any nominal value and its deviation percentage are written to the texts. Second one is selection by maximum and minimum values. User determines his limit values by entering maximum and minimum values. After determining the limit values, user should click “add criteria” button. The criterion designed by user is written to the criteria list. Finally, user click “list materials” button and the selected steels with respect to developed criterion are listed.



STEEL STANDARD	MATERIAL DESIGNATION	MATERIAL NO.	APPLICATION
DIN (GERMANY)	C80W1	1.1525	COLD IMPACT TOOLS, COLD CUTTING AND PUNCHING DIES, STRAINERS, SNAP DIES
DIN (GERMANY)	C70W2	1.1620	PNEUMATIC TOOLS FOR MINING AND ROAD BUILDING
DIN (GERMANY)	C80W2	1.1625	HAMMERS, HAMMER DIES, HAMMER SADDLES, TRIM TOOLS, LEATHER AND SPOON DIES, MIDDLE HARD STONE TOOLS
DIN (GERMANY)	C105W2	1.1645	HARD STONE TOOLS, EMBOSSING TOOLS
DIN (GERMANY)	C110W	1.1654	VERY HARD STONE TOOLS, WOOD AND LEATHER WORKING TOOLS
DIN (GERMANY)	C135W	1.1673	FILES, DRAWING AND MACHINING TOOLS
DIN (GERMANY)	C60W	1.1740	TOOL SHANKS, BARS, NEEDLE BEDS, STONE BREAKERS HAMMERS
DIN (GERMANY)	C67W	1.1744	KNIVES, VEGETABLE BLENDER TOOLS, HAND SAWS
DIN (GERMANY)	125Cr1	1.2002	MANDRELS, DRAWING DIES, PUNCHES, CUTTING TOOLS, TAPS, COUNTERSINKS
DIN (GERMANY)	75Cr1	1.2003	SMALL MANDRELS, PUNCHES, STAMPING TOOLS,RAZOR BLADES
DIN (GERMANY)	85Cr1	1.2004	MEASURING TOOLS, SHEET GAGES, CUTTERS, KNIVES
DIN (GERMANY)	140Cr3	1.2008	PRECISION CUTTING TOOLS,CUTTERS, FILES, BURNISHING TOOLS
DIN (GERMANY)	X210Cr12	1.2080	HEAVY DUTY CUTTING AND PUNCHING TOOLS, SHEAR BLADES, REAMERS.

Figure A.13 Selection by application.

More than one criterion can be determined during selection and certain criteria in the criteria list can be removed. This removal is achieved by “remove criteria” button. To start a new selection, “new search” button is designed for users. Moreover, user observes the properties of any steel obeying the determined criteria by selecting the steel in the list and then pressing “show properties” button.

Certain properties of steels in the database such as poisson's ratio possess very small numerical values. Developed algorithm in the selection by properties module provides possibility of entering these small numerical values to the limit values. The selection is accomplished under the consideration of decimal numbers in the limit values determined by user. Most of the mechanical, physical and thermal properties, and all chemical composition data are stored with minimum and maximum values in the database. During selection operation, this range is always considered and all steels having an intersection, which is equal to or greater than zero, with the user defined range are taken as acceptable steels. The window of the selection by properties is shown in Figure A.14.

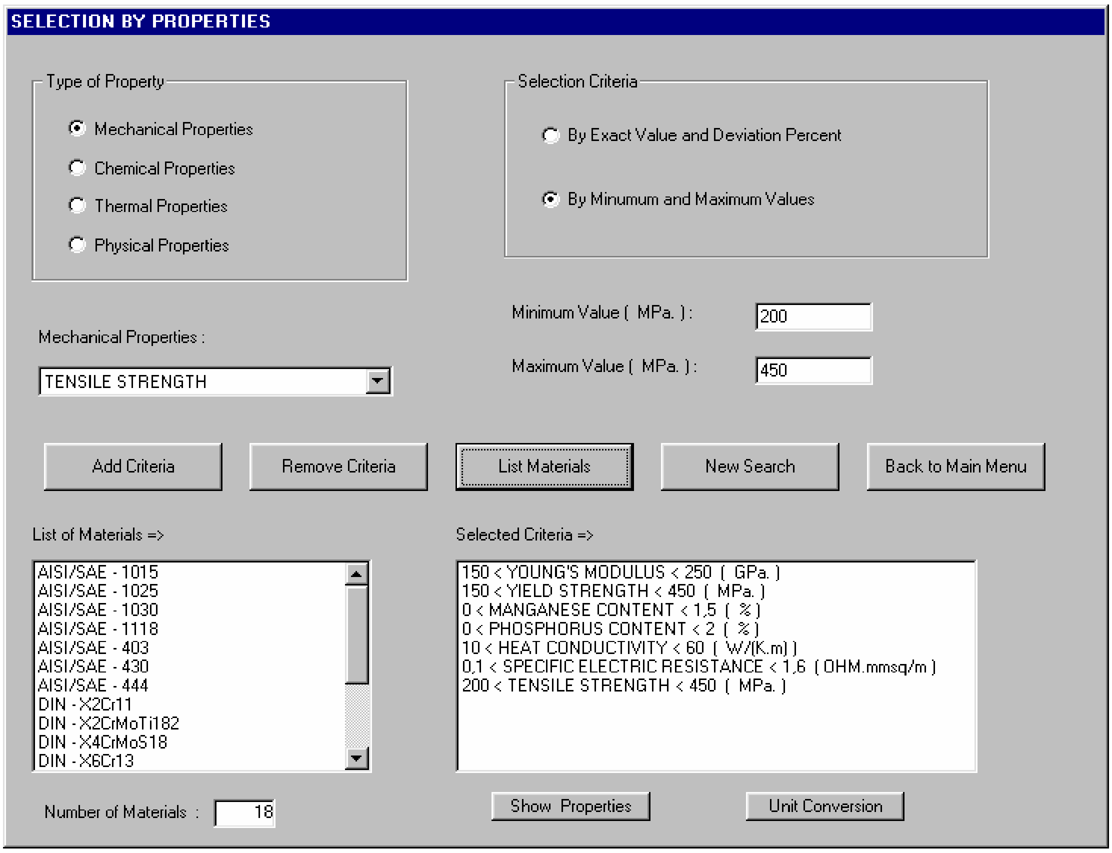


Figure A.14 Selection by properties window.

