PREFORM DESIGN FOR FORGING OF HEAVY VEHICLE STEERING JOINT

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ABSTRACT

PREFORM DESIGN FOR FORGING OF HEAVY VEHICLE
STEERING JOINT

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In automotive industry, forgings are widely used especially in safety related applications, typically suspension, brake and steering systems. In this study, forging process of a steering joint used in heavy vehicles has been examined. This particular part has a non-planar parting surface and requires a series of operations, which includes fullering, bending and piercing on a forging press. Forging companies generally use trial-and-error methods during the design stage. Also to ensure complete die filling at the final stage, extra material is added to the billet geometry. However, the forging industry is becoming more competitive finding a way to improve the quality of the product while reducing the production costs.

For this purpose, a method is proposed for the design of the preform dies to reduce the material wastage, number of applied strokes and production costs. The designed operations were examined by using a commercially available finite volume analysis software. The necessary dies have been manufactured in METU-BILTIR CAD/CAM Center. The designed process has been verified by the experimental work in a forging company. As a result of this study, remarkable reduction in the flash, i.e. waste of material, has been achieved with a reasonable number of forging operations.

In addition to forging of the steering joint, forging of a chain bracket, which has bent sections with planar parting surface, has also been observed and analyzed during the study. An intermediate bending stage has been proposed to replace the manual hammering stage and satisfactory results have been observed in simulations.

Keywords: Metal Forming, Press Forging, Hammer Forging, Hot Forging, Open-Die Forging, Closed-Die Forging, Preform Design, Finite Volume Analysis

ÖZ

AĞIR VASITA SÜRÜŞ SİSTEMİ BAĞLANTI PARÇASININ DÖVME İŞLEMİ İÇİN ÖNFORM TASARIMI

GÜLBAHAR, Sertan

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Dövme parçaları, otomotiv endüstrisinde, özellikle süspansiyon, fren ve sürüş sistemlerinde, gibi güvenlik ile ilgili uygulamalarda yaygın olarak kullanılmaktadır. Bu çalışma dahilinde ağır vasıta sürüş sistemi bağlantı parçasının dövme prosesi incelenmiştir. Bu parça, düzlemsel olmayan ayırma yüzeyine sahip olup, dövme presinde uzama, bükme ve delme işlemlerine ihtiyaç duymaktadır. Dövme firmaları tasarım sürecinde genellikle deneme yanılma yöntemini kullanmaktadır. Ayrıca, son aşamada kalıbın tam olarak dolduğundan emin olmak için, başlangıç parça hacmine ekstra malzeme eklemektedirler. Fakat dövme endüstrisi, üretim fiyatlarını azaltıp, kaliteyi arttırma yönünde gittikçe daha rekabetçi olmaktadır.

Bu amaç doğrultusunda malzeme kaybını, vuruş sayısını ve üretim maliyetini azaltmak amacıyla önform kalıplarının tasarımı için bir metod önerilmiştir. Tasarlanmış operasyonlar ticari sonlu hacim analiz yazılımı kullanılarak incelenmiştir. Gerekli kalıplar ODTÜ-BİLTİR CAD/CAM

Merkezinde üretilmiştir. Tasarlanmış prosesin doğruluğu bir dövme firmasında yapılan testler sonucunda kanıtlanmıştır. Bu çalışmanın sonucunda makul sayıda dövme operasyonu kullanılarak çapak miktarında (malzeme kaybında) önemli oranda azalma sağlanmıştır.

Sürüş bağlantı parçasının dövme işlemine ek olarak, düzlemsel kalıp ayırma yüzeyine sahip, bükülmüş kısımlardan oluşan mapa parçasının dövme işlemi incelenmiş ve analiz edilmiştir. Elle yapılan çekiçleme aşamasının yerine, bir ara bükme aşaması önerilmiş ve yapılan simülasyonlarda tatmin edici sonuçlar elde edilmiştir.

Anahtar Kelimeler: Metal Çekillendirme, Pres Dövme, Çekiç Dövme, Sıcak Dövme, Açık Kalıpta Dövme, Kapalı Kalıpta Dövme, Ön Şekil Tasarımı, Sonlu Hacim Analizi

To My Family,

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SYMBOL

A_c	Mean Cross-sectional Area of the Part
A_t	Total Projected Area of the Forging
D	Billet Diameter
D_c	Diameter of the Circumscribing Cylinder of the Forging
D_o	Diameter of the Initial Round Stock
F_a	Surface Area of the Axial Cross-section of the Forging, Includes the Entire Axis of Symmetry
F_c	Surface Area of the Axial Cross-section of the Cylinder, Circumscribes the Forging
L_b	Length of the Billet
m	Interface Friction Factor
P	Perimeter of the Axial Cross-section of the Forging
P_c	Perimeter of the Axial Cross-section of the Cylinder, Circumscribes the Forging
R_c	Maximum Radius of the Forged Part, Equla to the Radius of the Circumscribing Cylinder
R_g	Radial Distance from the Symmetry Axis to the Center of Gravity of the Cross-section
S	Side Length of the Square Billet
Q	Weight of the Forging
Q_f	Weight of the Flash

r_1	Corner Radius
r_4	Fillet Radius
t_f	Flash Thickness
V	Total Volume of the Part
w_f	Flash-land Width in Die
Z	Shape Difficulty Factor
α_1	Longitudinal Shape Factor
β_1	Lateral Shape Factor
μ	Coefficient of Friction
σ_a	Average Flow Stress at the Given Average Forgin Temperature and Average Strain Rate
σ_n	Normal Stress
τ	Frictional Shear Stress
τ_{yield}	Flow Stress in Shear

CHAPTER 1

INTRODUCTION

In forging, a piece of metal is shaped to the desired form by plastic deformation of a simple starting form such as bar, billet, bloom or ingot. A machine tool such as hammer, press, horizontal forging machine, etc., applies the energy required for the deformation of the metal, either alone or in combination. The shape is imparted by the tools, called dies, which contact the workpiece.

Forging offers some basic advantages besides other metal forming processes. It refines the grain structure and develops the optimum grain flow, which imparts desirable directional properties such as tensile strength, ductility, impact toughness, and fracture toughness and fatigue strength. Forgings are free from internal voids and porosity. The process achieves very consistent material uniformity, which results in uniform mechanical properties and a uniform, predictable response to heat treatment. The properties provided forging brings advantageous in safety related applications, such as aerospace structural components and automotive components, typically suspension, brake and steering systems, which are subject to shock, impact and cyclic loads.

Today, forging industry try to make developments in all areas of forging in order to keep pace with other metal forming processes. Objectives of these ongoing improvements can be clarified as (a) increasing the production rate, (b) improving forging tolerances, (c) reducing costs by minimizing scrap losses, by reducing preforming steps, and by increasing tool life, and (d) expanding capacity to forge larger and more intricate parts.

1.1 Forging Process

There are various classifications applied for the forging process. In general, forging processes can be classified as:

- Temperature: Hor Forging, Cold Forging, Warm Forging
- Type of Machine Used: Hammer, Press, Horizontal Upsetting Machine
- Type of die set: Closed die, Open die

1.1.1 Classification of Forging Process According to Temperature

In hot forging, the billet is heated above its recrystallization temperature thus avoiding strain hardening. A greater degree of deformation can be achieved in a single operation than in cold or warm forging method. Die wear is also reduced in hot forging. However, the requirements for uniform and controllable die heating systems, formation of the scale and low dimensional accuracy are the main disadvantages of this process.

The temperature of metals being cold forged may range from room temperature to several hundred degrees. The primary advantage is the material savings achieved through precision shapes that require little finishing. While cold forging usually improves mechanical properties, the improvement is not useful in many common applications and economic advantages remain the primary interest. Tool design and manufacture are critical.

Warm forging has a number of cost-saving advantages that underscore its increasing use as a manufacturing method. This process is performed with the workpiece heated to a range that is generally above the work hardening temperature and below the temperature at which scale forms. Such forgings can be manufactured with excellent definition and can incorporate features that are not possible with conventional forgings. Compared with cold forging, warm forging has the potential advantages of: reduced tooling loads, reduced press loads, increased steel ductility, elimination of need to anneal prior to forging, and favorable as-forged properties that can eliminate heat treatment. Shafts, gears and automotive front wheel drive tulips are some examples for warm forged components.

1.1.2 Types of Machine Used

Forgings can be classified into four main categories according to the type of machine used. These are,

- Hammer Forging (Board Drop Hammers, Power Drop Hammers, Air-Lift Gravity Drop Hammers, Counterblow Hammers)
- Press Forging (Mechanical Presses, Hydraulic Presses, Multiple Ram Presses, Friction Screw Presses)
- Horizontal Forging Machine
- Roll Forging

Forgings made by using hammer and press forgings are discussed in this section, since the forgings analyzed in this study will be formed on these machines. The characteristics of these machines have been given in several publications [1, 2, 3].

With the exception of the counterblow hammer, forging hammers have a weighted ram, which moves vertically in a downward stroke; thus, exerts a striking force against a stationary component of the anvil near the base of the hammer. The upper half of a pair of dies is fastened to the weighted ram, and lower half to the anvil cap. Initially heated billet is placed on the lower die, and the striking force is imposed on the work metal by the upper die and ram, causing it to deform plastically with each successive blow. The hammer is an energy-restricted machine. During a working stroke, the deformation proceeds until the total kinetic energy is dissipated by plastic deformation of the forging stock and by elastic deformation of the ram and anvil when the die faces contact with each other.

Forging presses generally incorporate a ram that moves in a vertical direction to exert a squeezing action on the workpiece. Depending on the source of the power, forging presses are classified as mechanical or hydraulic. The operation of hydraulic press is relatively simple and is based on the motion of a hydraulic piston guided in a cylinder. Hydraulic presses are essentially load-restricted machines. Maximum capacities exceeding those of the largest power drop hammers are developed by hydraulic presses. Since most of the load is available during the entire stroke, relatively large energies are available for deformation. Within the capacity of a hydraulic press, the maximum load can be limited to protect the tooling and within the limits of the machine , the ram speed can be varied continuously during an entire stroke cycle with an adequate control system. In general, presses can produce all types of the forgings that can be produced by hammers and in addition some alloys of moderate ductility that would break under the blows of a hammer can be forged.

The mechanical forging press is an efficient machine, and it is the most widely used equipment for closed-die forging. The drive of the most mechanical presses is based on a slider-crank mechanism that translates rotary motion into reciprocating linear motion. The eccentric shaft is connected through a clutch and brake system directly to the flywheel. For larger capacities, the flywheel is located on the pinion shaft, which drives the eccentric shaft. The constant clutch torque is available at the eccentric shaft, which transmits the torque and the flywheel energy to the slide through the connecting rod. The flywheel, which is driven by an electric motor, stores energy that is used during deformation of the forged part.

There are some advantages and disadvantages of forging presses. The crank and eccentric presses are displacement-restricted machines. The slide velocity and the available slide load vary in accordance with the position of the slide before the bottom dead center. Higher production rates are possible with presses than with hammers. Because the impact is less in presses than in hammers, the dies can be less massive, thus requiring less tool steel to make the dies.

1.1.3 Types of Die Set

Open die forging is a forming process that uses standard flat, V-shaped, concave or convex dies in presses. Open die forging processes allow the grain flow in one or two directions. The workpiece is generally compreses in the axial direction (direction of the movement of the upper die) with no lateral constraint. Lateral dimensions are developed by controlling the amount of axial deflection, or by rotating the workpiece. In addition to round, square, rectangular, hexagonal bars and other basic shapes, open-die processes can produce step shafts, solid shafts (spindles or rotors) whose diameter increase or decrease (steps down) at multiple locations along the longitudinal axis; hollows cylindrical in shape, usually with length much greater than the diameter of the part (Length, wall thickness, inner and outer diameter can be varied as needed); ring-like parts; contour-formed metal shells like pressure vessels, which may incorporate extruded nozzles and other design features.

Closed die forging (also called as impression die forging) is basically the shaping of metals in between closed die cavities. As the two dies approach, the workpiece undergoes plastic deformation, flowing laterally until it touches the side walls of the impression. Therefore, the dimensional control of the forging in lateral directions is controlled by the walls of the die, and is ensured by complete fill. Dimensional control in the axial direction is achieved by bringing the die faces to a predetermined position.

While flash can promote complete fill of the cavity, it causes extremely high die pressures in the flash area. High pressures are undesirable because they reduce die life and require additional power. A flash gutter is often formed in the dies to receive the flash and allow the dies to reach the predetermined position at lower pressures.

1.2 Forging Defects and Error Sources in Forgings

Forging defects are defined as those that result from improper forging operations. They can be generalized as laps, coarse-grain wrinkles, flow-through defects, thermal cracks, hot tears and center bursts [2].

Laps includes a large amount of defects that form whenever metal folds over itself during the forging process. Laps are found most frequently where vertical and horizontal sections intersect. In these cases, the causes are usually traceable to improper selection of the fillet radii. Metal flowing nonuniformly in vertical cavities may form a lap when the metal finally fills the cavity. This is a particular problem when the vertical sections of a forging vary significantly in volume requirements. Laps may also occur during the preliminary forging operations as swaging, rolling, edging, and fullering.

Forging billets containing coarse grains, whether as cast or wrought, may develop wrinkles during forging. When such billets are forged in closed dies, these wrinkles often fold in to cause a series of small laps. Although they are seldom very deep, these laps may produce a poor surface appearance that often necessitates considerable grinding and restrike forging.

Flow-through defects are essentially laps that form when metal flows past die recesses after they have filled. Figure 1.1 shows, how a completely filled, sound rib-web forging may develop flow-through defects by continuing to forge after filling is complete.

Flow-through defects may also occur even when the die impression is not completely filled. This happens most often when the metal in the rib or projection exhibits an increasing resistance to flow due to work hardening or die-chilling effects. These type defects also occur when the trapped lubricant forces metal to flow past an impression.

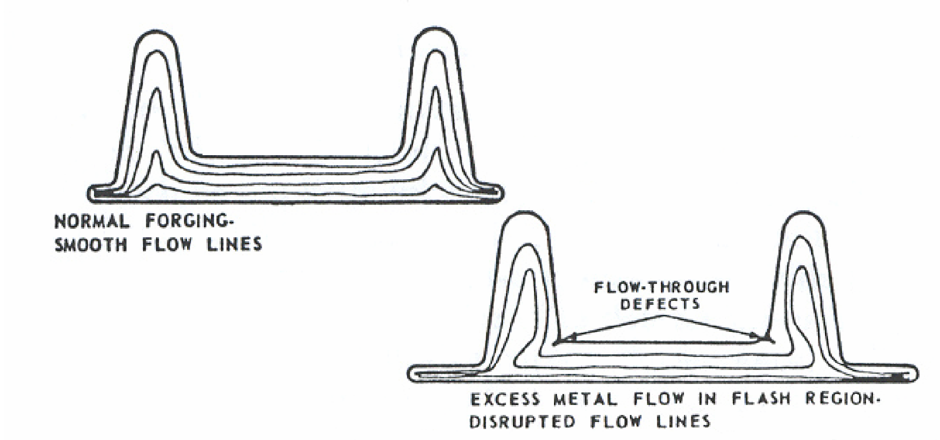


Figure 1.1 – Typical Cause of Flow-through Defects [4]

Thermal cracks are cracks caused by the stresses resulting from non-uniform temperatures within a metal. In order to avoid from this type of cracks, forgings should be cooled slowly either in an insulating material or in a furnace. Another type of thermal crack occurs when forgings are heated too rapidly. The internal ruptures form, because the hotter surface layers expand more than the cooler metal near the center. Hot tears are surface defects that occur when metals ruptures during forging.

Center bursts are ruptures that occur in the center of billets. They sometimes occur at centerlines as a result of high forces.

Most generally the errors in forgings occur due to the improper design of the forging process, operator faults, and wrong selection of the billet material. Typical error source percentages have been acquired from AKSAN forging company, which is based in Ankara [5]. They have been working on hot forging and have a capacity of 10,000 tons per year (today). Weight of the forging products of the company range from 0.3 kg to 32 kg. Since they have been working on hot forging more than 35 years, their technical data sheet, Table 1.1, clarifies fault areas in hot forging.

Table 1.1 – Classification of Scrap Metal in Hot Forging according to Fault Types [5]

#	Fault Areas in Hot Forging	% to Total
1	Wrong design of the preform dies	17.2
2	Trial forging processes	10.1
3	Lamination on the forging, emerging from perform design	9.4
4	Misalignment of die pairs	9.0
5	Wrong placement of the forging	6.9
6	Short billet size	6.8
7	Defect in the billet material	5.6
8	Unsuitable material properties (hardness, heat treatment)	5.4
9	Die fatigue	4.3
10	Inadequate metal flow in die cavity (incomplete impression)	3.5
11	Forging tilted during forging operation	2.9
12	Crack propagation on the billet during preforming operation	1.4
13	Others	17.5

As seen from the Table 1.1, the error source with the highest percentage is the wrong design of the perform dies, the trial forging processes, lamination of the forging emerging from the preform design, inadequate metal flow in the die cavity, and the crack propagation on the billet during preforming operation, which is 41.6% of the total error amount. This data clearly shows the importance of the perform design period both for economically and for loss of production time.

Errors related to the operator faults cannot be undervalued. It can be seen from items 4, 5, 6, and 11, which are misalignment of die pairs, wrong placement of the forging, short billet size, and tilted forging during forging operations, which is 25.6% of the total error amount. This classification briefly clarifies the importance of the operator's experience factor for the forging operations.

Item numbers 7, 8 and 9 are related with material properties of either die pairs or the billet. Reasons for these errors are desired billet or die material cannot be obtained exactly from the suppliers such as hardness and coating (especially for the die pairs).

During the forging processes, some other problems may also occur. These problems occur because of the repeated mechanical loading which is due to the forming resistance and the geometrical conditions; thermal stressing because of the workpiece and tool temperature as well as the pressure contact time; and tribological conditions at the contact zone between workpiece and dies.

1.3 Usage of CAD/CAM/CAE for Analysis of Forging Process

Today, in some of the forging companies, the design of the dies and the selection of process conditions in forging process are still performed by trial-and-error methods to a large extend. In many cases, this method causes waste of material, early die wear, increasing cost, etc. With the development of Computer-Aided-Design (CAD), Computer-Aided-Manufacturing (CAM) and Computer-Aided-Engineering (CAE) techniques, the reduced time and effort on design and manufacturing stages have become possible.

By using CAD/CAM software, the designer can create the 3-D model of the forgings, preform geometries, and the necessary dies. These provide the comfort of easily changing the parameters such as dimensions, taper angles, fillet radii, shrinking factor, etc. Designer can also point out the problems that may occur during the preforming stages by the help of the computer analysis techniques; thus, reduces the cost and time [6]. However, the experienced designer who should manage to design the process and dies properly is still essential in real-life applications.

Finite Element Method (FEM), which is one of the computer analysis techniques, is a widely used numerical technique for finding solutions in metal forming processes. FEM is based on discretizing a domain into elements (and nodes) and constructing basis (or interpolation) functions across the elements. Applications of finite element method include linear and nonlinear structural, thermal, dynamic, electromagnetic, and flow analysis. Some programs used as simulation packages which use this algorithm are ANSYS, MARK, DEFORM, FORM etc. [7-10]. By using these programs, metal flow, stress, strain and temperature distributions can be predicted.

Finite Volume Method (FVM) [11] is utilized in forging simulations. FVM is common practice for material flow simulations of events like sloshing; the movement of the interface between two different fluids, often as a result of external excitation, underwater explosion, etc. Unlike a traditional FE mesh, which distorts while attempting to follow the deformation material, the mesh is a fixed frame of reference and material simply flows through the finite volume mesh. Forging typically involves large material flow as well.

MSC.Superforge [12] is based on finite volume rather than finite element technology. This finite volume technology is particularly suited for simulating the gross material deformations inherent in forging operations, and at the same time completely eliminates the need for volume re-meshing techniques, commonly considered as the main bottleneck in 3-D forging simulations based on the finite element method [13].

Some previous studies have been conducted on different types of forgings. As a Ph.D. study at University of Birmingham, Gökler [14] developed a computer program for the design of the operational sequences and the dies for horizontal forging machines. Upset forging has also been studied by Kazancı [15]. He developed a program named as Pro/UPSETTER for the sequence and die design of solid hot upset forgings having circular shanks and upset regions with non-circular cross-sections. In another study, Moğulkoç [16] rationalized the design rules for upsetting and piercing on horizontal forging machines and suggested a new methodology for the geometry of the profiles by using the finite element analysis technique.