Furthermore, some of the error messages are designed such that user can obtain easier data input. For example, if the limit value is not proper for steels in the selection process, a message box appears on the screen to warn user for the illogical property value. One of the message boxes is shown in Figure A.15.

Figure A.15 Error message box.

A.3.4. Process

User can obtain minimum required load and maximum applicable load for bulk deformation processes. The system uses the formulae, which are explained in the previous parts, to calculate the loads. The program includes 13 processes, which are extrusion through conical dies, extrusion through square dies, cold rolling, cold rolling for different cross-section, hot rolling, hot rolling for different cross-section, rod drawing, strip drawing, tube drawing with mandrel, tube drawing with plug, tube sinking, wire drawing and forging

In each form of these processes, there are two check boxes used to specify the demonstration of steels in the list. If user selects “material designation” check box, steels in the list are arranged according to material designation. Classification groups are also listed in the combo box, and user can choose any of them.

Moreover, there are certain parameters related to the processes in the forms, and all of them must be determined before calculating critical load values for the processes.

If one of them is missing in the text boxes, load cannot be calculated. For lacking of necessary parameters, certain error message boxes appear on the form.

"Calculate" button is designed to run the load calculation system. Same parameters can be used for different steels in the list that is developed by the user. Therefore, there is no need to change the parameters when user selects another steel from the list.

To calculate proper loads in the system user should enter logical parameter values for the bulk deformation processes. For example, the initial diameter of the tube cannot be smaller than the final diameter of the tube in tube sinking processes. Therefore, if user enters any initial diameter value smaller than the final diameter in tube sinking, the calculation of load becomes impossible or illogical. To eliminate the problem, program also provides some error messages to inform the user for the values of the parameters used in the process parts. The window for cold rolling bulk deformation process is shown in Figure A.16.

A.3.5. Update

In the update section, it is possible to enter a new steel and delete any existing steel in the database. Two separate parts are constructed in the update facility to achieve these operations. These are "Load New Steel to Database" that is designed to add steel, and "Delete Steel from Database" that is used to remove steel.

To create a new steel in the database, main specification information related to the steel must be determined by the user. The information is composed of material designation, material number, classification group, country or standard name of the steel. As mentioned before, some steel standards define steels with only material designation, or only material number, or both material designation and number. Therefore, either material designation or material number should be determined by the user during loading of the new steel. User must pay attention to material designation and it should be entered as it is given in the source. Moreover, record number is designed for each new steel and determined by the program automatically.

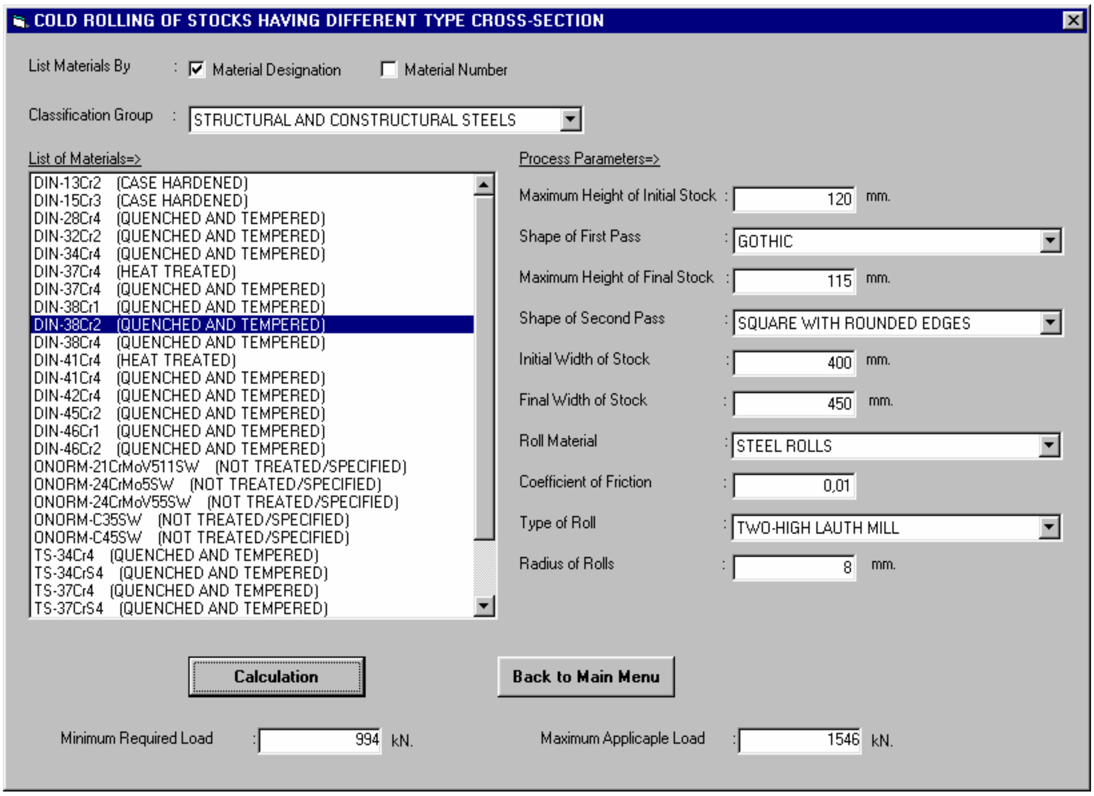


Figure A.16. Cold rolling process window.