Ceran [17] studied on hot upset forging process by using a commercial finite element code coupled with thermal analysis in order to determine effects of the process on the header die for the taper preform stages. A study on upset forging process and the design limits for tapered preforms had been conducted by Elmaskaya [18] by using the elastic-plastic finite element method. İsbir [19] studied on the finite element simulation of shearing using the element elimination method to examine trimming operation on forged parts. In the study of Doğan [20] the effects of the tapered preform shapes on the final product in cold upset forging had been investigated by using the elastic-plastic finite element method.

Alper [21] developed a computer program for axisymmetric press forgings, which designs the forging geometry and the die cavity for preforms and finishing operation.

Kutlu [22] studied on the design and analysis of preforms in hot forging for non-axisymmetric press forgings. Karagözler [23] studied on the analysis and preform design for long press forgings with non-planar parting surfaces.

1.4 Scope of the Thesis

As described in previous section, most of the errors in forging are resulted from the wrong design of the process and improper preform geometries. To be sure of the complete die-fill at the finishing stage, excess flash allowances are employed by the designer. In some cases this portion is about 40 % of the initial material. Usage of excess material will lead to the need of revised die set after forging of small batches because of early die wear due to the excess flash. All these increase the forging cost in terms of used material, process time, die cost, etc. To avoid these types of problems, CAD/CAM/CAE techniques have been employed for many forgings with different geometries by several researchers [14-23] as discussed in the previous section. In this study, the analysis and design of bent forgings with planar and non-planar parting surfaces will be focused.

The basic design considerations in forging process are presented in Chapter 2. In Chapter 3, the proposed preform design methodology is explained in detail. The studies performed for two different forged parts, which are “Chain Bracket”, and “Steering Joint of a Heavy Vehicle” are described in Chapters 4 and 5, respectively. Conclusions of this study will be presented in Chapter 6.

CHAPTER 2

DESIGN FOR FORGING PROCESS

Forging part design is much like the design for other metalworking processes; it is influenced by the nature of the metal being processed and the capabilities and limitations of the available forging equipment and tools. Parts can be forged in the greatest variety of shapes and designs. Forging part designs are classified into four general categories [2]:

a- Blocker-type designs

b- Commercial designs

c- Close-tolerance designs

d- Precision designs

The first three categories represent designs that are progressively closer to the final-part outline and, accordingly, progressively require an increasing number of forging dies and forging steps. The blocker-type designs are characterized by generous contours, large radii, draft angles of 7 degrees or more, and moderate finish allowances. The commercial designs have more refined details, standard draft (5 to 7 degrees), smaller radii and finish allowances, and specific dimensional tolerances that can be achieved on most commercial forging equipment. Close-tolerance designs are generally considered as those having low draft angles (1 to 3 degrees), little or no finish allowance, and dimensional tolerances of less than half those for commercial designs.

Close-tolerance forgings are normally forged in conventional equipment but usually require extra operations such as coining.

The term “precision” is applied to forging design, which can be also named as “close-finish” forging, “draftless” forging, “close tolerance” forging, and “net-shape” forging. These designs are either forged or, in some cases, forged and spot machined to precise dimensions with maximum variations on the order of ±0.025 mm. Precision forging generally requires the use of additional tooling, special forging techniques, and specialized forging machinery.

For most of the forgings, the overall design procedure starts with the estimation step. This step includes determining the number of preform steps, auxiliary operations and the cost of the forging, based on the number of necessary operations [1, 24].

During the design stage of the forging process, some certain aspects should be considered and with these considerations, necessary calculations, predictions and estimations should be done. These aspects can be classified as Forging Part Design, Process Sequence and Preform Design, Flash Estimation, and Forging Load and Energy [1]. These design aspects will be discussed in the following sections.

2.1 Forging Part Design

Forging part design mainly includes location of parting line, determination of forging draft, corner and fillet radii, and shrinking allowance.

2.1.1 Location of Parting Line

For forging of a part, the first step in forging design is to locate and determine the shape of the parting line (sometimes called “flash line” or “split line”). Typical hammer and press forging employs an upper and a lower die. Each die contains a machined impression that describes the exterior configuration of the forged workpiece. The “parting line” is the projected line around the periphery of a forging that is defined by the adjacent and mating faces of the forging dies when the dies are closed as shown in Fig 2.1. Decision of the location of the “parting line” influences other design factors such as die design and construction, grain flow, and trimming procedure. If the parting line remains straight around the periphery of the forging, it will lie in a plane corresponding to that of the mating die surfaces, which is called “forging plane”. The forging plane is normal to the direction of the closure of the dies, or to the “direction of ram”.

In some cases, parting line remains straight, but some variations on the parting plane may occur. This occurs, for example, when the web of a forging is located above or below central plane, the parting line is typically raised or lowered in order to maintain its central position with respect to the web, and thus to facilitate symmetrical flow of metal.

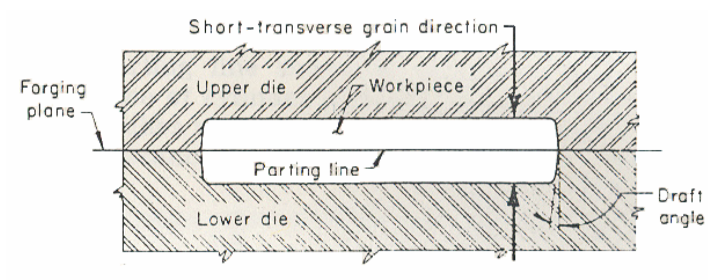


Figure 2.1 – Forging with Straight Parting Line [25]

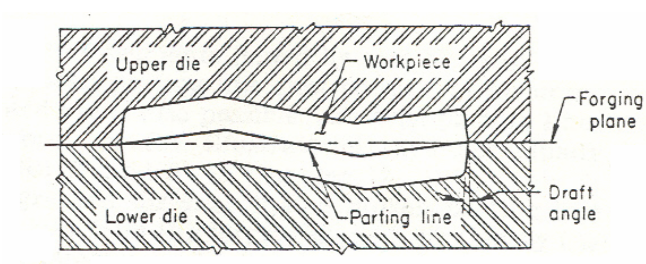


Figure 2.2 - Forging with Broken Parting Line [25]

It is not always possible or feasible to design a parting line that is straight and in the forging plane. The alternative is a “stepped parting line” that does not follow continuously along the forging plane but departs from it at one or more points as seen in Fig. 2.2. The variety of designs with broken parting lines is unlimited. Such designs are practical in spite of increased machining of dies. Even when the design of a forging is simple, the direction of the parting line may change two or three times. Although the parting lines in Fig. 2.4 return to the forging plane at each end of the forging, the parting line in Fig. 2.3(a) returns to the forging plane at one end only, necessitating the use of a “counterlock”. The counterlock resists side thrust and serves to prevent displacement of the mating dies. The counterlock can be eliminated, as shown in Fig. 2.3(b), by forging two workpiece in a common set of dies, or as shown in Fig. 2.2, by positioning the forging plane.

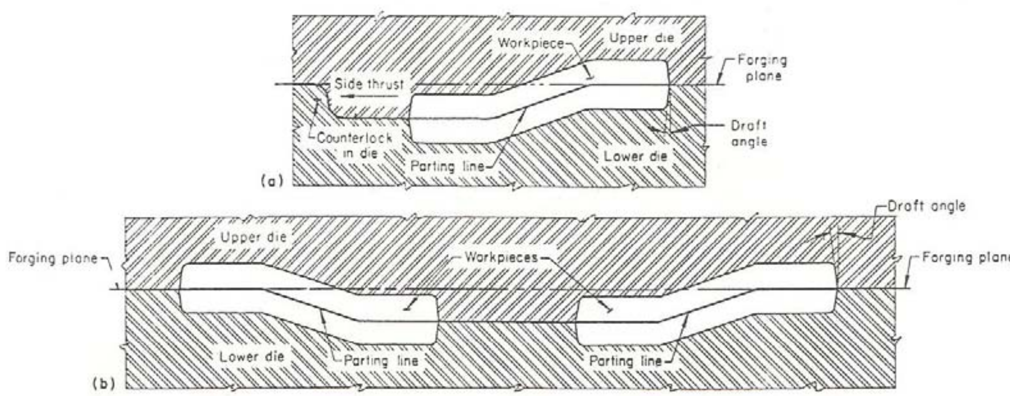


Figure 2.3 – (a) Die Set with Counterlock, (b) Balanced Pair of Forgings in a Single Die Set [25]

When the broken parting line departs upward or downward from the forging plane, it is suggested that the included angle (Fig. 2.4) described by the parting line and forging plane not exceed 75° [25].

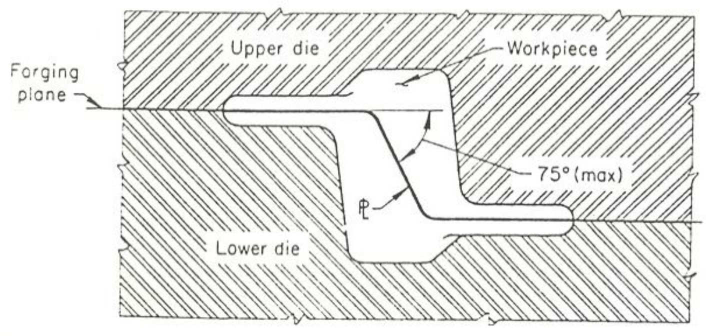


Figure 2.4 – Die Set for Producing a Forging with Broken Parting Line [25]

2.1.2 Draft Angle

Axial projections on a forging are usually tapered so that the forging can be easily removed from the die cavity. This taper is usually called draft. Basic types of drafts used in forging designs are illustrated schematically in Figure 2.5.

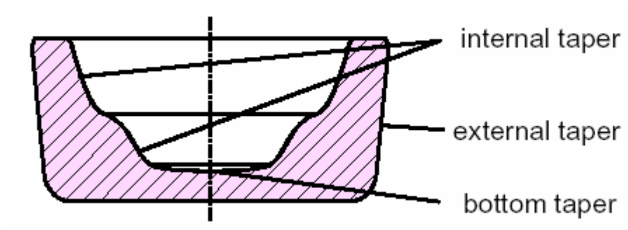


Figure 2.5 – Basic Types of Drafts

Zero and 1^{o} draft angles may be used on aluminum and magnesium forgings of extrusion types. Back-extruded cylinders and shafts are frequently designed with a 1-degree draft. A 3^{o} to 5^{o} degree draft angle is suitable for most forgings of carbon, low-alloy, and stainless steels, and for some of the nickel-base alloys. A 5^{o} draft angle is generally considered the minimum for titanium alloys because shallower drafts often lead to seizing and galling problems, which is a severe type of wear that occurs when relative motion exists between contacting surfaces with extensive local adhesion. A 7^o or greater draft angle is generally required for forging of alloys requiring extreme pressures such as refractory metals, the nickel-base superalloys, and the hot-cold worked austenitic stainless steels [2].

2.1.3 Corner and Fillet Radii

On closed-die forgings, corners and fillets are the curved connecting surfaces that unite smoothly the converging or intersecting sides of forged elements, such as ribs, bosses and webs. Corner radius on forging will be fillet radius on the die. This is same for the fillet radius of the part and the corner radius of the die.

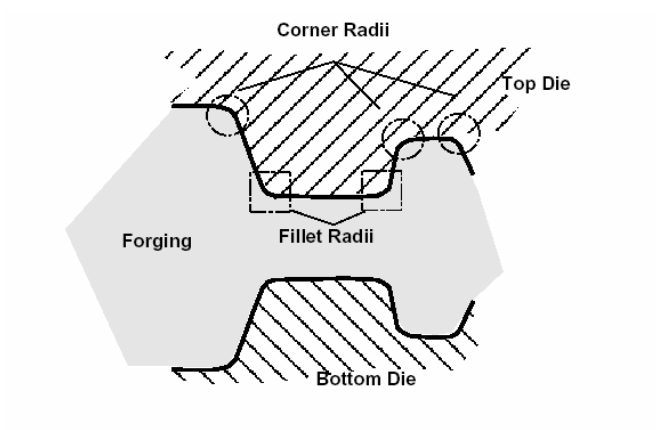


Figure 2.6– Illustration of Corner and Fillet Radii for a Part [26]

A lap or cold shut can form as a direct result of flow-through as discussed in the previous chapter if the fillet radius is too small. Smaller corner radii generally increase the chances for die failure and are more difficult to fill. Large corner radii are preferred for bosses and ribs on forging part, and a full radius is considered optimum for ribs. Fig. 2.6 shows the illustration for corner and fillet radii.

Table 2.1 presents some recommended values for fillet and corner radii based on forging weight [2]. Except for very small forgings, the fillet radii are normally twice the recommended corner radii. In the case of elongated forgings like camshafts and crankshafts, for the internal and external fillet radii values are recommended by the DIN Standard 7523 [27].

Table 2.1 – General Recommendations for Minimum Fillet and Corner Radii [2]

Forging Weight (kg)	**Fillet Radius (mm)**	**Corner Radius (mm)**
0.45	1.2 – 3.2	1.2 – 3.2
0.9	1.6 – 3.2	1.6 – 3.2
2.25	3.2 – 6.4	3.2
4.5	3.2 – 6.4	2.4 – 3.2
13.5	6.4 – 12.7	3.2 – 6.4
45	12.7	6.4

2.1.4 Scale Allowance

Steel forgings are coated on the surface with a thin layer of iron oxide or scale, which is caused by contact of the heated steel with air. Steel begins to oxidize at about 204^{o}C; however, serious scaling (where substantial material may be lost and oxidized material spalls off the surface of the material) does not begin until the material reaches about 843^{o}C. [28]. The amount of scale that is formed depends upon the forging temperature to which the steel is heated and the length of time. The scale that is formed during the heating stage must be cleaned before putting the billet on the die. Sometimes in the practice, the heated stock is being hammered or squeezed between the dies; hence, the formed scale begins to crack and separate from the forged material, and fall into the die. Because of this scale formation problem, a scale allowance has to be applied to the calculations of the billet volume. Bruchanow and Rebelski [29] recommended the values given in Table 2.2 for the calculation of scale allowance.

Table 2.2 – Scale Allowance Values [29]

Type of Furnace	Scale Allowance
Oil Box	4 %
Gas Box	3 %
Gas Continuous	2.5 %
Electric	1.5 %
Induction	1 %

2.2 Flash Design

Flash is the metal, which is forced outward from the workpiece while it is being forged to the configuration of the closed-die impression. In other means, it is the metal in excess of that required to fill the impression. The flash that extends beyond the flash land is contained in a holder referred to as the "flash gutter" as seen in Fig. 2.7. The gutter, an integral part of the dies, is intentionally designed to some extent oversize to accommodate all excess metal, allowing the mating surfaces to close.

In terms of its contribution to the closed-die hammer and press forging processes, flash serves two basic functions [30]. First, by providing a convenient means for disposing of excess metal, it makes possible the use of slightly oversized billets and renders other billet dimensional variations, such as deviations in cutting to length or metal losses caused by oxidation during forging or heating of billet, much less critical. Availability of excess metal also increases possibility of the die filling. Second, flash provides useful constraint of metal flow during forging, which helps in filling the die impressions. Before complete closure of dies, the presence of some flash metal at the periphery of the workpiece promotes containment of the workpiece metal within the impressions.

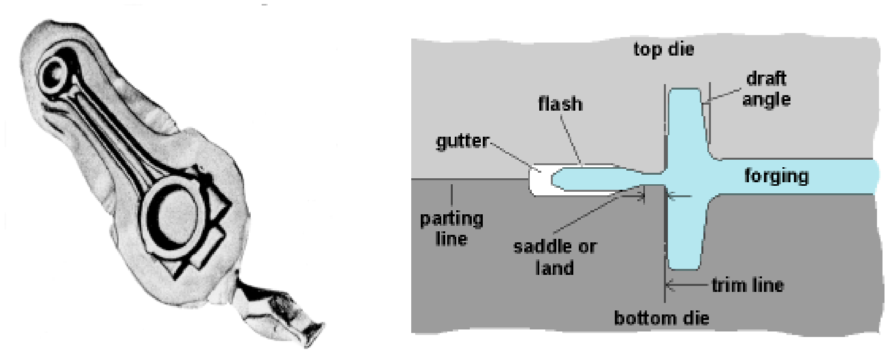


Figure 2.7 – Flash Distribution for a Forged Part [2]

On the other hand, because of flash formation, forged parts require a trimming operation to remove the flash. This removed metal is categorized as scrap. Also formation of flash increases the die wear.

Flash thickness and flash-land width have great influence on forging pressure. Essentially, forging pressure increases with decreasing flash thickness and increasing flash-land width because of combination of increasing restriction, increasing frictional forces, and decreasing metal temperatures at the flash gap.

A typical load-versus-stroke curve for a closed-die forging is shown in Fig. 2.8. Loads are relatively low until the more difficult details are partly filled and the metal reaches the flash opening. As the dies continue to close, the loads increase sharply at point P_2, the stage at which the die cavity is filled completely. However, P_3 represents the final load reached in normal practice for insuring that the die cavity is completely filled and that the forging has proper dimensions. During the stroke from P_2 to P_3, all metal flow occurs only near or in the flash gap, which in turn becomes more restrictive as the dies close. In that respect, the detail most difficult to fill determines the minimum load for producing a fully filled forging. Thus, the dimensions of the flash determine the final load required for closing the die [1].

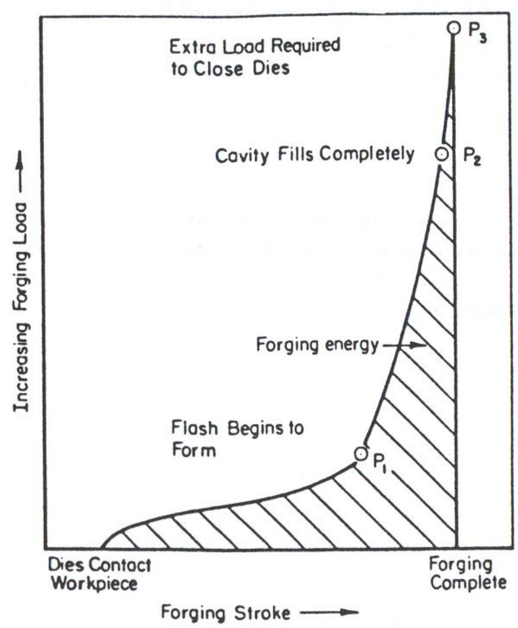


Figure 2.8 – Typical Forging-Load Curve for Closed-Die Forging [1]

The formation of the flash, however, is greatly influenced by the amount of excess material available in the cavity, since that amount determines the instantaneous height of the extruded flash.

It is obvious that flash thickness and flash land dimensions have great importance during the design stage of the forging. For this reason, many studies have been made in order to determine the proper flash dimensions for various forgings.

In order to determine the flash thickness, Bruchanow and Rebelski [29] derives a formula which determines the flash thickness t_f as a function of the projected area of the forging, A_t which is,

$$t_f = 0.015 \cdot \sqrt{A_t} \tag{2.1}$$

where t_f is in mm and A_t is in mm^2.

For forgings with circular cross-sections at the parting plane, Voigtlander derived a set of formula for determining the flash land dimensions, t_f and w_f. Thomas [31] later revised the formulae as,

$$t_f = 0.016 \cdot D_c \tag{2.2}$$

$$\frac{w_f}{t_f} = \frac{63}{D_c} \tag{2.3}$$

where D_c is the diameter of the circumscribing cylinder of the forging.