If user’s steel standard is not in the standard list, he must select “OTH” from the combo box. If classification group and standard number of the new steel are not in the lists, user can also add the new classification group or standard number to the database by clicking “add new group” and “add new standard” respectively. As adding a new standard number to the database, the standard name portion is eliminated from the standard number. For instance, DIN EN 10083-2 is a standard number in DIN form, only EN 10083-2 part is written during loading the standard number.

After entering the main information of the new steel, the update window enlarges and some certain additional buttons appear in the form (Figure A.17) unless the steel that is entered by user exists in the database. If the program accepts the main steel information, it cannot be changed. Additional buttons consists of "chemical composition", "mechanical properties", "thermal properties", "physical properties", "heat treatment", "equivalents" and "application". User can fill the detailed information of the steel by clicking the desired buttons present in the form. There is no need to complete all text boxes in new forms. However, some critical points exist in the steel data entrance and they are explained in the following paragraphs.

Mechanical properties depend on the size of the material, and the values stored in the database are taken from the literature for a certain range between 3 and 40 mm. If the values in the specified range are not obtained for the new steel, size range should be explained in the "notes" section.

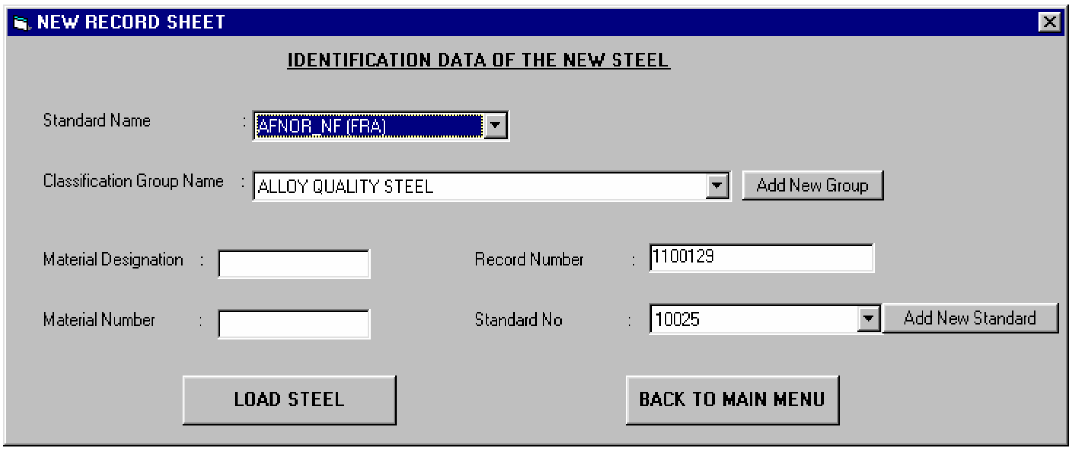


Figure A.17 New record sheet window in the update module.

During determining the equivalence of the new steel, it is enough to store only one equivalent from the database. The program automatically appoints other equivalences because the connection between the equivalence steels is constructed in the design stage of the database. The user should control the other equivalences after loading the new steel from general properties part.

The "notes" interval capacity is limited by 250 characters for chemical compositions, mechanical properties and heat treatment parameters. Same numbers of characters are also assigned for the application field in the database.

Furthermore, conversion facility is also presented by the system during the entrance of the property values. Any unit used in the different unit system can be converted to the units used in the database with this module. "Unit conversion" buttons are used to utilize the conversion part of the system.

At the end of the data entering process of the new steel, user can finish the update program or pass filling information of next new steel by clicking "Next Steel" button.

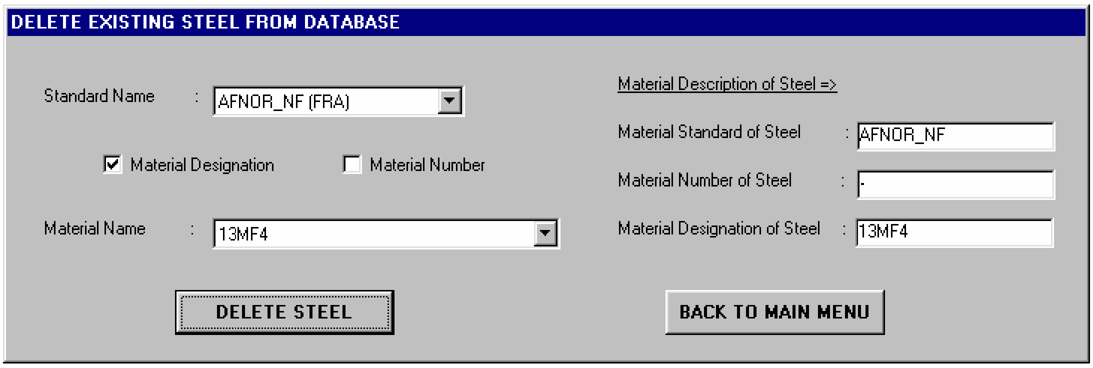


Figure A.18 Delete steel from database window.

There is an also “delete existing steel from database” sub-module (Figure A.18) in the update section. User can select any steel from the database and delete it by clicking “delete steel” button. This part is very useful to delete the incorrectly loaded steel by the user.

A.3.6. Conversion

Certain units are used in the values of the properties in the database. However, different types of units can be present in the literature. In the conversion part of the system (Figure A.19), any property unit storing in the database can be converted into other units. The properties, in which the unit conversion is possible, are mechanical, physical and thermal properties. The desired type of property can be selected from options on the screen and the names of the properties in the database are listed in the combo box. User can select any property from the combo box and convert any value from any unit to another unit in the list as clicking “convert button”.