Teterin and Tarnovskij conducted a statistical study on more than 1500 round steel forgings of various weights and established an empirical formula for flash thickness, t_f, based on forging weight, Q. using English units, inch for t_f, and pounds for Q, their formulas are: [1]

$$t_f = \frac{(-0.09 + 2\sqrt[3]{Q/2.2} - 0.01 \cdot Q/2.2)}{25.4} \tag{2.4}$$

$$\frac{w_f}{t_f} = -0.02 + 0.0038 \cdot Z \cdot \frac{D_o}{t_f} + \frac{4.93}{(Q/2.2)^{0.2}} \tag{2.5}$$

where,

w_f = flash-land width in die, inch

D_o = diameter of the initial round stock, inch

Q = forging weight, without flash losses, pounds

Z = dimensionless Shape Difficulty Factor

In order to calculate the Shape Difficulty Factor, Z, Teterin has suggested a set of definitions. A "longitudinal shape factor", α_1 is defined as [1]:

$$\alpha_1 = \frac{X_f}{X_c} \tag{2.6}$$

with,

$$X_f = \frac{P^2}{F_a} \tag{2.7}$$

$$X_c = \frac{P_c^{\,2}}{F_c} \tag{2.8}$$

where,

P = perimeter of the axial cross-section of the forging

F_a = surface area of the axial cross-section of the forging (surface that includes the entire axis of symmetry)

P_c = perimeter of the axial cross-section of the cylinder which circumscribes the forging

F_c = surface area of the axial cross-section of the cylinder which circumscribes the forging

On round forgings, bosses and rims placed farther away from the center are increasingly more difficult to forge. Therefore, a “lateral shape factor”, β_1, is defined as:

$$\beta_1 = \frac{2 \cdot R_g}{R_c} \tag{2.9}$$

where,

R_g = radial distance from the symmetry axis to the center of gravity of half of the cross-section

R_c = maximum radius of the forged part, which is equal to the radius of the circumscribing cylinder

A “Shape Difficulty Factor”, Z incorporating both the longitudinal and the lateral factors is defined as [1]:

$$Z = \alpha_1 \cdot \beta_1 \tag{2.10}$$

Neuberger and Mockel also suggested a set of empirical equations (2.11 and 2.12) for the parts that are expected to have uniform flash dimensions [23].

$$t_f = 0.89 \cdot \sqrt{Q} - 0.017 \cdot Q + 1.13 \tag{2.11}$$

$$w_f = t_f \cdot (3 + 1.2 \cdot e^{-1.09 \cdot Q}) \tag{2.12}$$

where,

Q = mass of forging, in kg

t_f = flash thickness, in mm

w_f = flash width, in mm

Table 2.3 – Recommendation of NADF for Flash Mass of the Forging [23]

Forging Mass (in kg)	Flash Mass (in kg/cm of periphery)
0 - 0.450	0.0047
0.450 – 2.273	0.0063
2.273 – 4.545	0.0098
4.545 – 6.818	0.0130
6.818 – 11.364	0.0168
11.364 – 22.727	0.0223
22.727 – 45.455	0.0324
45.455 or above	0.0477

"National Association of Drop Forgings (NADF)" also recommended a method for estimating the flash weight [23]. According to this recommendation, mass of the flash is calculated by multiplying the periphery of the forging by a constant, which is identified for different ranges of forging weight. This relation is given in Table 2.3.

2.3 Process Sequence and Preform Design

In a forging process, the material state and geometry of the final product depend on several process parameters like, loading conditions, geometry of the die surfaces, die lubrication conditions, geometry of the initial workpiece, etc. Considering a fixed amount of deformation induced in a process, designer wants to control the process parameters in such a way that a final product with a desired material state and geometry can be achieved. The design of forming processes can also be considered as the design of the initial workpiece and of the subsequent shapes at each of the forming stages known as preforms.

In designing any die the flow of material must be considered. In preforming operations, the material should be properly distributed for finishing operation. In order to achieve the proper distribution for a part, types and number of preforming operations have to be determined. This determination mainly depends on the shape complexity of the part. With properly designed preform dies; complete die fill can be achieved in the finisher die with a defect-free forging and minimum loss of metal in the form of flash. Fig 2.9 shows the preforming operations (1 to 4) for a part that is to be forged.

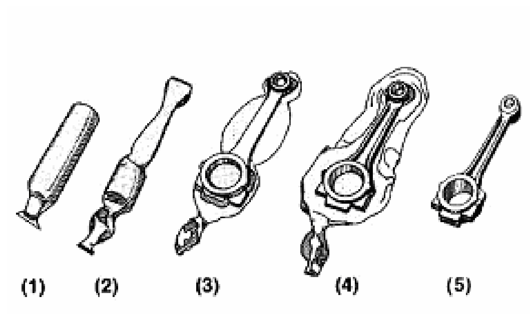


Figure 2.9 – Preform and Final Stages of a Forged Part

As the complexity of the forged part increases, type and number of the performing operations increases. However, complexities in the forging geometry make the number and shape of the perform impressions difficult to determine. Forging companies generally use their experience-based knowledge, coming from various forgings produced in time.

2.3.1 Types of Preform Impressions in Dies

Several different types of impressions can be used in a forging die, each type being designed to serve a specific function. In particular, the design of one impression should provide for location of the workpiece in the succeeding impression. In general, preform operations include fullers, edgers, flatteners, benders, rollers, splitters and blockers [3, 32].

Fullering is an operation used for reducing the cross section and to lengthen a portion of the forging stock. In longitudinal cross section, the fuller is usually elliptical or oval, to obtain optimum metal flow without producing laps, folds or cold shuts. Fullers may be used in combination with edgers or rollers, or as the only impression prior to the blocker of finisher.

Edging operation is usually carried out on stock, which has been fullered. The function of the edger is to gather the metal locally, removing any sharp corners, which might give rise to fault.

Flattening is used to increase its area by decreasing its thickness. It is sometimes found necessary when material in bar form is insufficient in area to cover the required impression. This may be brought by economical requirements that a smaller sectional bar being cheaper to cut.

Benders are used to bend the stock, generally, along its longitudinal axis, in two or more planes. There are two basic designs of bender impressions, which are free-flow and trapped-stock. With a free-flow bender, usually a single bend is made. One or both ends of the forging are free to move into the bender. This type of bending may cause folds or small wrinkles on the inside of the bend. On the other hand, the trapped-stock bender usually employed for making multiple bends. In this type of bending, the stock is gripped at both ends as the blow is struck and the stock in between is bent. Because the metal is held at both ends, it is usually stretched during bending. There is a slight reduction in cross-sectional area in the bend, and the workpiece is less likely to wrinkle or fold than in a free-flow bender.

Rollers are used to round the stock and often to provide some redistribution of mass in preparation for the next impression. The stock is usually rotated during the operation.

In making fork-type forgings, frequently part of the workpiece are split, so that it conforms more closely to the subsequent blocker impression. In a splitting operation, the stock is forced outward from its longitudinal axis by action of the splitter. Generous radii should be used to prevent the formation of laps and folds.

The blocker impression immediately precedes the finisher impression and serves to refine the shape of the metal preparatory to forging to final shape in the finishing die. A blocker may be a smooth model of the finisher. Smoothing helps the metal to flow around the radii, thus, reducing the possibility of cold shuts or other defects.

In some forgeries, the impression of the blocker is made by duplicating the finisher impression in the die block and then rounding it off as required for smooth flow of metal. In this case, the volume of the metal in the blocker preform is greater than that will be needed in the finisher operation. If the blocker impression is larger at the parting line than the finisher impression, this excess metal causes the finisher impression to wear at the flash land.

In a multiple impression die, it will be necessary to position the operations. As the finishing operation requires the highest loading and the movement of material may be least, it should be located on the centerline of the ram (especially for hammer). This will minimize tipping of the ram, reduce wear on the ram guides, and help to maintain the thickness dimensions of the forging. This can be generalized as the impression requiring the greatest forging force is placed at the center of the die block. Such a die pair can be seen in Fig 2.10.

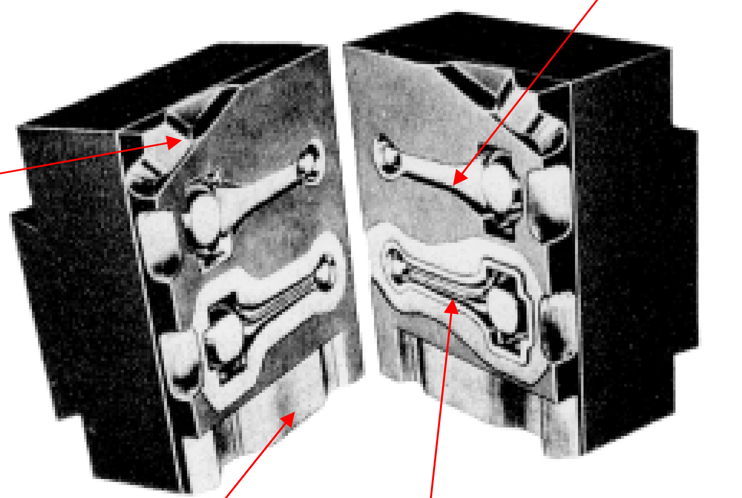


Figure 2.10 – Typical Multiple Impression Dies for Closed-die Forging [33]

2.4 Prediction of Pressure, Load and Energy in Closed-Die Forging

The prediction of forging load and pressure in closed-die forging operations is an extremely difficult and complex task. During most forging operations, metal flow, stresses and temperatures vary continuously during the process. In addition to these, forgings comprise a large number of geometrical shapes and materials.

In order to estimate the forging load, mainly three methods are being used, that are namely [1],

(a) Past experience – the estimates for each new part are based on data available from previous forging of similar part

(b) Empirical procedures – empirical formulas developed by experience applied using the flow stress of the material and estimating the shape complexity of the forging

(c) Analytical methods – a forging is viewed as being composed of several components. Forces and stresses are calculated for every component and then added together to give the total forging load and stresses. The approximate theory most widely used for analytical predictions is the "Sachs" or "Slab" method analysis.

Some methods have been suggested by Schey [34], Kurrein [35], and Neuberger and Pannasch [36] in order to estimate the maximum load of forging. For this study, while determining forging machinery, results of the finite volume analysis software will be used.

CHAPTER 3

PROPOSED METHOD FOR PREFORM DESIGN FOR BENT FORGINGS

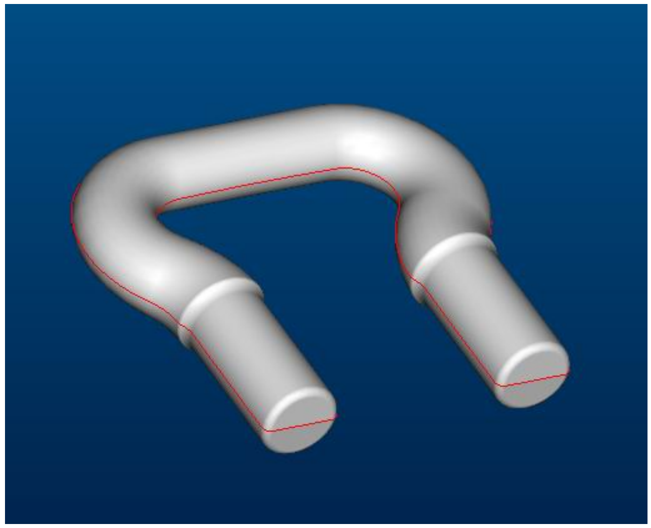
In this chapter, the proposed method for preform design, which has been used throughout the study, will be explained in detail.

If the 3-D model is not provided, forging process design starts with gathering 2-D technical drawings and/or sample parts from the customer. With the detail examination of these, the 3-D model of the desired part is produced with the usage of CAD programs. Throughout this study, Pro/E [37] is used as CAD software.

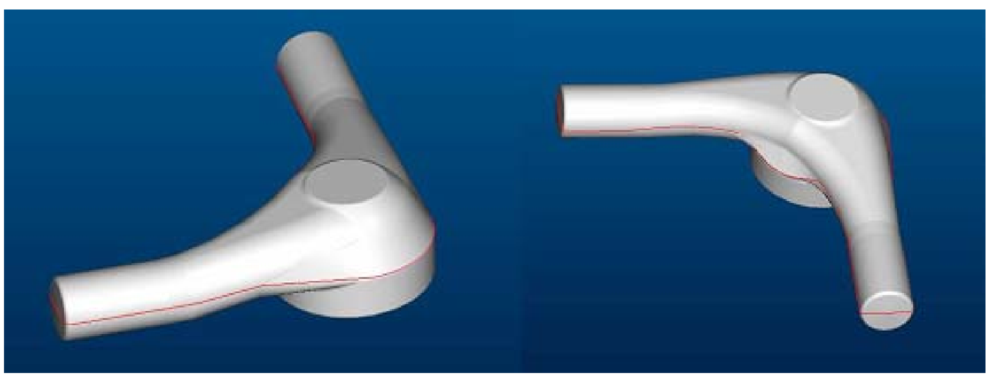
3.1 Parting Line and Surface Construction

As described in Chapter 2, the parting line construction is the first step of the forging process design. Parting plane determination has a key role for further steps, because it affects the grain flow, draft requirements, design of preforms and trimming procedure, and die costs, etc. Once the parting line is located, the depth and the position of the impressions in the upper and lower forging dies are fixed which means design of finishing dies are almost done in this step.

Illustrations of parting line can be seen in Fig. 3.1. In Fig. 3.1 (a), parting line with planar construction and in (b), non-planar (i.e. complex) parting line construction is illustrated. After the parting line is constructed, a parting surface is modeled on the 3-D model as seen in Fig 3.2. In this thesis study, forgings with non-planar parting surfaces, which require bending operation during preform stage, is dealt with.



(a) Planar Construction



(b) Non-planar Construction

Figure 3.1 – Parting Line Types

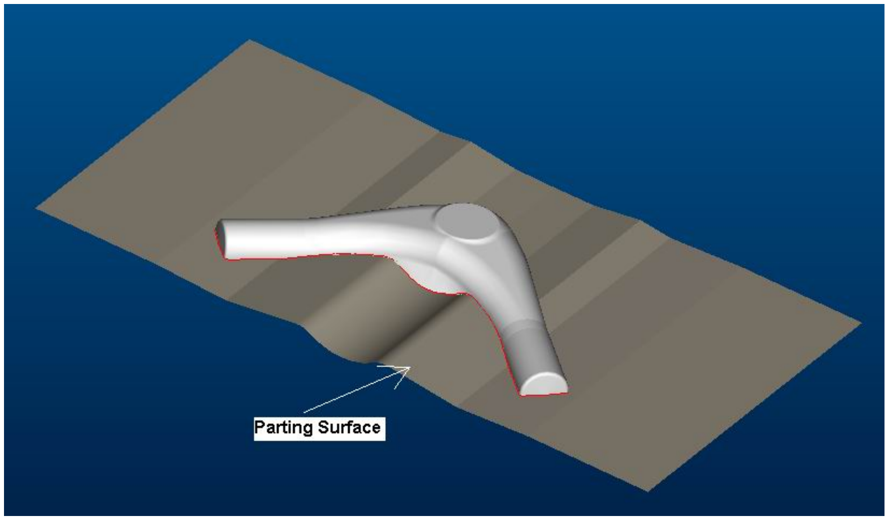


Figure 3.2 – Non-planar Parting Surface Arrangement of a Part

3.2 Estimation of the Flash Volume

Estimation of the flash dimensions and geometry is a very difficult step, because many forgings do not have a uniform flash distribution. Most of the formulae like that suggested by Neuberger and Mockel that are derived to estimate the flash geometry is applicable for simple parts; thus, estimating the thickness and width of the flash uniform throughout the part. However, as the shape complexity factor of the forging part increases, it is hard to determine the flash dimensions uniformly throughout the parts like in Fig. 3.3. There will be variations in the flash geometry through the part due to the occurrence of deep cavities, holes, bended sections, etc. In these cases, more general flash estimation methods are needed.

The recommendation of “National Association of Drop Forgings (NADF)” provides a total flash mass, which is calculated by multiplying the periphery length of the part with a constant, which is determined for different forging weight ranges as discussed in Chapter 2. Also, in a thesis study realized in METU [23], it has been verified that NADF recommendation gives a close value for press forgings with non-planar parting surfaces. Therefore, this method will be used for the estimation of the flash mass in this study.

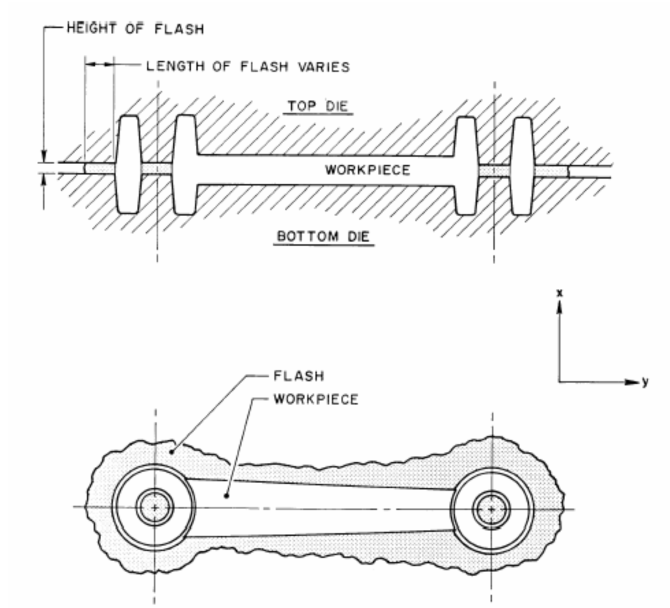


Figure 3.3 – Non-uniform Flash Distribution of a Forged Part [38]

As the flash volume is estimated, a flash geometry is modeled on the CAD model of the part at the periphery of the parting surface. This estimation can be revised in order to obtain a suitable geometry due to the current process and initial computer analysis results.

After the part geometry with the estimated flash geometry is modeled, total volume of the part (including flash) is calculated. This flash geometry and the volume will be used to determine the required billet dimension, analysis of volume distribution through the part and for the design of preform steps.

3.3 Analysis of the CAD Model

With the Pro/E software, the model properties like, volume, mass, dimensions can be observed. Besides these, section analysis, volume-distribution curve plotting and analysis, volume decomposition for die modeling can be done.

At this step, it should be taken into account that, if there is a possibility of a bending operation during preform operations, proper volume distribution should be obtained before the bending operation. This is why material cannot be transformed between regions after the bending operation.

As the CAD model with flash is modeled, volume of this part is decomposed into sections in order to investigate the changes of volume in different sections; thus, identifying the significant changes in the model. By performing this analysis, preform operations can be decided and also the required billet geometry can be obtained.

Volume-distribution curve is considered as the plot of a sequential cross-sectional areas calculated from the final forging geometry. This curve is plotted as cross-sectional area versus length of the forging. The area under this curve gives the total volume of the forging. Beside this curve, also another curve is obtained for the final forging geometry with the estimated flash geometry. The area under this type of geometry gives the volume of the required billet geometry of the forging.

These cross-sectional areas can be calculated by using the facilities of Pro/E software [39]. For planar parting surface arrangements, datum planes are placed with pattern logic through the part, automatically by Pro/E. Subsequently, with the model analysis option, cross-sectional areas at these datum planes automatically send to MS.Excel; thus, volume distribution curve can be plotted. However, for non-planar parting surface arrangements, datum planes cannot be placed in pattern logic with this program. Because of this, required datum planes are plotted manually and cross-sectional areas are calculated with X-Section Analysis option of the Pro/E (Fig 3.4) [39]. From this data, the volume distribution curve is obtained by using MS.Excel. An example for datum plane construction can be seen in Fig 3.5.

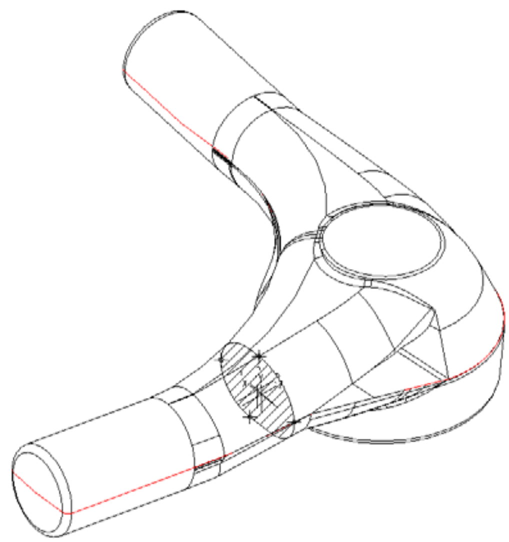


Figure 3.4 – X-Section Analysis with Pro/E

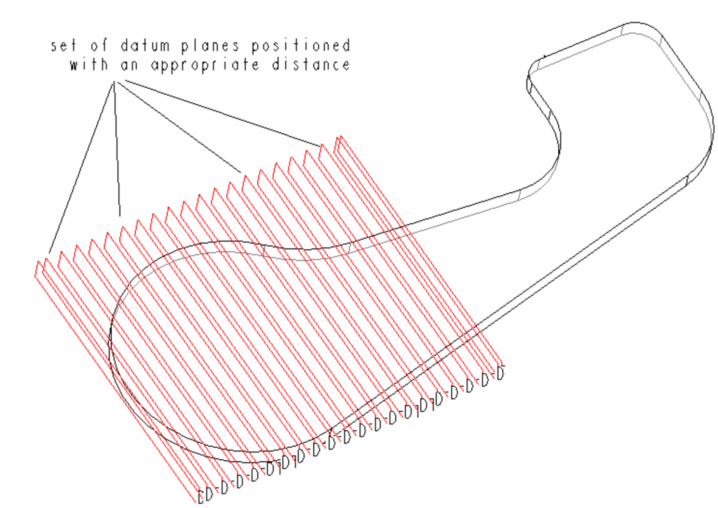


Figure 3.5 - Datum Planes Constructed on an Example Wireframe Model [22]

After the volume distribution curve is plotted on the CAD model, and the cross-sectional areas are examined for rapid changes. These points will be referred as cross-section boundaries, which will be used to decompose the part into main sections. These sections are then used to identify the metal flow directions; thus, required preforming operations.

3.4 Decision of Billet Geometry and Dimensions

Decision of the billet geometry is the next step after plotting the volume distribution curve of a part. Main criterion for the determination of the billet geometry is the final geometry of the part. Therefore, the decision for the right billet depends on the experienced-based knowledge of the designer. Another restriction for the decision of the right billet geometry is the commercially existence of the raw materials. In general, these raw materials are found in round or square cross-sections. In Turkey, round cross-sections can be found in the range of 15 to 125 mm in diameter with a step of 2 mm.; and square cross-sections can be found in the range of 50 to 120 mm with a step of 5mm. as standard [5].

For the decision of the billet geometry, the volume distribution curve is used. By considering each cross-section, the required billet dimension is calculated. For round billets, required billet diameter (D) is calculated as follows:

$$D = \sqrt{\frac{4 \cdot A_c}{\pi}} \qquad (3.1)$$

where, A_c is the mean cross-sectional area of the part (with or without flash).

For square billets, side length (S) is calculated as follows,

$$S = \sqrt{A_c} \qquad (3.2)$$

After the calculation of the billet's cross-section dimension, length of the billet can be calculated from,

$$L_b = \frac{V}{A_c} \tag{3.3}$$

where, L_b corresponds to length of the billet, and V corresponds to total volume of the part (with or without flash).

3.5 Preform Design and Modeling

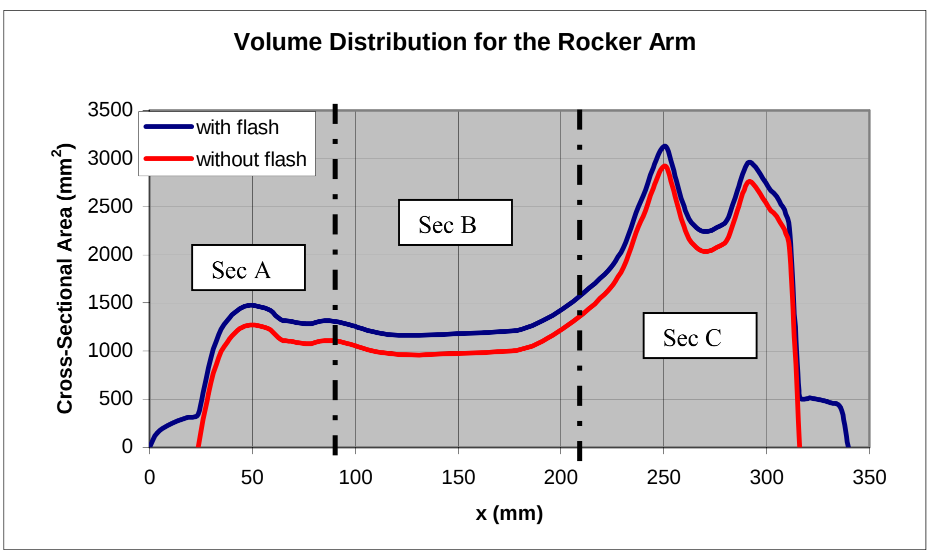
The achievement of a high quality product by metalworking involves choice of the optimal form of the tool, of the workpiece and of the process parameters. In order to achieve this product, the designer should determine the number of preform steps.

Main parameter of the preform design sequence is the shape complexity (factor) of the final part. For simpler parts, there may be no need to design a preform step, because the billet material is directly forged to obtain the final part. However, as the complexity of the part increases, one or more preform steps are needed to forge the part to the final shape. Designer should determine which type(s) of the performing steps would be used. Types of performing steps are discussed in Chapter 2.

Before the designer determines the types of preforming steps that is to be used, the forging machinery should be determined. At this step, important considerations are the press or hammer's forging capacity and its working envelope. For each preform step, the required forging load should be calculated. After this calculation, the required forging machinery is selected. In some cases, the designer tries to perform all forming operations in a single machine with a capacity, which is sufficient for each process. Here, the working envelope becomes important.

Another parameter is the economical considerations. The total cost of forging sequence includes the cost of material, forging equipment, setup, tooling, labor, overhead and administration costs [25]. Some of these costs are directly related with the time of the process; therefore, related with the number of preform steps. For this reason, optimum number of preform steps and billet geometry should be considered. In this thesis study, computer-aided design methodology has been used.


(a)



(b)

Figure 3.6 – (a) CAD model of a Part; (b) Volume Distribution Curves for the Part [23]

As the volumes of these sections are calculated, required preform geometry is modeled. This can be done by two different methods.

In the first method, the datum curves are plotted on the CAD model at the datum planes according to the volume distribution curve. These curves are then exported to another Pro/E file. This step is done for all datum planes. As all of the curves are exported, a proposed preform cross-section is drawn with simpler dimensions with regard to the considered preform design. It should be noted that, if this method is performed for the preform operation just before the finishing operation, almost all of the volume should be remain inside the impressions; thus, no or very little amount of flash occurs. Additionally, all of the radii of this type of preform are recommended to be larger than the radii of the forged part [1].

There is also a need for examining the variations in the longitudinal cross-section geometries in addition to the lateral cross-section geometries. Consideration of lateral cross-sections is not sufficient for preform design alone, because, distribution of the volume along the longitudinal and lateral directions may require different considerations. Preforming sequence design should compromise for the requirements of these two. It should be decided whether the material would be distributed in the lateral direction as first and longitudinal direction as second or vice versa.

In the second method, the preform geometry is modeled just like modeling of the final geometry. As the critical geometries like length of each divided section and their volumes are obtained from the volume distribution curve, model of each section can be done between its cross-section boundaries. Also, as the cross-sectional areas are known at these boundaries, transaction between these regions can be done. This method is more applicable for fullering and edging type preforming operations and it has been used in this study.

In order to obtain the optimum solution for the preforming stages, several trial analyses should be performed.

After the preform models are done, they are used to obtain the die impressions. Pro/E - Mold Cavity module [40] is used to obtain 3-D models of the split dies. At this module, model of the part is implemented and then required die block is modeled. Then, the parting surface that is previously determined and constructed is selected. CAD software automatically splits the die block into two parts as upper and lower die with their impressions on them. An illustration of this method can be seen in Fig.'s 3.7 and 3.8. However, for some complex shapes, this cannot be done by this method. In that case, die blocks and their impressions are separately modeled by using the exporting the surfaces of the part just like the curves exported for the volume distribution analysis. These exported surfaces are then merged and die blocks are obtained.

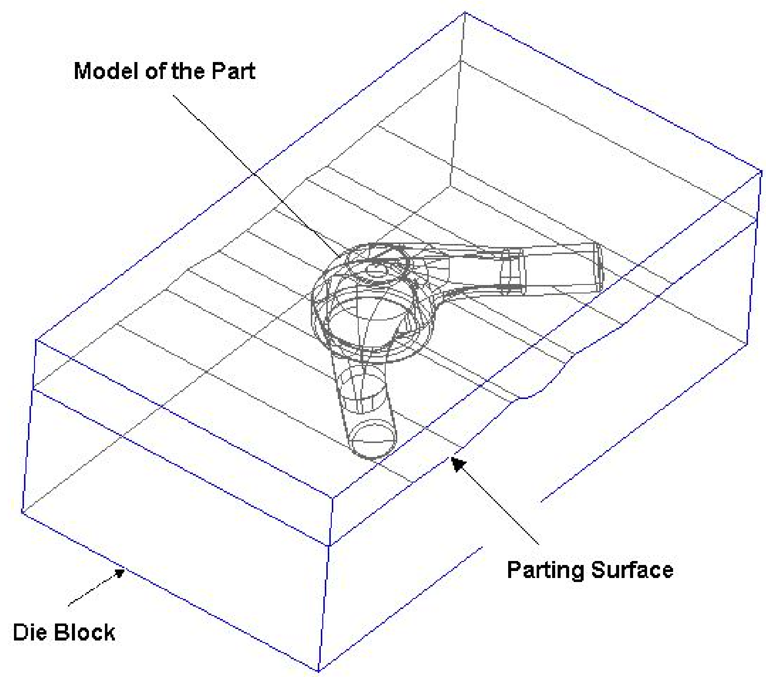


Figure 3.7 – Parting Surface and Die Block Arrangement of a Sample Part

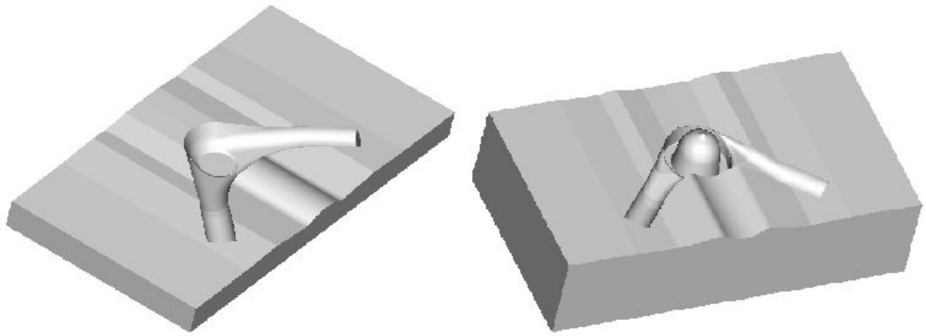


Figure 3.8 –Upper and Lower Dies of a Sample Part

3.6 Analysis of Designs using Finite Volume Method

As the design of preforming sequence and their impressions, is a complex and long task, the simulation packages have been used in the industries worldwide. Forging simulation offers significant cost and time advantages by providing detailed insight into the forging process before tool selection and process decisions are made on the shop floor. Process data such as material flow; stresses and strains are readily accessible to a user at any point throughout the simulation process, as well as at any location within the forged part. Potential defects such as laps and under-fill of die cavities can be easily identified and corrected before part production begins. In this study, MSC.Superforge is used as the analysis and simulation package.

MSC.SuperForge [41] is a software package for the computer simulation of the industrial forging processes. It combines a robust finite volume solver with an easy-to-use graphical interface specifically designed for the simulation of 3-D bulk forming operations. MSC.SuperForge is being effectively utilized by forging companies and suppliers worldwide to successfully simulate the forging of a variety of practical industrial parts.

In the software, the advantages of the finite element and the finite volume approach are combined; it employs a finite volume mesh for tracking material deformation and an automatically refined facet surface to accurately track the free surface of the deforming material. This approach is both fast and accurate since flow calculations are performed on a fixed finite volume mesh and material simply flows through it. It is also robust since re-meshing techniques are completely eliminated [13]. This provides a unique advantage in the simulation of three-dimensional parts; where finite element based solutions typically break down.

MSC.Superforge [41] allows user to simulate forging process in an easy to use Windows environment. Both single-stage and multi-stage forging simulations can be performed. For a forging process, software includes the following steps:

– Importing Models: Models for upper die, lower die and billet geometry should be imported to the program in STL (stereolithography) format. In this format, the surface models consist of triangular shaped facets only. It should be noted that MSC.Superforge requires a closed-volume surface model for both workpiece and dies.

– Positioning of models: After import of the models for dies and workpiece, the position of them with respect to each other may not be correct according to the alignment of the die pairs. These models are firstly aligned with using “Moving Option Toolbar”. Once the objects are aligned along the vertical axis, user can drop the workpiece in place and position the dies against the workpiece by using “Positioning” option. During the positioning, dies will only translate until they are in contact with another object. The workpiece however will be first translated until it contacts another object, followed by a free ‘settling’ period under gravity.

– Giving material definitions: Since dies are considered to be rigid (undeformable) bodies in this study, a material model only needs to be defined for the workpiece. MSC.Superforge provides elastic-plastic material models. There are forging specific material models available for either cold forging or hot forging operations in the library of the software.

- Forging Equipment: Software can represent six different types of forging machines; these are Crank press, Multi-blow Hammer, Screw Press, Hydraulic Press, Mechanical Press with Scotch Yoke drive and an alternate press defined by a table of time vs. speed. As the machinery type is selected, the required data is entered and this definition is assigned to the upper die.
- Process Parameters: Parameters like heat transfer coefficient between workpiece and dies, ambient temperature, initial temperatures of both dies and workpiece are defined.
- Friction model: Because, two bodies that are in contact have rough surfaces and are forced to move tangentially with respect to one another, frictional shear stresses will develop at the interface. Therefore, a friction model should be applied to both of the dies. MSC.Superforge provides three alternative models for friction, which are coulomb and plastic, shear friction, or combined coulomb-plastic shear friction.
- Assigning simulation type and parameters: In this step, stroke of the operation, size of the finite volume workpiece and die element sizes, output step size (as percentage of the process time or in defined stroke step sizes), problem type (closed-die, open die, bending, forward extrusion, backward extrusion, rolling and also hot or cold forging) is defined. Also, a solver optimizer is implemented in this simulation control unit; thus, user can change finite volume element size at any time and also coarsen the workpiece to decrease the number of elements.

After all of these steps have been performed, the simulation can be successfully started. At this step, the software performs a model check in order to control whether all of the simulation parameters defined correctly or not. After completing the model check, simulation starts and during simulation user can monitor the simulation progress from the simulation bar. Sample view of a completed simulation process can be seen in Fig 3.9.

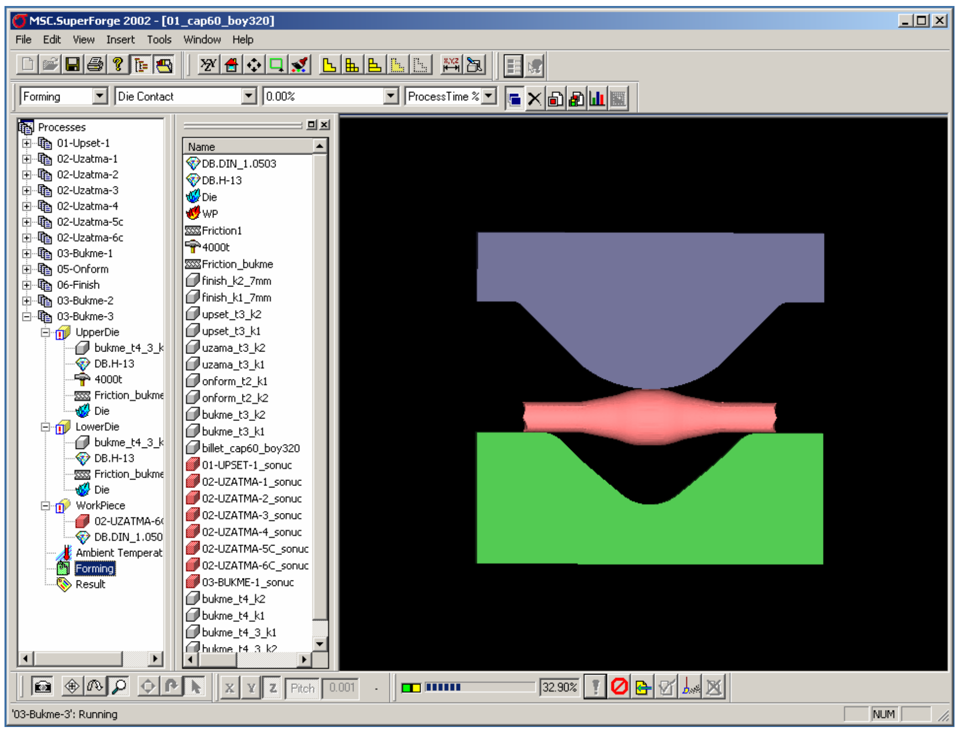


Figure 3.9 – Sample View of a Simulation Performed in MSC.Superforge

3.7 Iteration and Verification of the Preform Geometry

A preform can be designed in many ways; however, in order to find the acceptable solution, different preform designs should be performed and analyzed on computer.

In many companies, a design is considered as successful if the finisher dies are filled with an acceptable amount of flash. However, how the metal flow during the process is also important as the filling of the finisher dies. Some of the problems that can be encountered during the simulation of the designs can be listed as:

- Extreme flash regions,
- Unfilling of the dies,
- Laps and folds, wrinkles
- Non-uniform material flow (with particle tracking),
- Early formation of flash (before finishing operation).

As, to obtain the acceptable solution lots of simulation would be performed; each simulation will be analyzed by the usage of Result Toolbar of MSC.Superforge [41]. This software is capable of investigating Die Contact (is one where there is contact between workpiece and die and zero otherwise), X-Force (the x-component of the force on the grid point), Y-Force (y-component), Z-force (z-component), X-Velocity, Y-velocity, Z-velocity, Element Density (the density of the workpiece material), Pressure, X, Y, Z-Stress (the XX-, YY-, ZZ-Stress, etc.), Effective plastic strain, Effective stress, Temperature, Yield stress, Contact pressure, Velocity vector, Stress vector, Normal distance to the die (the smallest distance from the workpiece grid point to the die. When distances are becoming too large the result is plotted as gray.). Also geometrical analysis like distances between nodes, calculation of volume can be performed in MSC.Superforge by using measuring option.

If one of the problems mentioned previously is encountered through these analyses, the preform design is changed with a new or modified design and simulation of this new design is performed. The geometry of the billet and the die impressions should be iteratively modified to reach satisfactory results. This procedure continues until a satisfactory and more economical result is obtained.

After the satisfactory result has been obtained, verification of this design is done by real-life testing on a forging press.

Before real-life testing, the dies are produced. For this step, Pro/E NC-Mill [42] option is used. In this module, the required machining codes are prepared for the manufacturing of dies. If EDM sinking operation is necessary for dies, the machining codes of electrodes are also prepared in this module.

After productions of all die blocks have been completed, they are mounted on the appropriate forging press and their facial clearances are aligned. To extend die life by decreasing thermal fatigue, the dies are heated up on the press. For the control of the die temperature, optical pyrometer is used. The billets are prepared by cutting to the required length by cropping.

After the heating up period of the dies has finished, lubrication is applied to the impression surfaces to decrease the die wear. Billets are put into the induction furnace for heating. As the billets exits from the furnace, the forging process starts with the first pair of dies. The forging shape obtained in each step is compared with the analysis results. After the flash around the forgings are trimmed, the flash geometry and the final part geometry are also compared with the design values.

CHAPTER 4

MODELING AND COMPUTER SIMULATION OF FORGING OF CHAIN BRACKET

This chapter includes a case study, that is, analysis of a complete forging process, which is currently being performed in AKSAN Forging Company [5]. The particular part shown in Fig. 4.1, which is called as “Chain bracket (shackles)” is a bent forging with a planar parting surface. It is used as lifting accessory in the industry as seen in Fig 4.2. This part has a standard as DIN 745 and this standard consists of 9 different models. Detail of DIN 745 is given in Appendix A. In this section, DIN 745 – 63 has been considered as a reference model.