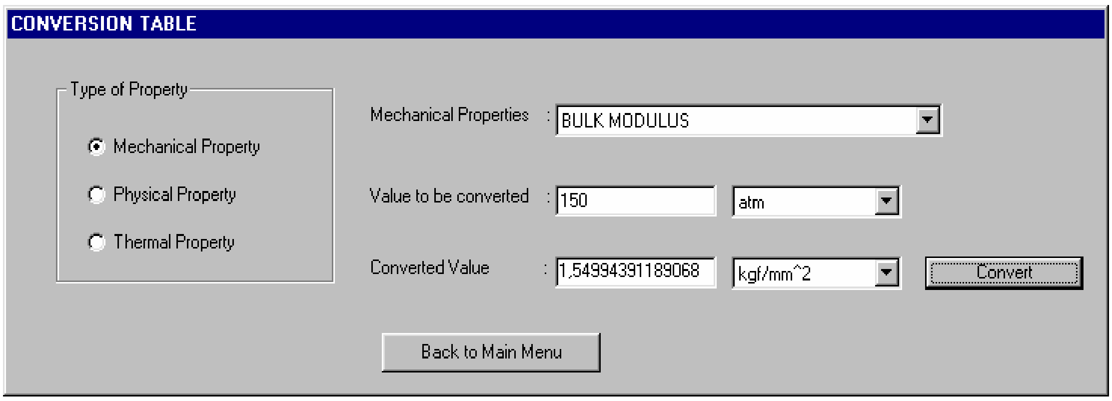


Figure A.19 Unit conversion module.

Conversion module also appears in the selection by property and certain forms in the update part of the system with addition of “unit conversion” buttons in the forms. In this respect, user can make a unit conversion during determining the selection criterion limits in the selection part and storing the property values of the new steel in the update part.

A.3.7. About

The main information about the developed system is given to the user in the “About” section. The objectives of the program are explained. Moreover, the information about the designer of the programs such as their names and contact information can be examined in the “about” section of the program. The information about the designers is very important because the user can reach and send or submit inquiries related to the program to the designers.

APPENDIX B

SAMPLE RUNS

Sample Run 1

In this run, load calculation analyses are carried out.

Inputs are:

Material Parameters:

Type of list	: Material Designation
Classification group	: Low alloy steel
Material designation	: AISI/SAE - 5140
Specified condition	: Annealed

Process parameters:

Process name	: Cold rolling of stocks having different type of cross-section
Maximum height of initial stock	: 85 mm
Cross-section of first pass	: Square with sharp edges
Maximum height of final stock	: 75 mm
Cross-section of second pass	: Diamond with rounded edges
Initial width of the stock	: 400 mm
Final width of the stock	: 425 mm
Roll material	: Steel
Coefficient of friction	: 0.01
Type of roll	: Three-high lauth mill
Radius of first roll	: 40 mm
Radius of second roll	: 35 mm

Outputs are:

Minimum required load	: 509 kN
Maximum applicable load	: 999 kN

Sample Run 2

In this run, load calculation analyses are carried out.

Inputs are:

Material Parameters:

Type of list	: Material Number
Classification group	: Structural and constructional steel
Material designation	: DIN - 1.7020
Specified condition	: Quenched and tempered

Process parameters:

Process name	: Tube drawing with a mandrel
Initial thickness of the tube	: 20 mm
Final thickness of the tube	: 18 mm
Semi-cone angle of die	: 15 degree
Semi-cone angle of mandrel	: 10 degree
Mean radius of tube	: 75 mm
Coefficient of friction between tube and die wall	: 0,015
Coefficient of friction between tube and mandrel	: 0,01

Outputs are:

Minimum required load	: 380 kN
Maximum applicable load	: 651 kN

Sample Run 3

Sample run is taken place in selection by properties module

Inputs are:

Selection criterions:

In mechanical properties:

Maximum yield strength	: 400	MPa
Minimum yield strength	: 200	MPa
Maximum tensile strength	: 1500	MPa
Minimum tensile strength	: 800	MPa
Maximum hardness number	: 550	HV
Minimum hardness number	: 250	HV

In chemical composition:

Maximum carbon content	: 0,92	%
Minimum carbon content	: 0,02	%
Maximum nickel content	: 25	%
Minimum nickel content	: 0	%
Maximum sulphur content	: 0,01	%
Minimum sulphur content	: 0,40	%

In thermal properties:

Maximum heat conductivity	: 50	W/Km
Minimum heat conductivity	: 10	W/Km

Out puts are:

List of selected material with respect to their material designation:

AISI/SAE – 201
AISI/SAE – 202
AISI/SAE - 403
AISI/SAE – 9310
DIN – X1NiCrMoCuN25206
DIN – X2CrNiMoN17122
DIN – X2CrNiMoN17133
DIN – X2CrNiMoN17135

Sample run 4

Sample run is carried out in the material designation matching module of the system.

Inputs are:

Material designation expression to be searched : cr + ni + mo + ti

Statement of the matching : In the combined statement

Outputs are:

List of materials having the expressions that are searched:

DIN	GERMANY	X10CrNiMoTi1812	1.4573
DIN	GERMANY	X3CrNiMoTi2525	1.4577
DIN	GERMANY	X5NiCrMoCuTi2018	1.4506
DIN	GERMANY	X6CrNiMoTi17122	1.4571
ISO	ISO	X6CrNiMoTi17-12-2E	-
STAS/SR	RUMANIA	10TiMoNiCr175	-
TS	TÜRKİYE	X10Cr18Ni10MoTi	1.4571

Sample Run 5

Sample run is taken place in the material properties with material number section of the system.