Figure 4.1 – Chain Bracket (DIN 745 – 63)

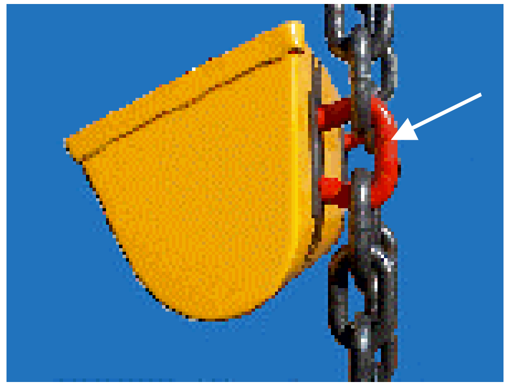


Figure 4.2 – An Industrial Application of Chain Bracket [43]

4.1 Current Practice in the Company

AKSAN has been producing the Chain bracket (DIN 745 - 63) since many years. The production performed in AKSAN has been observed.

Table 4.1 – Operation Sheet for Chain Bracket (DIN 745 - 63) [5]

Op #	Operation	Equipment
1	Crop the bar to length of: 260-265 mm if stock diameter is 20 mm 240-245 mm if stock diameter is 22 mm	Cropping Tool
2	Heat the stock up to 1050 – 1200 ^{o}C	100 KW Induction Heater
3	Check the temperature with optical pyrometer	Optical Pyrometer
4	Bend the bar to V-shape	200 tonf Mech. Press
5	Hammer the legs of the preform to form a U-shape	Manual forging by the operator
6	Heading of the U-shaped preform	200 tonf Mech. Press
7	Place the preform on the finisher die and forge the final shape	5000 kgm Hammer
8	Place the forged product on the cut-off dies and trim the flash	100 tonf Mech. Press

The Chain bracket (DIN 745 - 63) has an average mass of 636 g. with flash and a net mass of 600 g. after trimming. It means that 6% of the forging mass occurs as the flash. The particular part has a bent geometry with continuously changing cross-section geometry. Geometrical details of this part are given in Appendix A, and the operation sheet of this forging process is given in Table 4.1 [5].

Before starting the forging process, the billets are prepared in the length of 260^{+5} mm with diameter of 20 mm or the length of 240^{+5} mm with the diameter of 22 mm. Material of the billet is C45 steel, which is equivalent to DIN 1.0503. The properties of DIN 1.0503 are given in Appendix B [44]. These prepared billets are fed into the 100 kW induction heater. Before starting to forging process, the dies are heated to 200 – 250^{o}C in order to prevent die failure due to thermal stress.

(a) (b)

Figure 4.3 – (a) “5000 kgm” Drop Hammer; (b) “200 tonf” Mechanical Press

The particular part is forged in three forging steps. For first two preform operations the “200 tonf” mechanical press; for the finishing operation the “5000 kgm” Drop Hammer are used (Fig 4.3). Die sets of the forging operations can be seen in Fig. 4.4. After the dies are pre-heated, the first operation, which is bending the part to an approximate V-shape, starts (Fig. 4.5(a)). The preform is then placed into 2nd preform dies for squeezing the part (Fig. 4.5(b) and Fig. 4.5(c)). However, for this operation, the part is hammered manually by the operator in order to obtain a U-shaped part. This action causes time loss; thus, excess cooling of the part. Die sets of both of two processes are placed on a single block and these operations are performed at 200 tonf mechanical press.

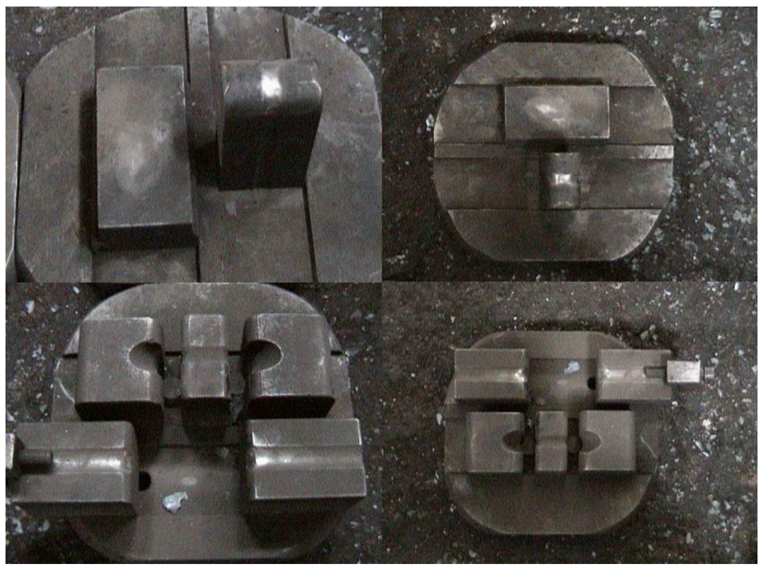


Figure 4.4 – Die Sets of 1st and 2nd Preform Operations

(a) (b) (c)

Figure 4.5 – (a) Part before 1st Preform; (b) Part after 1st Preform; (c) Part after 2nd Preform

After the 2^{nd} preform operation finishes, the part placed in finishing dies. This process is operator-dependent action because operator decides the number of blows performed by the hammer. Operator examines each forged part by eye and decides whether another blow is needed for complete fill or not. Throughout the production, that was observed, 2 – 3 blows are applied at this stage. Die set and a forged part at this stage can be seen in Fig. 4.6. Parts with flash after finishing operation for two alternative stocks is shown in Fig 4.7.

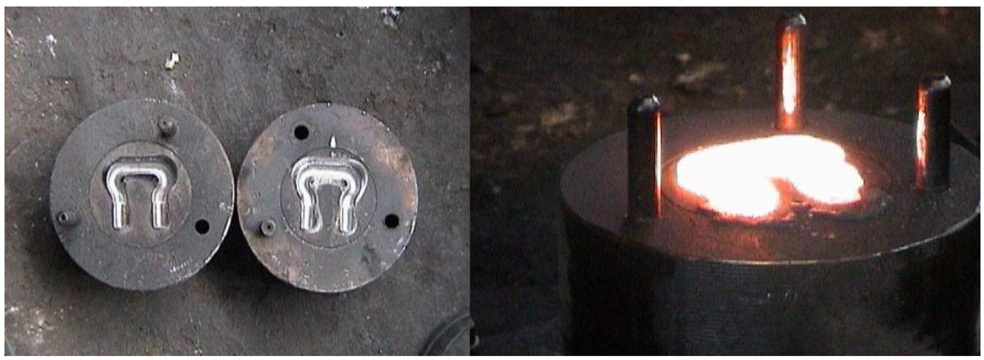


Figure 4.6 – Die Set of Finishing Operation and a Sample Part at Finishing Stage

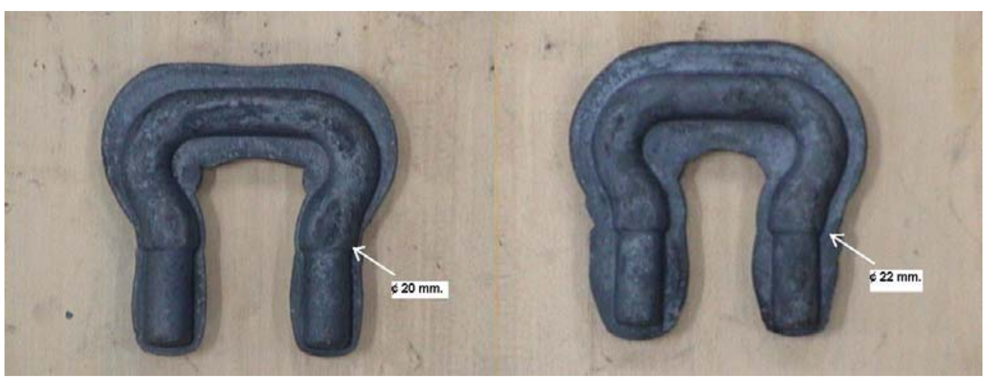


Figure 4.7 – Parts with Flash After Finishing Operation (for 20 and 22 mm diameter of billet)

The observation of the process steps in AKSAN brings out that the placement of the preform into the finisher die plays an important role for the flash formation. Meanwhile, because of the rapid bending of the part, sometimes flow-through defects have been observed at the intersection of legs with the head of the part.

4.2 Analysis of the Current Practice

Due to the problems explained in the previous section, a new preform sequence (See Fig. 4.8) has been proposed for the forging of the particular part. The proposed preform sequence consists of three bending operations. First and third operations serve the same functions of the bending operations of the current practice of the company. Instead of the manual operation of the operator, a new forging operation has been proposed to bend the both legs to the desired U-shape.

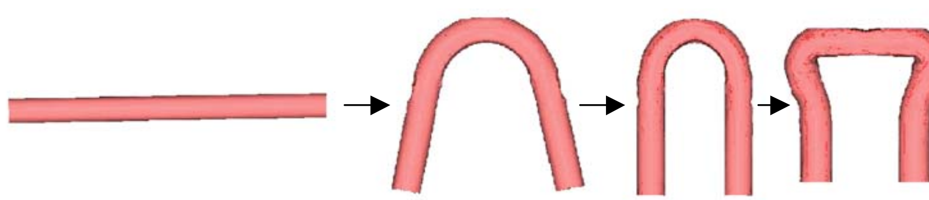
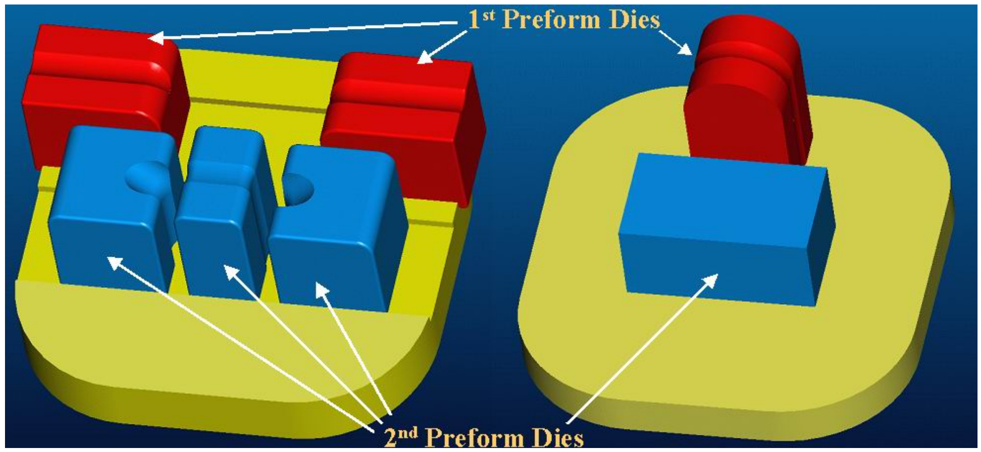


Figure 4.8 – Proposed Preform Geometries

The CAD models of 1st and 3rd preform operation die set (See Fig. 4.9), the finishing die set and the billet geometry that is being used in the current practice have been modeled according to the technical drawings provided by AKSAN [5]. MSC.Superforge treats the die models as rigid bodies; thus, the external geometries of the die sets did not modeled exactly as the real ones.

However, the die cavities were modeled with the correct geometries and the dimensions.



Lower Die Upper Die

Figure 4.9 – CAD Models of 1st and 3rd Preform Operations Die Set

After the models have been created, the steps that have been explained in Section 3.6 performed. Initially, the temperature on the billet surface is taken as 1200°C for the 1st preform operation. Also, each die is assumed to pre-heated to 200°C. At the simulation set-up, billet is positioned by the positioner option of the software [41]. Simulation set-up of 1st preform operation can be seen in Fig 4.10.

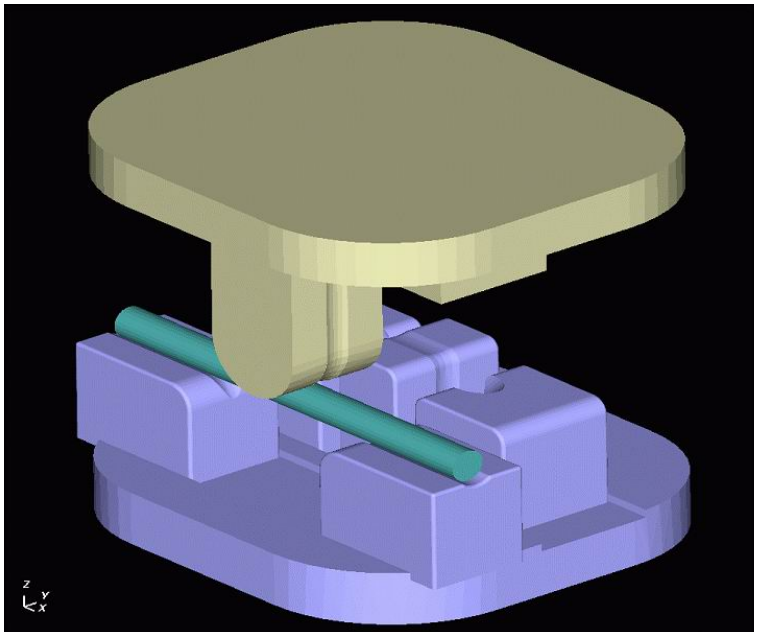


Figure 4.10 – Simulation Set-up of 1st Preform Operation

The friction always plays a particularly important role in metalworking processes. The properties of interface friction are very complex; for such friction is not only constant during the forming process but it is also a function of the working parameters such as strain, strain rate and temperature [45]. However, in MSC.Superforge [41] just one friction type can be applied to each die and this will be constant for all surfaces of the dies. For bending operations of steel, it is suggested that friction model is considered as plastic shear friction and with a value of 0.2 [41]. Therefore, this suggestion is applied for the simulations.

After the first bending operation, the preform is placed into the second bending operation dies. Lower die has the punch of the first preform die. Role of this punch is to position the part properly and give the correct inside leg clearance to the part. Upper die blocks have round profiles inside, which will guide the part when going downwards. At the end of this step, the forged part will take the geometry of the punch. This operation serves an intermediate role between the two preform operations, i.e. V-bending and heading of the U-shaped preform. Simulation set-up of this process could be seen in Fig. 4.11.

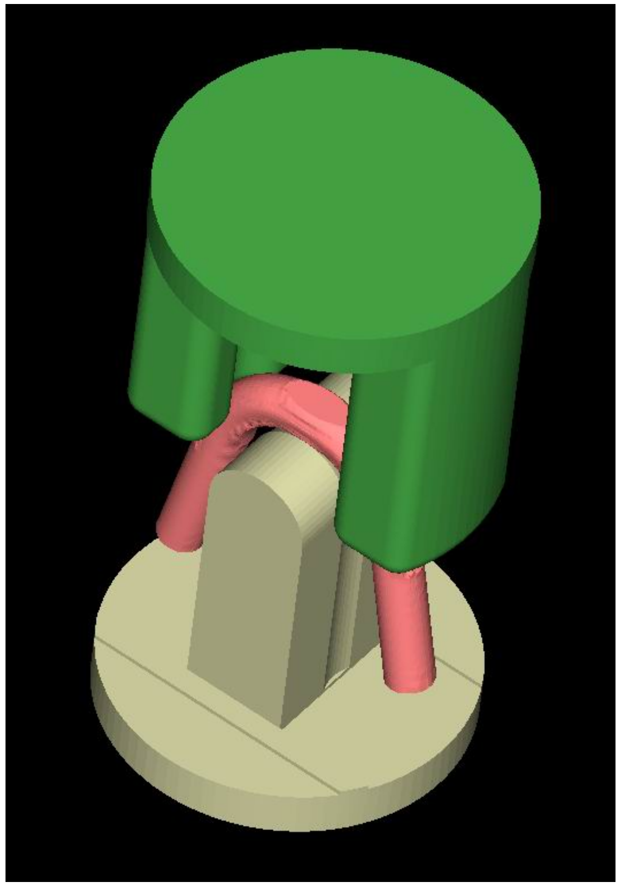
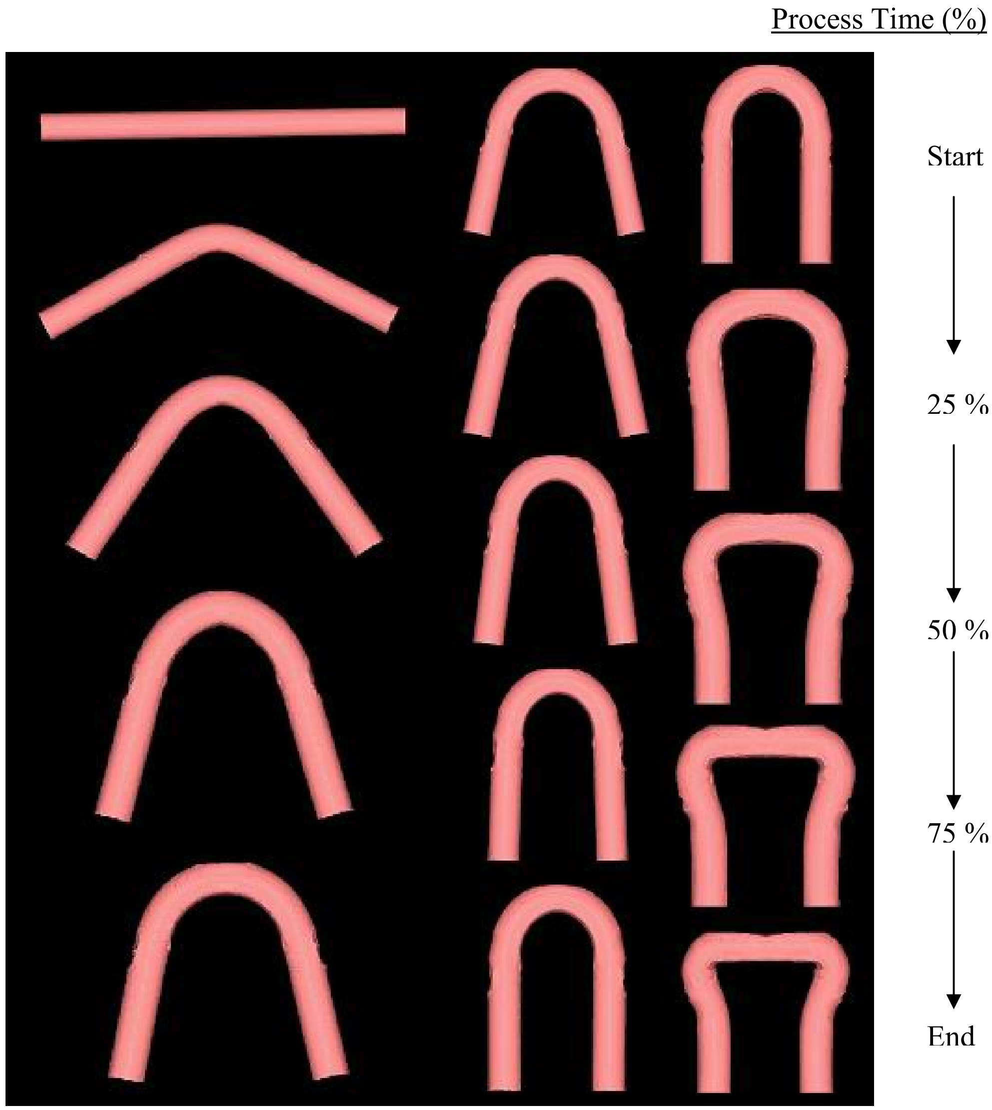


Figure 4.11 – Simulation Set-up of the Proposed Bending Operation

At the third preforming operation, the U-shaped part found in the second stage is forged to approximate geometry of the final shape. Part is squeezed from top with flat, rectangular upper die. At this time, both of the legs take the desired shape of the lower die.



1st Preform Proposed Operation 2nd Preform

Figure 4.12 – Simulation Results of Preforming Operations

The simulation results of preforming operations with a step of 25 % of the process time can be seen in Fig 4.12. After the preform operations have been completed, the part is placed into the finisher dies. The finisher dies designed for 2 mm of flash thickness. In simulation, the stroke is adjusted for this amount of flash thickness. For material DIN 1.0503, the combined coulomb-plastic shear friction is suggested with values 0.3 for static friction and 0.05 for interface friction factor [22, 23]. Simulation of the finisher stage was performed for 3 blows as observed in AKSAN. The Die-part contact analysis result after the three successful blows is given in Fig 4.12. Dimensions identified in Fig 4.13 are compared for both sample parts and simulation result. In Table 4.2, results of this comparison are given.