Inputs are:

Standard name : DIN (GER)

Classification group of the steel : Stainless steel

Material number of steel : 1.4000

Outputs are:

In general properties:

National standard designation : DIN-X6Cr13

Material number	: 1.4000		
Standard number	: DIN 17440		
Country of steel	: Germany		
Equivalence	: EN-X6Cr13, UNI-X6Cr13, UNE-F.3110, TS-7Cr13, AISI/SAE-403, ASTM-A 580 (403), GOST-08Ch13		
Group of steel	: Stainless steel		
Application	: Structural parts in water and stream		

In chemical composition:

Carbon content	: 0-0,08	%
Chromium content	: 12-14	%
Manganese content	: 0-1	%
Phosphorus content	: 0-0,045	%
Sulphur content	: 0-0,03	%
Silicon content	: 0-1	%

In mechanical properties:

Condition name : Annealed

Yield strength	>	230	MPa
Tensile strength	:	400-630	MPa
Young's modulus	<	220	GPa
Hardness	<	210	HV
Elongation	>	20	%
Reduction in area	:	60	%

Condition name : Quenched and tempered

Yield strength	>	400	MPa
Tensile strength	:	550-700	MPa
Young's modulus	<	220	GPa
Hardness	<	168-221	HV
Elongation	>	18	%
Poisson's ratio	:	0,275-0,285	
Remark	:	YS = 0,2%YS	

In physical properties:

Density	:	7,69-7,7	gr/cm^3
Specific electrical resistance	:	0,59-0,6	$ohm.mm^2/m$
Magnetizibility	:	Yes	
Weldability	:	Yes	

In thermal properties:

Specific heat	:	455-460	J/(kg.K)
Thermal conductivity	:	29-30	W/(K.m)
Thermal expansion coefficient	:	10,5-12,1	(10E-6)/K

In heat treatment:

Hot working temperature	:	800-1100	K
Soft annealing temperature	:	750-800	K
Duration time for soft annealing	:	15-30	minutes
Hardening temperature	:	950-1000	K
Cooling media for hardening	:	Oil, air	
Tempering temperature	:	650-750	K
Notes about welding	:	Preheating to 250 ^oC in welding, Annealing temperature = 750 ^oC after welding	

APPENDIX C

FLOW CHARTS OF PROGRAM

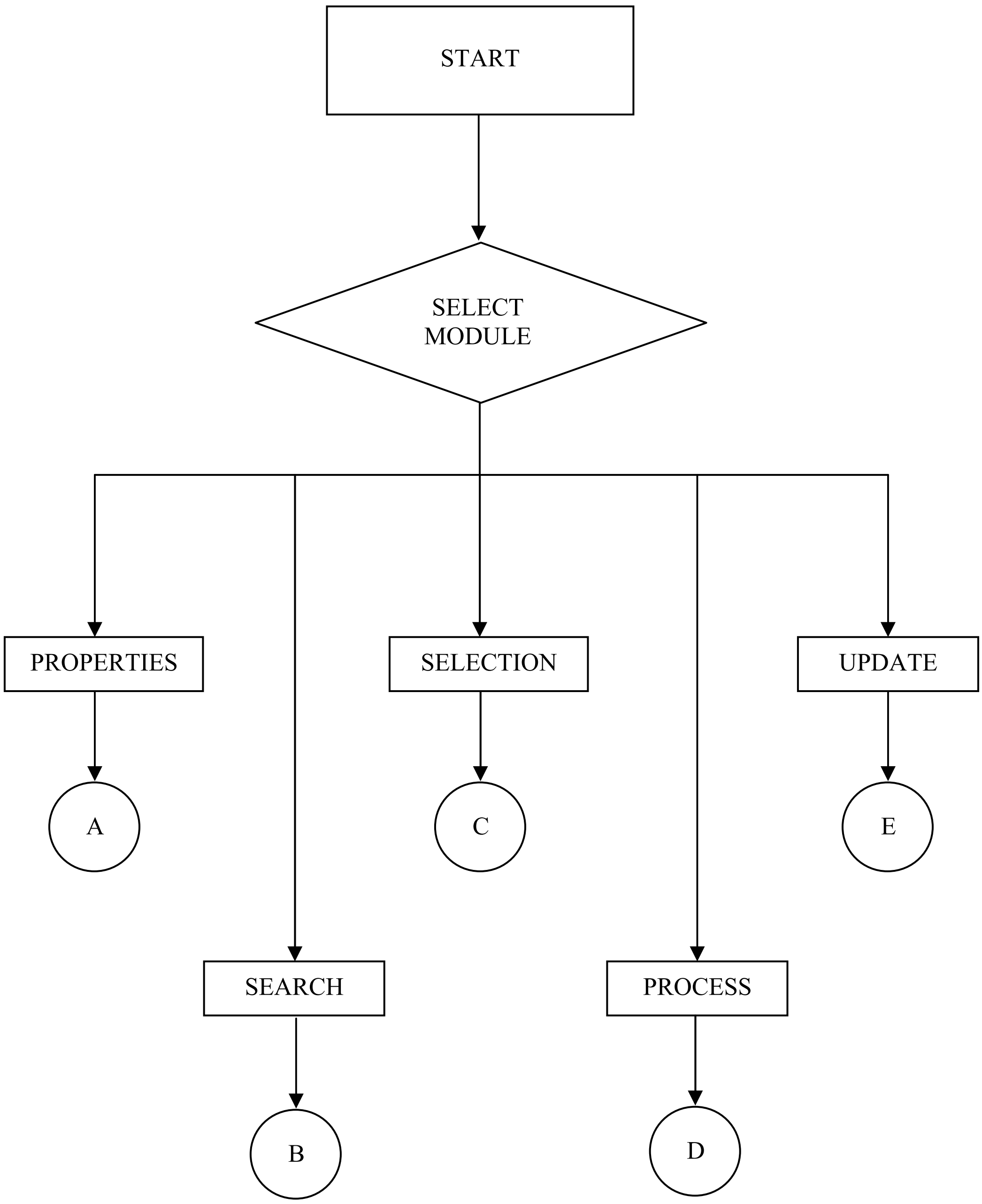


Figure C.1 Flow chart of the main module.

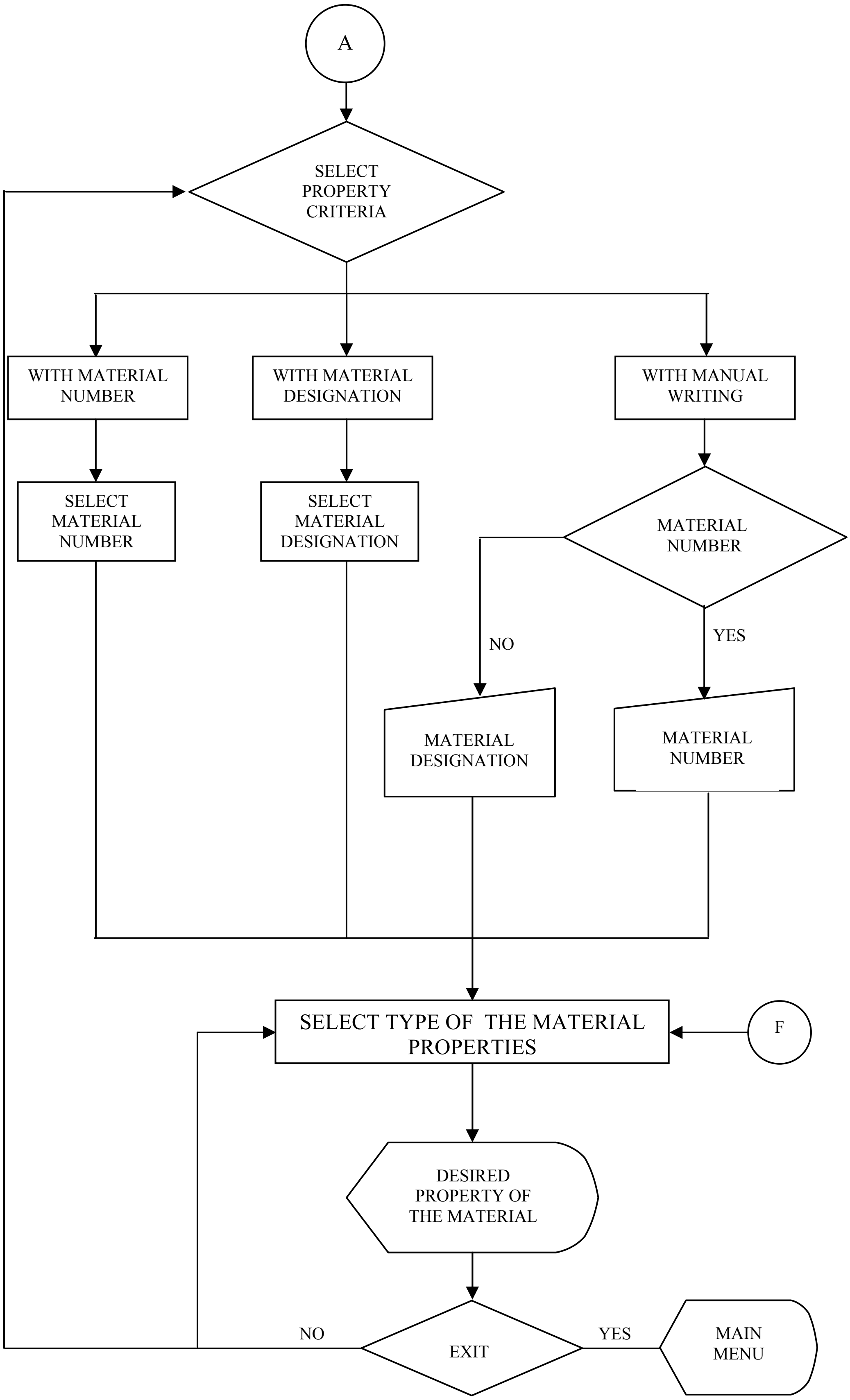


Figure C.2 Flow chart of the properties module

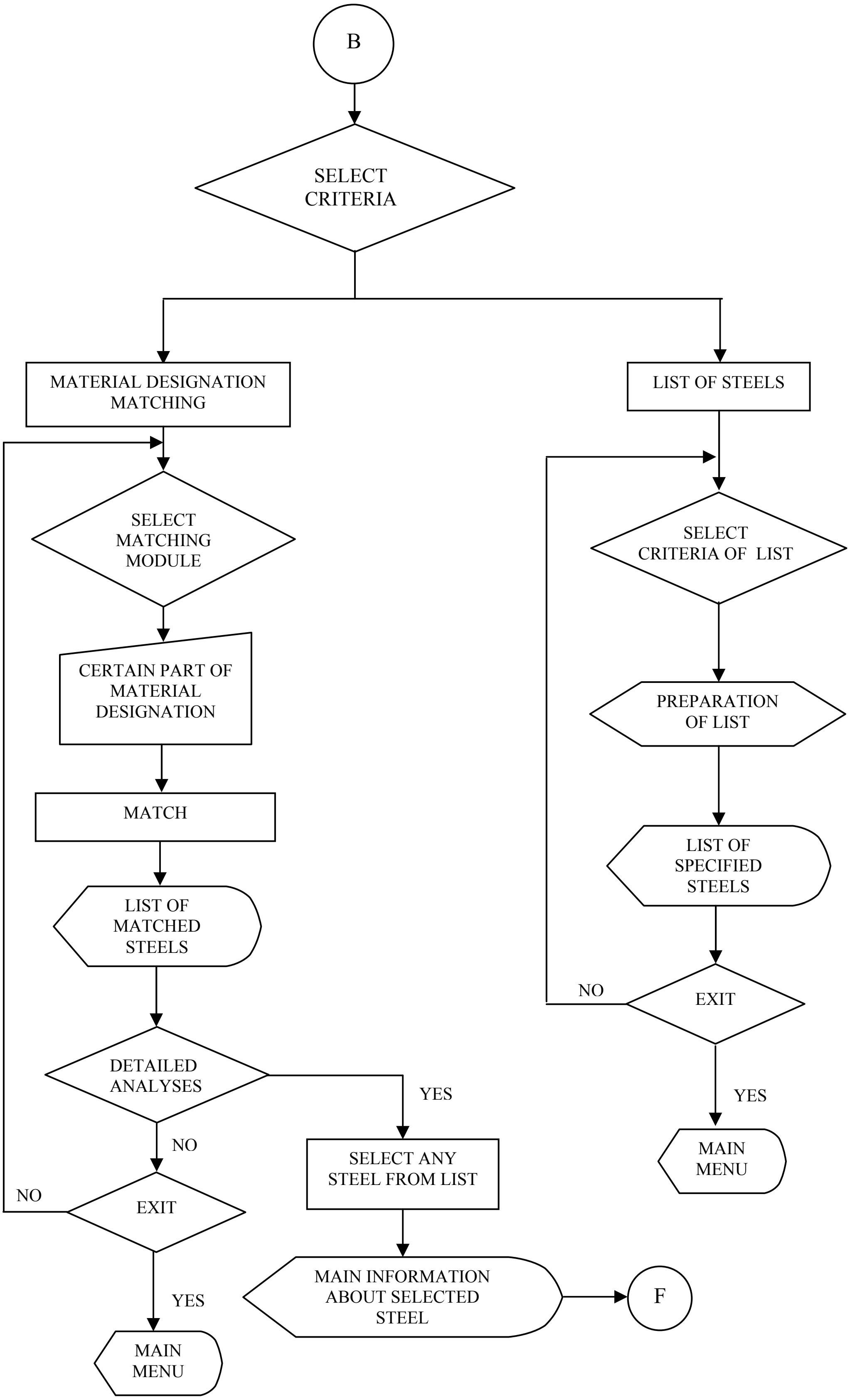