Table 4.2 – Average Dimensions of the Final Flash Width for the Sample Parts and the Simulation Results

	A	**B**	**C**	**D**	**E**	**F**
Simulation	7.8	8	9.3	6.2	6.6	10.3
Sample	8.8	6.8	8.6	2	3.9	9.2

Due to the comparison, same deviations occur especially for the dimensions D and E. These deviations may be resulted from the initial billet length and also due to the placement of the billets in the dies. However, for other dimensions like A, C and F, results of measures are almost same. During the simulations, the preform geometries were placed exactly to the desired position; thus, this may lead some changes in the flash formation with respect to the current process in AKSAN. Another point is that in the current practice of the company, the length of the billet varies between 260 to 265 mm; thus, the volume of the billet changes for each billet. However, the simulations have been performed with a billet length of 265 mm.

With this modeling and computer simulation practice, forging processes, especially the bending operation, and its simulation parameters have been examined. Comparison of the real life experimentation and the computer simulations has been performed.

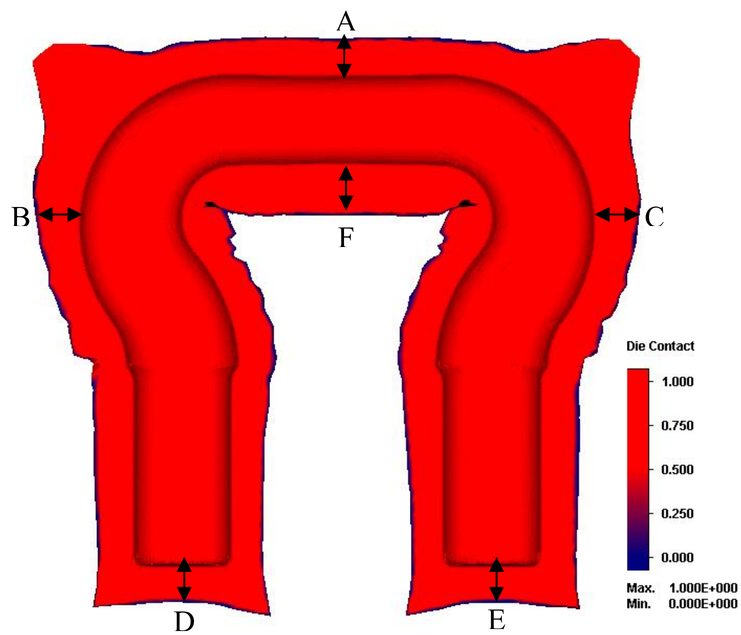


Figure 4.13 – Die Contact Computer Analysis After 3 Blows of the Finishing Dies

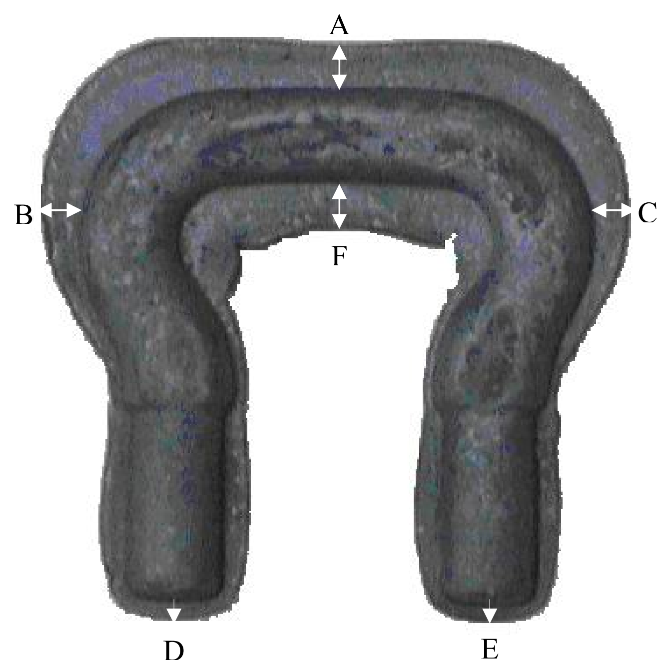


Figure 4.14 – Flash Formation after the Finishing Stage for the Current Process

CHAPTER 5

MODELING, COMPUTER SIMULATION AND REAL-LIFE EXPERIMENTATION OF FORGING OF STEERING JOINT

In this chapter, computer simulation and real-life experimentation for forging of the Ball Joint of the Heavy Vehicle Steering System will be presented. Aim of this case study is to analyze the current forging process and design new preform operations to forge the part with less amount of flash formation with the reduced number of preform steps according to the procedure given in Chapter 3. This design will then be verified by real life experimentation.

5.1 Geometry of the Forged Part

The particular part is a bent forging with a non-planar parting surface as shown in Fig 5.1. It is used in steering systems of the heavy vehicles and is currently produced by AKSAN Steel Forging Company. The company specifies the part as "Ball Joint of the Heavy Vehicle Steering System" [5]. In following section this part will be named as "Ball Joint".

The "Ball Joint" has an average mass of 6050 g. after trimming operation. Part has a bent geometry with two circular cross-sectioned arms that are 90^{o} apart from each other; both arms with a diameter of 41 mm. are blended to a somehow semi-spherical body at the middle. This body has a pierced blind hole at the center with a diameter of 73.7 mm and a depth of 65 mm. The technical drawing of the "Ball Joint" is given in Appendix C. The part has a very complex parting surface orientation. The parting surface at the front of the part is different from the backside. An illustration of the parting surface of the part can be seen in Fig 5.2. The red lines and surfaces in the figure indicate the parting surfaces. A batch of 500 parts has been observed at the company observed at the company.

Figure 5.1 – "Ball Joint"

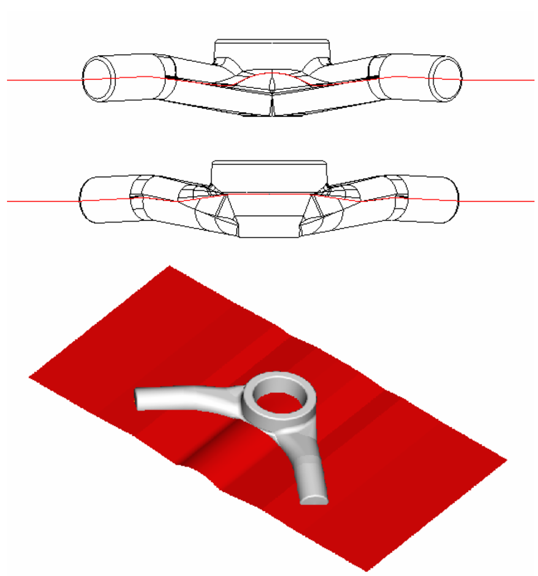


Figure 5.2 – Parting Surface Orientation of "Ball Joint"

5.2 Current Practice in the Company

In current practice, a 4000 tonf forging press line is used for forging of the particular part (See Fig 5.3). Press line consists of a mechanical press, which is labeled as “400 tonf mechanical press”, a trimming press (labeled as “500 tonf mechanical press”), and a 970 kW Induction furnace (See Fig 5.4). The operation sheet for the part is given in Table 5.1 [5].

Figure 5.3 – “4000 tonf” Press Line at AKSAN

Figure 5.4 – “970 kW” Induction Furnace of “4000 tonf” Press Line

Table 5.1 – Operation Sheet of "Ball Joint" [5]

Op #	Operation	Equipment
1	Crop the bar to length of 220-221 mm with stock diameter is 75 mm	Sawing Machine
2	Heat the stock up to 1050 – 1200 ^{o}C	970 KW Induction Heater
3	Check the temperature with optical pyrometer	Optical Pyrometer
4	Upset the stock to clean scale	4000 tonf Mech. Press
5	Place the stock to the fuller die and lengthen the stock	4000 tonf Mech. Press
6	Rotate 90^{o} and place the stock to the fuller die and lengthen the stock (this operation performed 9 times)	4000 tonf Mech. Press
7	Place the stock to the 2nd fuller die and lengthen the stock	4000 tonf Mech. Press
8	Rotate 90^{o} and place the stock to the fuller die and lengthen the stock (this operation performed 6 times)	4000 tonf Mech. Press
9	Place the stock on the bender die and bend the stock	4000 tonf Mech. Press
10	Place the stock on the blocker and preform the stock	4000 tonf Mech. Press
11	Place the preform on the finisher die and forge the final shape	4000 tonf Mech. Press
12	Place the finished part on the trimmer and trim the flash	500 tonf Mech. Press

The billets are cut in length of 220^{+1} mm with the diameter of 75 mm. After the billets are prepared, they are fed into the 970 kW induction furnace to heat them to about 1200 ^{o}C. The forging process is performed in seven different die sets, sequencially, upsetting, fullering whole stock, fullering the ends, bending, blocking, finishing and trimming die sets, as shown in Figures 5.5 – 5.11.

Before starting the process, the dies are preheated to 200 – 250 ^{o}C. The dies for the first upsetting stage have simply flat surfaces with rectangular blocks. In this stage, the stock is shortened by about 20 mm.; (i.e. to length (L) of

200 mm.) while increasing the diameter (D) to 76 mm. The part after this stage can be seen in Fig 5.5.

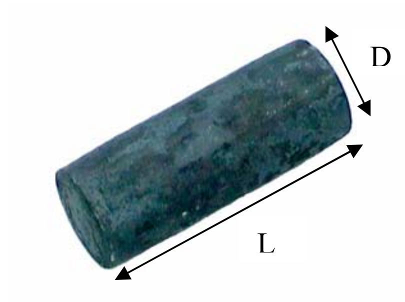


Figure 5.5 – Preform after Upsetting

In the second stage, the stock is placed in the first fullering dies. The part is elongated to 255^{+1} with an average cross-section of 61x68 mm as seen in Fig. 5.6. In order to achieve this goemetry, generally nine blows of the press are performed. At each blow, the stock is rotated about 90^o for more uniform deformation.

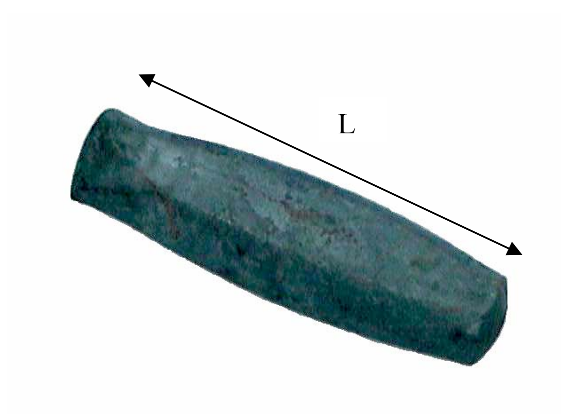


Figure 5.6 – Preform after 1st Fullering Operation

After the first fullering operation, the stock is placed in the second fullering dies. Generally six blows are performed at this stage. With this operation, the preform shape with an average cross-section of 40 x 45 mm at both ends and 81x63 mm at the middle is obtained. Length (L) of the part becomes approx. 390 mm (See Fig. 5.7).

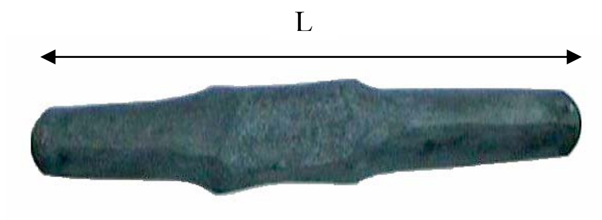


Figure 5.7 – Preform after 2nd Fullering Operation

With these first three stages, the desired material distribution must be obtained, since the material cannot be redistributed between the bent sections after the bending operation. However, the success of these three stages depends on the skill of the operator. As this material distribution is obtained, the part is placed into the bending dies. The bent forging can be seen in Fig 5.8.

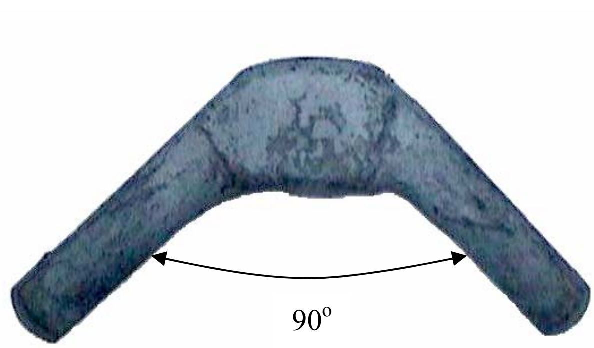


Figure 5.8 – Preform after Bending Operation

The preform stage (i.e. blocker stage) is performed by using the dies, which has the modified geometry of the finisher die cavity. AKSAN generally increases the facial clearance; the cavities are smoothened and larger radii are given to the impressions of the blocker dies [5] This approach may lead to early flash formations in blocker stages and early die wear. For "Ball Joint" the blocker stage is performed with a facial clearance of 14 mm. The preform after this stage can be seen in Fig 5.9.

Figure 5.9 – Preform after Blocking Operation

Figure 5.10 – Part after Finishing Operation

The finished part with flash can be seen in Fig 5.10. In finishing stage the flash thickness is 7 mm. Due to early flash formation at the blocker stage, the flash land in the finisher die is subjected to excessive pressures; therefore, rapid wear is observed in those sections of the dies. This fact leads to revision of the dies after each batch. For “Ball Joint”, number of part that is produced in each batch is considered as 500.

It is observed that an excessive material has been used to fill the finisher dies. As seen in Table 5.2, an average flash of 1720 g. is formed at the final stage.

Table 5.2 – Production Data of “Ball Joint”

Stock Size	**Part Mass (kg)**	**Flash Mass (kg)**	**Flash Mass with respect to Part Mass**
Ø75 mm, 220^{+1} mm in length	6.05	1.72	28.4 %

Figure 5.11 – Two Different Flash Formation Occur at Finishing Operation

Forging of “Ball Joint” requires an average of 20 blows. It is also observed that the placements of the billets in the dies at these stages influence the material flow which may lead to improper formation of the flash and, in some cases imcomplete die filling at the finisher stage may be encountered. Improper placement of the part at the intermediate stages may also lead to to improper distribution of the metal for the finisher dies. Two different flash formation due to the different placement of the part are shown in Fig 5.11.

Thus, with appropriate preform design, the amount of flash formation, forging process time and forging cost are expected to be decreased.

5.3 Proposed Preform Design

In this section, the preform design procedure of “Ball Joint” will be explained according to the method proposed in Chapter 3.

The 3-D model of the part is created by using Pro/E., considering the technical drawing of the part. Location of the parting surface, draft, contraction and machining allowances are considered with regard to the details explained in Chapter 2. A view of the created model of the forging can be seen in Fig. 5.12.

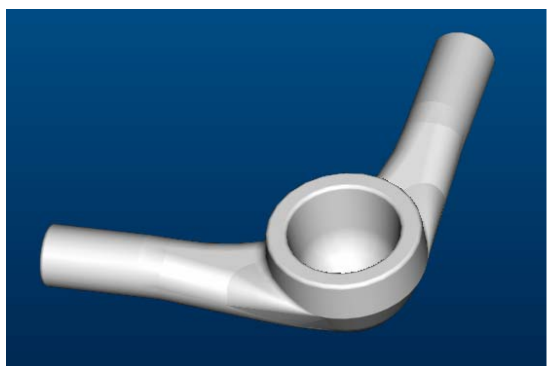


Figure 5.12 – Solid Model of “Ball Joint” Created by using Pro/E

The location of the parting suface is determined according to the geometrical limitations. As seen in Fig 5.2, the part has a very complex shape with bent arms extending away from a semi-sphere body with a blind hole at the center. Blending of these arms to the body differs at the front and the back; thus, parting surfaces at the front and at the back are different. Because of this difference, the front and back parting surfaces must be modeled separately and then both surfaces are merged to form a single parting surface which will be used for separating die pairs.

As one of the main aim of this study is to reduce the amount of flash, it is important to estimate the geometry of the flash. However, for complex forgings or hard-to-forge parts, it is difficult to estimate the flash geometry since the flash will not be formed uniformly throughout the perimeter of the part. Several methods have been mentioned in Chapter 2 for the flash geometry estimation. However, most of the methods are not applicable to this particular part due to its complexity. The recommendation of NADF given in Table 2.3, which is more applicable to non-uniform flash formation cases, is used to calculate the total flash mass.

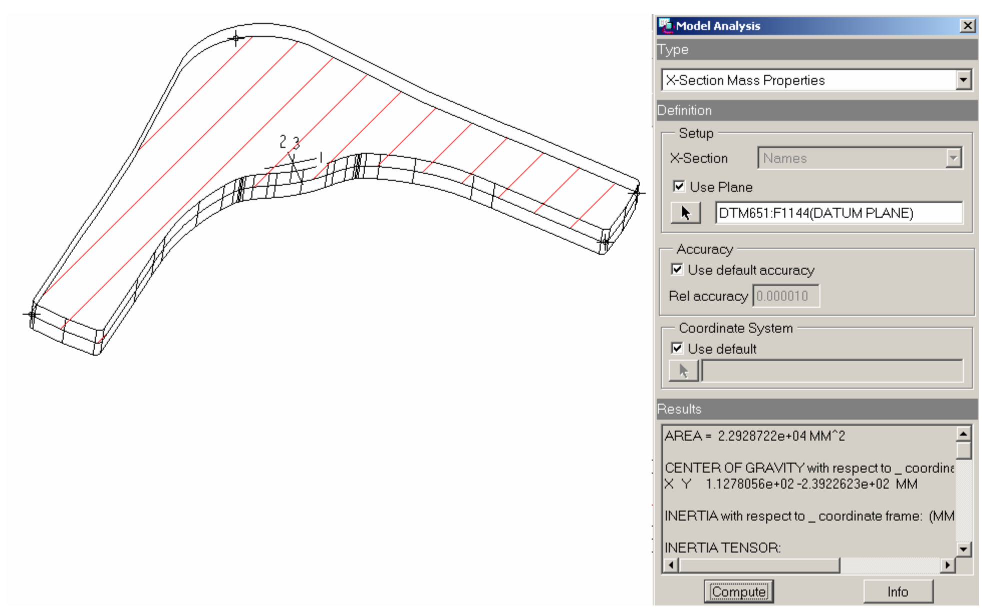


Figure 5.13 – Projected Area of “Ball Joint” Calculated by using Pro/E

As the mass of the part is 6.05 kg., the recommended value for the flash mass per cm. of the periphery is 0.013 according to Table 2.3. The perimeter of the part at the parting surface is calculated by Pro/E as 92 cm (See Fig 5.13). Therefore, the flash mass is calculated as:

$$Q_f = (0.013) \cdot (92) \tag{5.1}$$

$$Q_f = 1.196 \approx 1.2kg$$

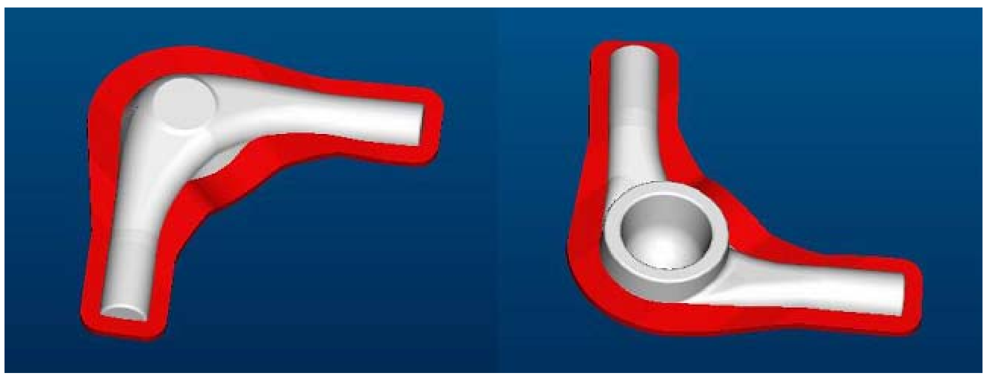


Figure 5.14 – The 3-D Model of the “Ball Joint” with the Estimated Flash Geometry

For the flash thickness, recommended facial clearance of forging press, which is 7 mm, will be used. A flash geometry is modeled around the part by considering these values. The flash added to the 3-D model of Ball Joint can be seen in Fig 5.14.

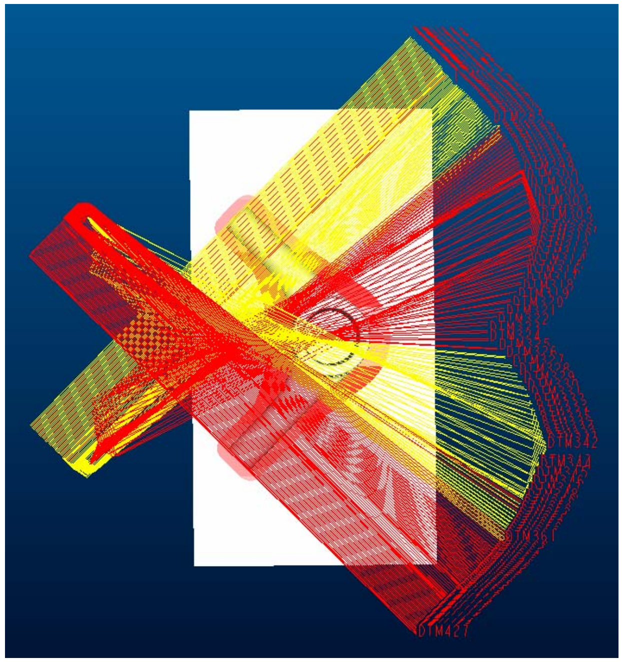


Figure 5.15 – Datum Planes Placed on the Model for Volume Distribution Curve Plotting

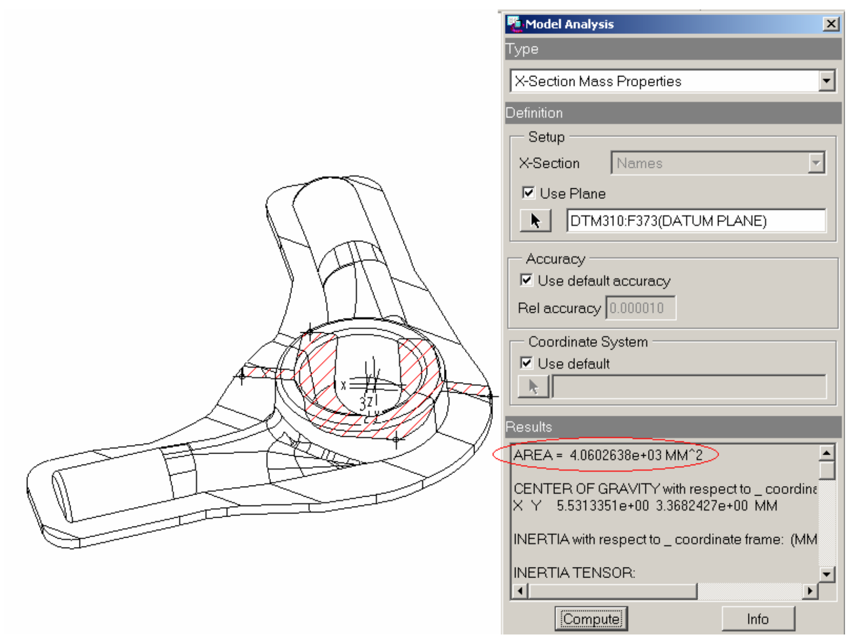
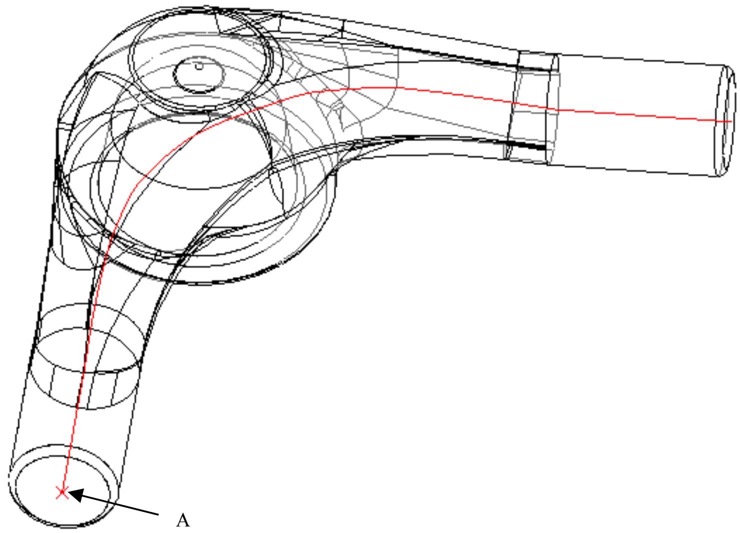
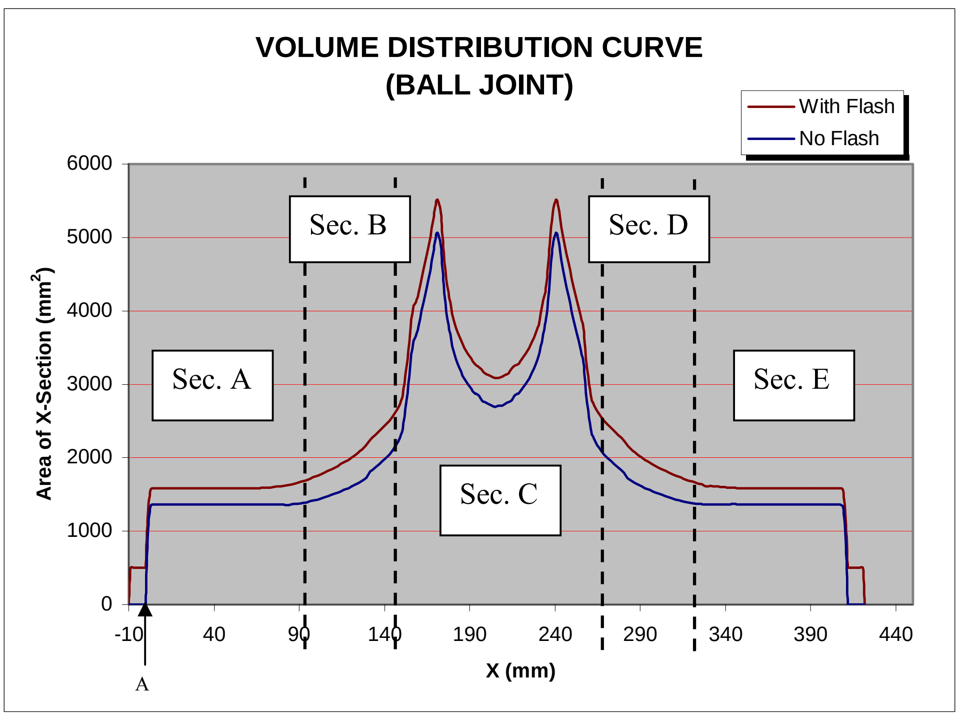


Figure 5.16 – A Sample Cross-Section Area Calculation for “Ball Joint”



(a)



(b)

Figure 5.17 – (a) Reference 3-D Model; (b) Volume Distribution Curves for “Ball Joint”

As described in Chapter 3, a volume distribution curve is obtained from the 3-D model of the part with the estimated flash geometry. With this plot, the particular part is divided into sections, which will be used to determine the required preforming steps and their geometries. For this purpose, datum planes, which are perpendicular to the parting plane, are placed with a distance of 2 mm between each other. With this distance, totally 208 datum planes are placed through the part; thus, accuracy of volume distribution curve is increased in comparison with previous studies [22, 23]. The arrangement of datum planes can be seen in Fig. 5.15. "X-Section Mass Properties" which is the analyzing option of the Pro/E [39] is used to obtain the cross-sectional area for each datum plane. A sample analysis can be seen in Fig. 5.16. All results are then transferred to MS.Excel and the volume distribution curve is obtained. Volume distribution curve of the "Ball Joint" is shown in Fig. 5.17(b). "X" is the position on the axis curve, shown with the red line in the Fig. 5.17(a), relative to the left end of the part without flash. In this figure, the volume distribution curve of the flashless part (blue line) starts from "0" and ends at "411", which is the length of the part along the axis of the part. Red line in this figure is the volume distribution curve of the created model with flash. This curve starts from "–10" and ends at "421". These locations indicate the start and end points of the flash along the parting surface. The volume of the part is divided into five sections corresponding to the changing in cross-section areas. In the given figure, the dashed lines indicate the section separation planes for this part. Analyzing of these sections gives the proper volume decompositions that will affect the preform geometries. In Table 5.3, the volume decomposition results of the part are given. It should be noted that these results are calculated for the hot dimensions of the part. AKSAN is currently producing the particular part with a shrinkage allowance of 1.6% on each dimension [5]. Therefore, the impressions of the finisher dies are modeled by giving this allowance to the 3-D model of the part.

Table 5.3 – Volume Decomposition Results for "Ball Joint"

	Range of the Section (mm)	Volume with Flash (mm^3)	% of Volume with Flash
Sec. A	-10 - 90.87	121697	12.8
Sec. B	90.87-144.87	125407	13.2
Sec. C	144.87-266.87	456992	48.0
Sec. D	266.87-320.87	125407	13.2
Sec. E	320.87-421	121697	12.8
Total	-10 - 421	951478	100.0

After the volume decomposition results have been obtained, the billet geometry is chosen. There exist two choices for the billet's cross-section geometry; either square or round. During the selection of the billet type, the required preforming steps and the heating and manufacturing availabilities for these steps should be considered. According to the procedure explained in Chapter 3, by using Eq.'s 3.1, 3.2 and 3.3 the results given in Table 5.4 are obtained. For the sections identified during the volume decomposition of the part, these average values are also calculated and the results are given in Table 5.5.

Table 5.4 – Dimension Ranges for Two Different Billet Geometry Options

Type of Billet Geometry	Minimum Value (mm)	Maximum Value (mm)	Average Value (mm)
Side length for square cross-section	33.85	74.24	47.49
Diameter for round cross-section	38.20	83.78	53.59

Table 5.5 – Average Dimensions for Square and Round Billet at Each Section

Section Identity	Average Side Length for Square Billet (mm)	Average Diameter for Round Billet (mm)
A	39.40	44.46
B	44.86	50.62
C	61.23	69.10
D	48.86	50.62
E	39.40	44.46

At this point, distribution of the metal should be considered. As seen from Table 5.5, the maximum average size occurs at section C, which is at the center of the part. The required billet sizes for the sections at the ends of the part are less than the size required at the center. In this situation, there are basically two alternatives applicable. In the first one, the larger cross-sectioned billet is chosen by considering the value for the section C and the fullering operations are applied for other sections to reduce the sizes. In the second case, the smaller cross-sectioned billet is chosen by considering the values at the ends of the part and an upsetting operation for the central section (i.e. Section C) is applied to increase the size of the billet for this region. As seen from Table 5.3, about half of the total volume of the part is at the section C; thus, an upsetting operation is preferred as the initial operation. At this point, capabilities of the 970 kW induction furnace and the 4000-tonf press are taken into account. In the 970 kW induction furnace, the billets with a side length of 50 to 120 mm can be heated. Another constraint comes from the working area of the press. The forging press has a ram stroke of 380 mm with a ram adjustment value of 20 mm. At the end of the stroke, the distance between the ram and the bed is 200 mm. Consequently, dies and the billet length must be designed according to the working height of 600 mm.

By considering these constraints and the round cross-sections at the both ends of the part at the final geometry, the round cross-section has been chosen for the billet. As the length of the Ball Joint is about 400 mm. from one end to the other on parting surface, billet with the smallest possible diameter is needed for the efficiency and the easiness of the fullering operation. For this reason, round billet with diameter of 60 mm is decided to use. Using Eq. 3.3 and calculating A_c with 60 mm as the billet diameter, the length of the billet becomes:

$$L_b \approx 320mm$$

As the workpiece is fullered, volume distribution at each section will be formed. Thus, as a next step, there will be a bending operation.

At the blocker stage, a new preform geometry, which has a volume of the final part with flash, will be modeled by using Pro/E to avoid flash formation before the final stage.

Therefore, the preform sequence of the particular part has been decided as:

1. Upsetting
2. Fullering
3. Bending
4. Blocking

5.4 Design of the Preforms and Analysis of the Stages

5.4.1 Upsetting Operation

In this operation, the upsetting volume is taken as equal to the volume of the Section C (See Fig. 5.17).

For hot upsetting taper preforms Gökler [14] suggested a relationship between the unsupported bar length beyond the cavity and the maximum taper diameter. This suggestion was also verified in the thesis study of Kazancı [15]. By also considering the design requirements explained in Appendix D, a preform geometry is created by using Pro/E with dimensions 260 mm for L_{u1}, 110 mm for L_{u2}, 75 mm for L_{u3}, 60.5 mm for D_{u1} (at the end) and 90 mm for D_{u2} (See Figure 5.18).

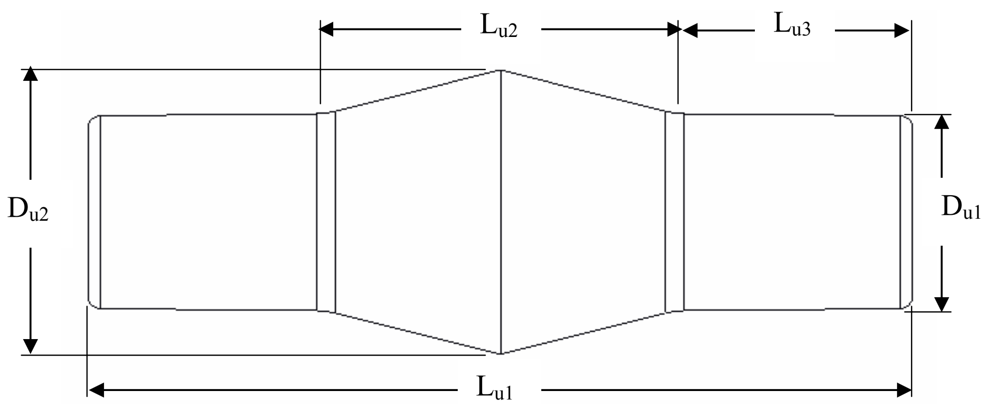


Figure 5.18 – Preform Geometry After Upsetting Operation

By using this model, die sets are split by using Pro/E (See Fig. 5.19) in order to form the upsetting cavities required for the simulations. Dies are designed for a facial clearance of 30 mm. and with a draft angle of 3^{o} on the shanks at the both ends of the part. H_{u1} of the die pairs is 135 mm. A corner radius of 4 mm is given to the dies. As the dies are mounted on the forging press, a distance of 330 mm remains between the dies when the ram is at the upper position, which is sufficient for placing the billet in the dies.

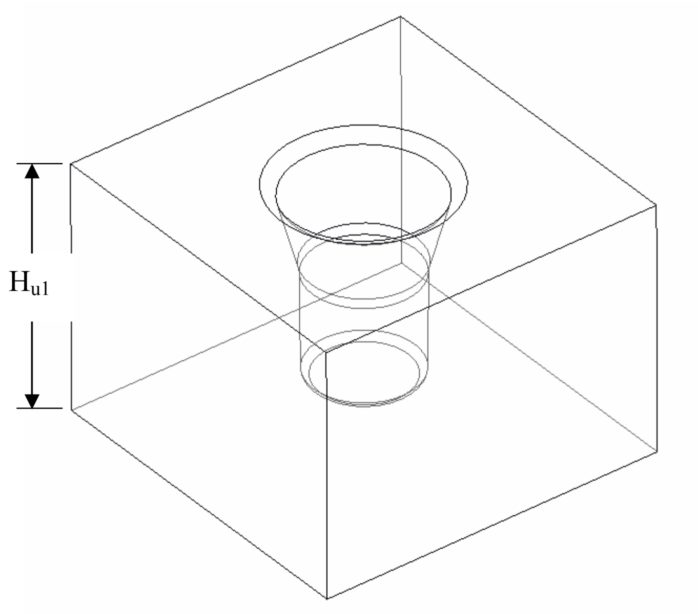


Figure 5.19 – One of the Die of the Upsetting Stage

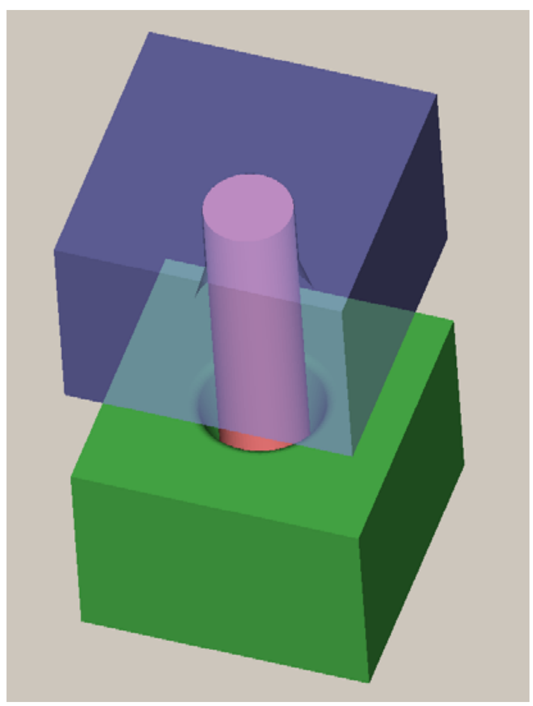


Figure 5.20 – Simulation Set-up of 1st Preform (Upset) Operation

After defining the process parameters for the finite volume analysis as explained in Appendix E, the simulations of the stages are initiated. Fig. 5.20 shows the simulation set-up of the upsetting operation. For this simulation, 4 mm of workpiece element size is used. As seen from Fig 5.21, the desired preform geometry was obtained at this stage.

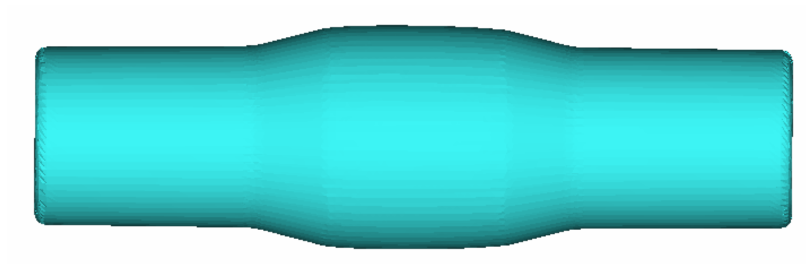


Figure 5.21 – Result After 1st Preform Operation

5.4.2 Fullering Operation

Aim of this operation is to obtain the desired volume distribution throughout the preform geometry. For this purpose, a new preform geometry is created (See Fig. 5.22).

Total length of the preform is taken as 360 mm. Diameter at the center of the section C is 85 mm and the diameter at the ends of the part is 44 mm. To avoid laps that can be form at the intersections of the section, proper radii are given during the blending of each section. Ranges of each section can be seen in Fig 5.23. In order to obtain this desired preform geometry, a couple of blows should be performed. Before each blow, the preform must be rotated 90^{o} for more uniform distribution of the metal.

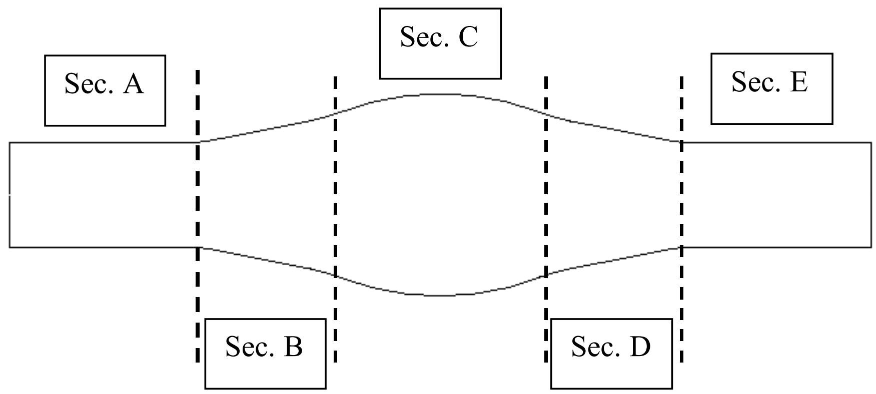


Figure 5.22 – Sections on the Preform Geometry of the Fullering Stage

From the created model given in Fig. 5.23, required die cavities are obtained by splitting the geometry from the die blocks. Cavity of the die of the fullering operation can be seen in Fig. 5.24.