Figure C.3 Flow chart of the search module.

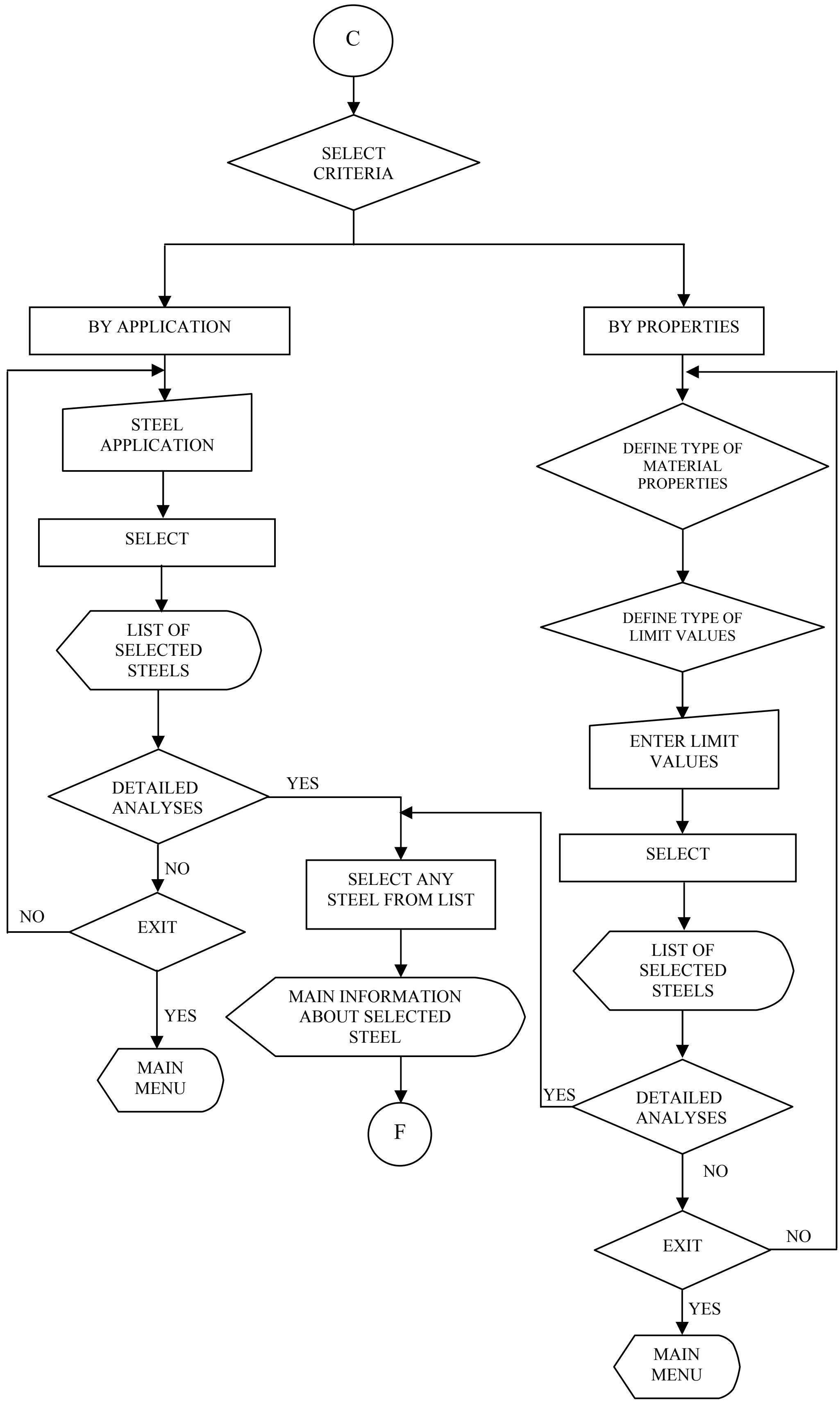


Figure C.4 Flow chart of the selection module.

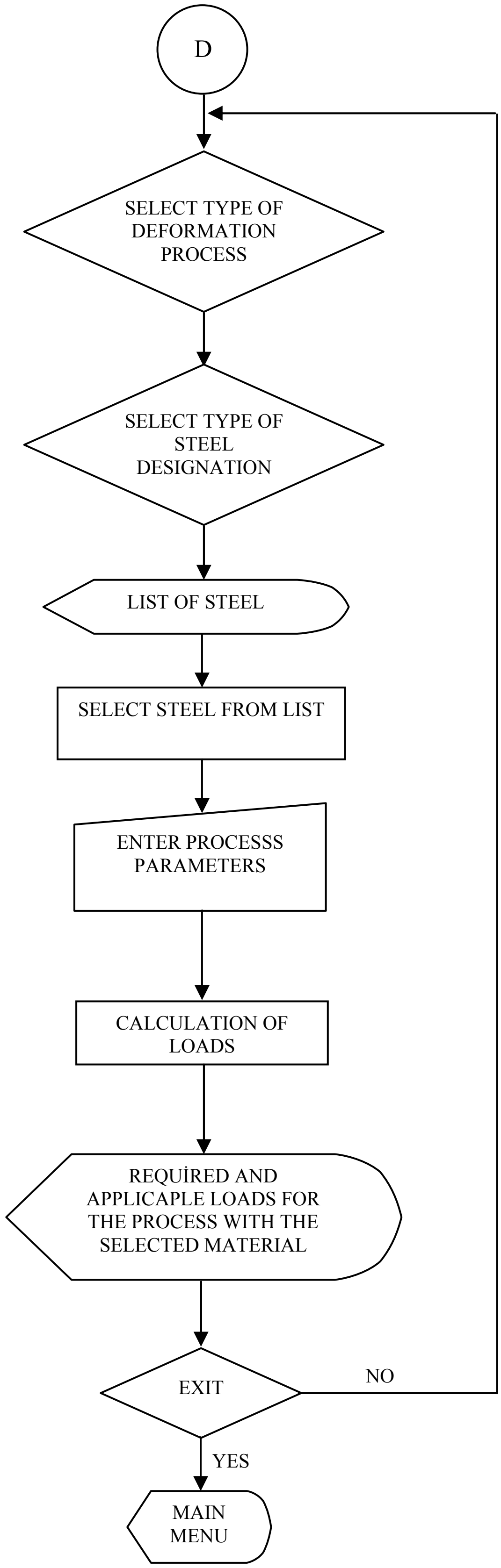


Figure C.5 Flow chart of the process module.

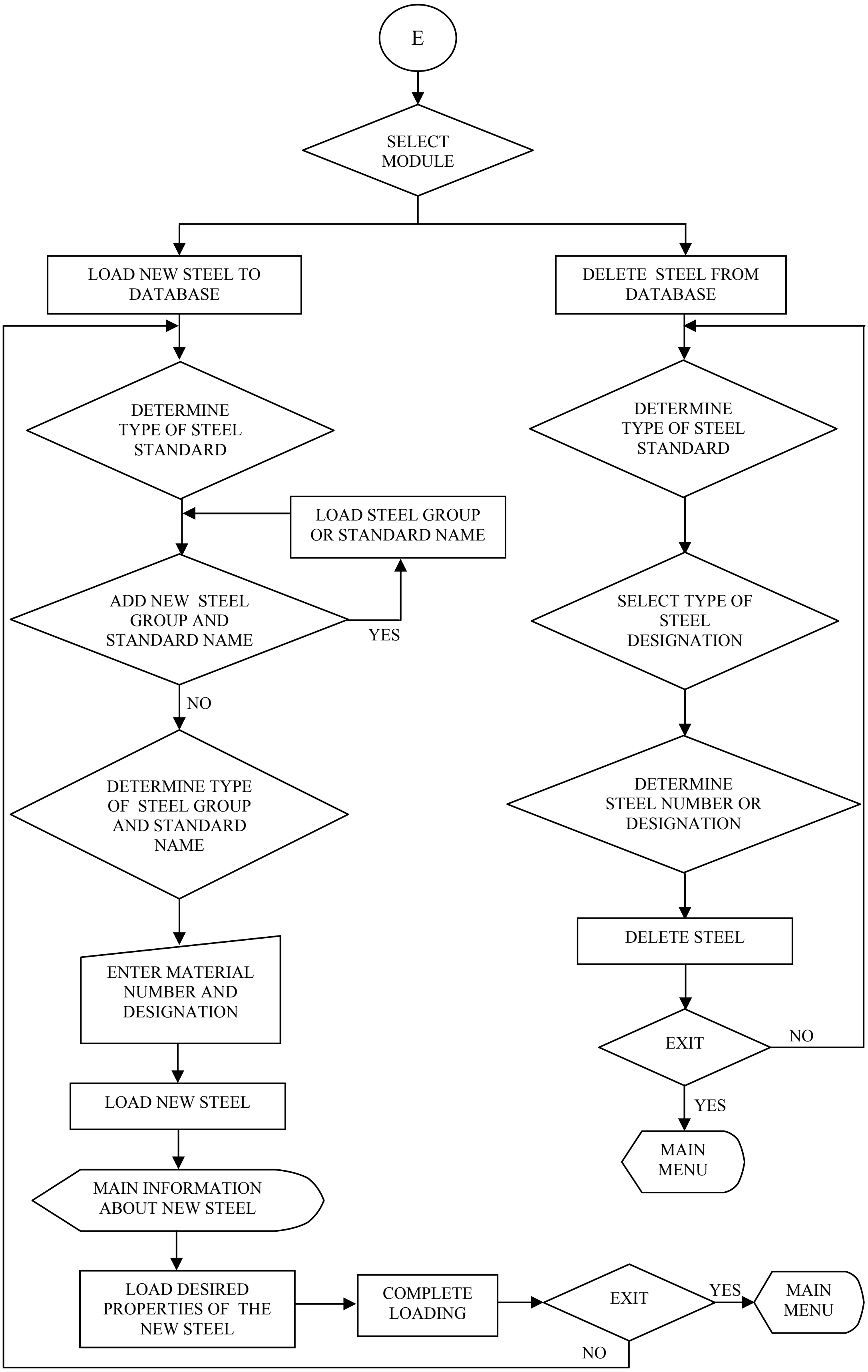


Figure C.6 Flow chart of the update module.