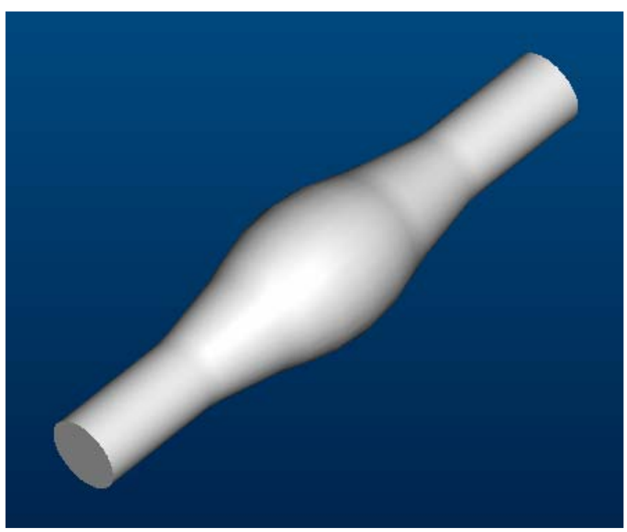


Figure 5.23 –3-D Model of the Preform Geometry After the Fullering Operation

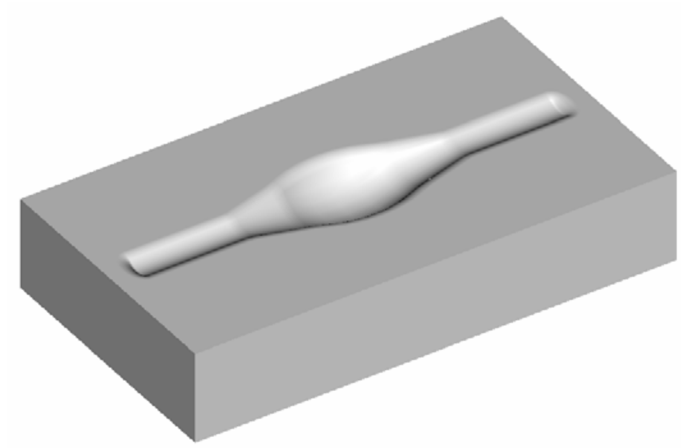


Figure 5.24 – One of the Die of the Fullering Stage

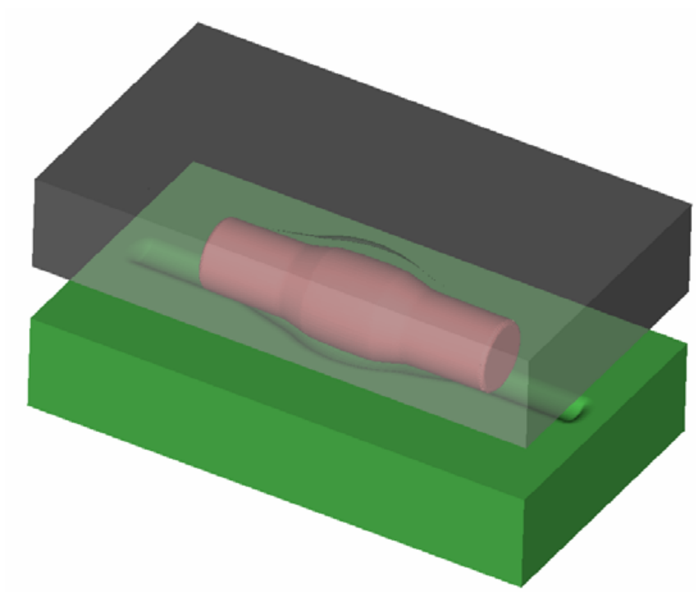


Figure 5.25 – Simulation Set-up of 2nd Preform (Fullering) Operation

The part geometry obtained as a result of the simulation of the upsetting operation is placed between the die of the fullering operation (See Fig 5.25). In order to achieve the desired preform geometry, the simulation is repeated for 6 times. The preform is rotated about 90^{o} after each run of the finite volume software. Resultant preform geometry after 6 blows can be seen in Fig 5.26.

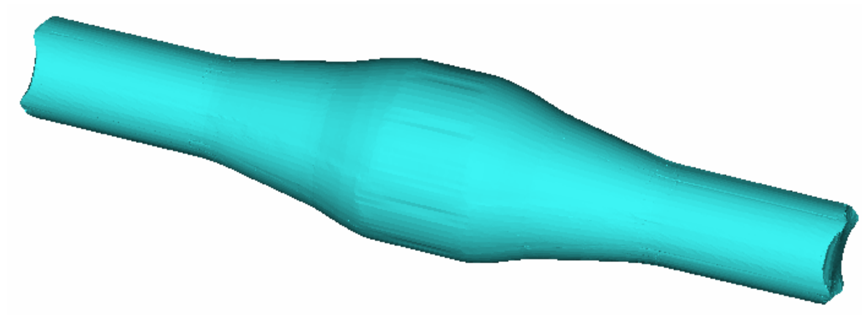


Figure 5.26 – Resultant Preform Geometry After Six Fullering Stages

5.4.3 Bending Operation

During bending operation, the angle between two arms is obtained by pushing the Section C with rounded upper die to a guiding cavity placed at the bottom as seen in Fig. 5.27.

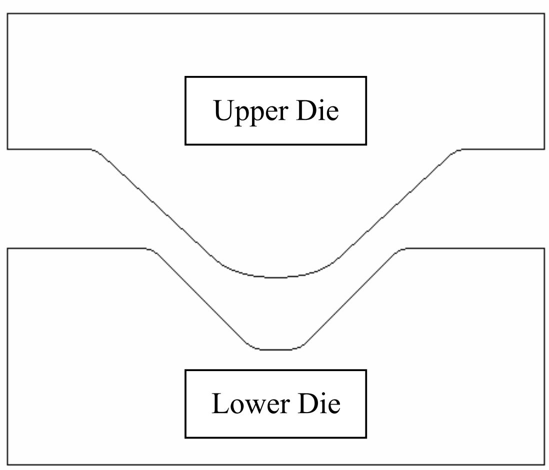


Figure 5.27 – Side View of the Die Set of the Bending Stage

Simulation result of the preform after final fullering stage is placed between bending dies (See Fig 5.28). Different simulations with different upper die angles have been performed in order to obtain a 90^o angle between the two distinct legs of the preform. The desired preform geometry has been obtained with a lower die of 90^o sidewall angle and with a upper die of 95^o sidewall angle. The resultant preform geometry after the bending operation can be seen in Fig 5.29.

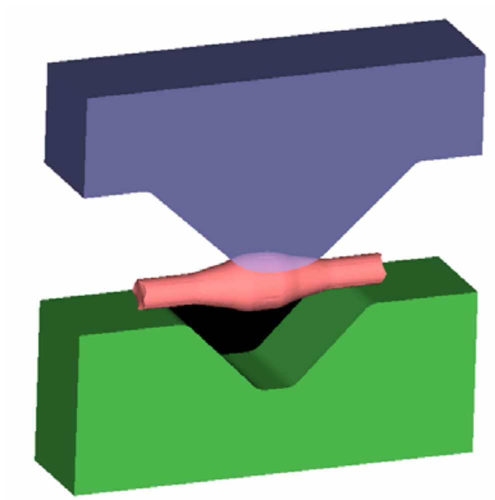


Figure 5.28 – Simulation Set-up of 3rd Preform (Bending) Operation

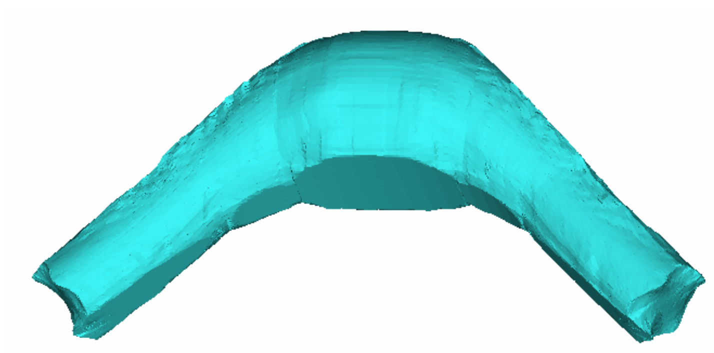


Figure 5.29 – Resultant Preform Geometry After the Bending Operation

5.4.4 Blocking Operation

At the current practice in AKSAN [5], a modified form of the final part is also used for the blocker stage. The die clearance of the blocker dies; therefore, the flash thickness is increased to 14 mm. Because of this method, undesirable flash formation occurs to a huge extent (See Fig. 5.9). However, there should be no or very little flash formed after this stage. For this operation, new preform geometry is created (See Fig. 5.30). In this model, volumes for each five section kept constant to maintain the volume distribution at this stage. Another important point at this stage is the dimensions of the punch for the middle blind hole. For producibility and prevention of excessive punch wear, a new piercer is designed on the basis of height-to-width ratio. For cavities circumscribed by ribs of circular configuration, maximum 0.75:1 height-to-width ratio is recommended [25].

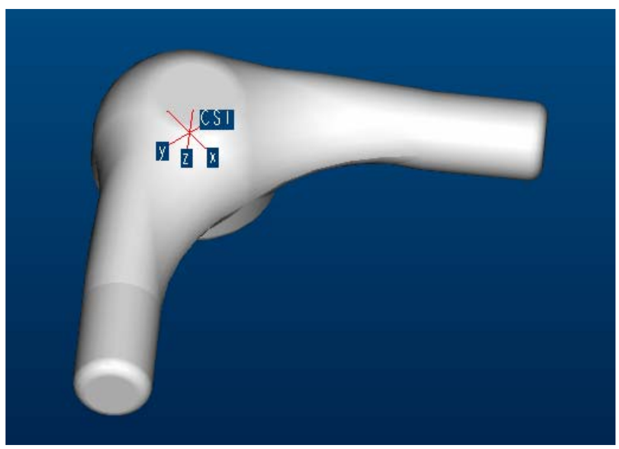


Figure 5.30 – 3-D Model of the Aimed Part at the Blocker Stage

For the simulation of this operation, the preform obtained as the result of the previous (bending) operation is placed into last preform dies (Fig. 5.31). The die cavities are designed so that no or very little flash will occur. Simulation results show that this aim at this stage is achieved by the designed die cavities. The resultant preform geometry of this stage can be seen in Fig 5.32.

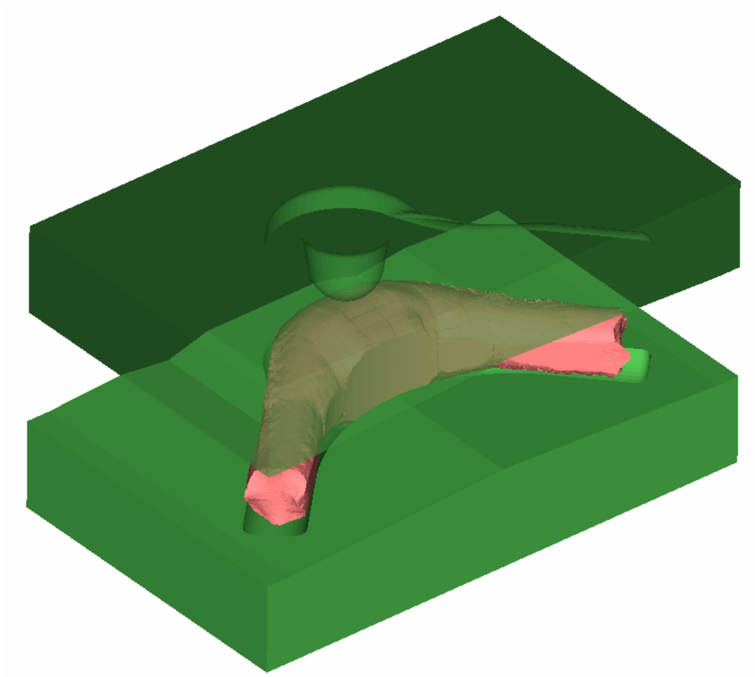


Figure 5.31 – Simulation Set-up of 4th Preform (Blocking) Operation

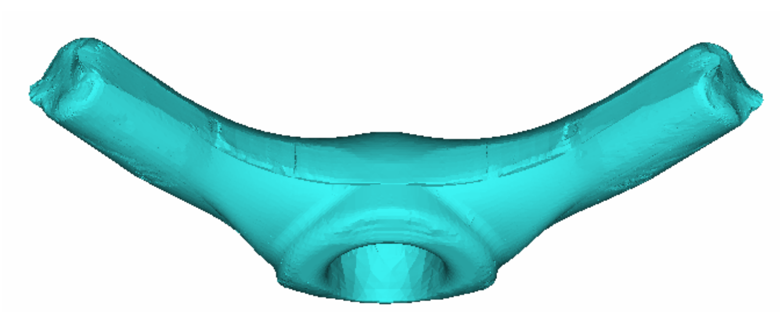


Figure 5.32 – Preform Geometry After the 4th Preform (Blocking) Operation

5.4.5 Finishing Operation

Die pair of the finishing stage are exactly the same as the die pair used by the company. Cavities of these dies are not changed because the desired final part is obtained after this stage. Fig. 5.33 shows the simulation set-up of the finishing stage.

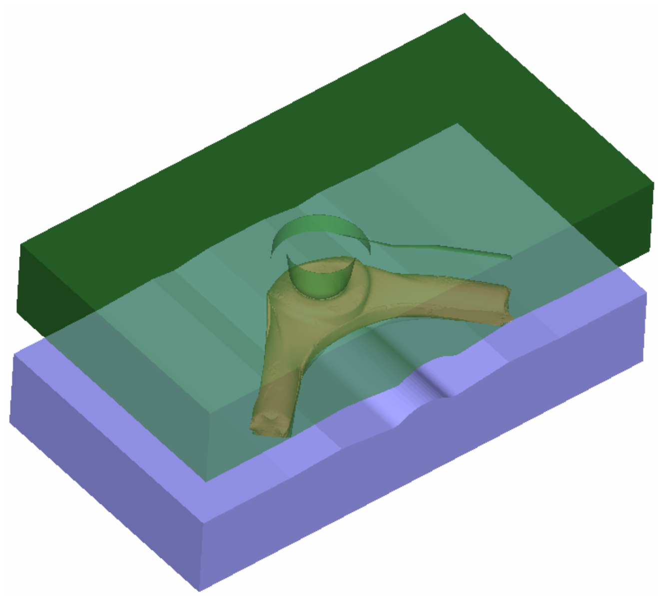


Figure 5.33 – Simulation Set-up of the Final Forging Stage

In Fig 5.34, the die-workpiece contact analysis of the finishing stage can be seen. Red color indicates the exact contact between the die and the workpiece; blue color indicates that there is no contact between the die and the workpiece. As seen from this figure, complete die fill at the impressions of the finisher operation has been obtained.

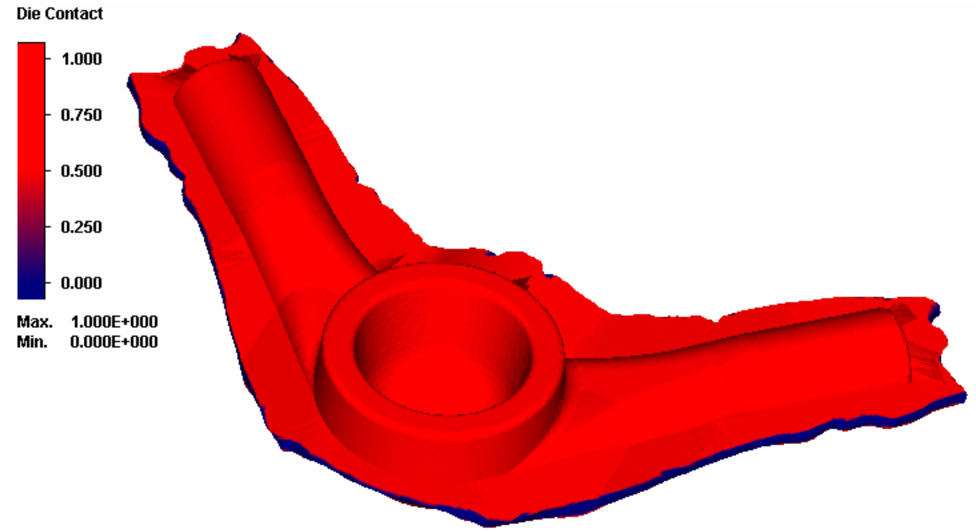


Figure 5.34 – Die Contact (Die Fill) Analysis of the Finishing Operation

Similar simulations are also performed in order to obtain a better result with different billet lengths. Table 5.6 gives the results of computer simulations.

Table 5.6 – Results of the Computer Simulations

Stock Type	Stock Diameter (mm)	Stock Length (mm)	Stock Volume (mm3)	Stock Mass (kg)	Flash Mass (kg)	% of Flash to Part Mass	# of Strokes	Die Fill
Round	60	320	904779	7238	1.188	19.6	10	Yes
Round	60	310	876504	7.012	0.962	15.9	10	Yes
Round	60	300	848230	6.786	0.736	12.2	10	Yes
Round	60	290	819956	6.56	0.51	8.4	10	No
Round	60	295	834093	6.672	0.622	10.3	10	No

5.5 Design and Manufacture of the Die Sets

Since the satisfactory results had been obtained from the computer simulations, die sets, which would be used on the forging press were designed and manufactured on CNC machines available in METU-BILTIR Center. CNC machining codes have been generated by using NC option of Pro/E [42]. The working area of the forging press in terms of length and width is 1200x600mm respectively. The upsetting and bending die sets are considered to combine to save the working space; in addition to this, the die costs also decrease. By using the cavities created for the simulations, die blocks have been designed by considering the mounting and operation requirements. Fig 5.35(a) shows the created 3-D models of the dies for manufacturing. Fig 5.35(b) shows the assembly model of the lower and upper dies at the end of the stroke of the forging press. The manufactured dies can be seen in Fig 5.36.

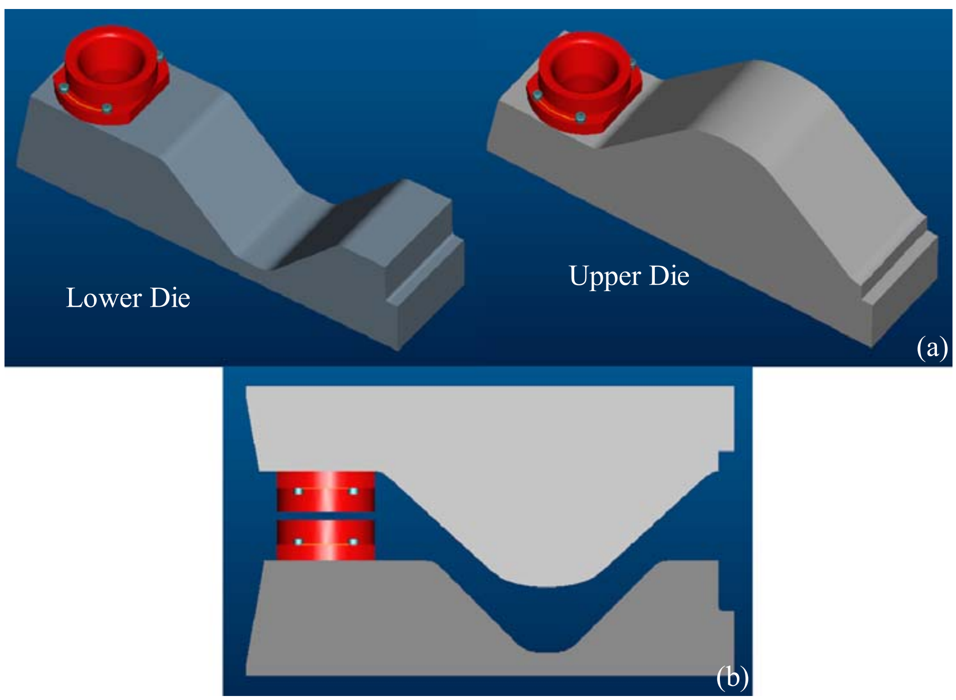


Figure 5.35 – (a) Created Models of the Dies; (b) Assembly Model of the Dies

Figure 5.36 – Manufactured Dies of 1st and 3rd Preform Operations (Upsetting and Bending)

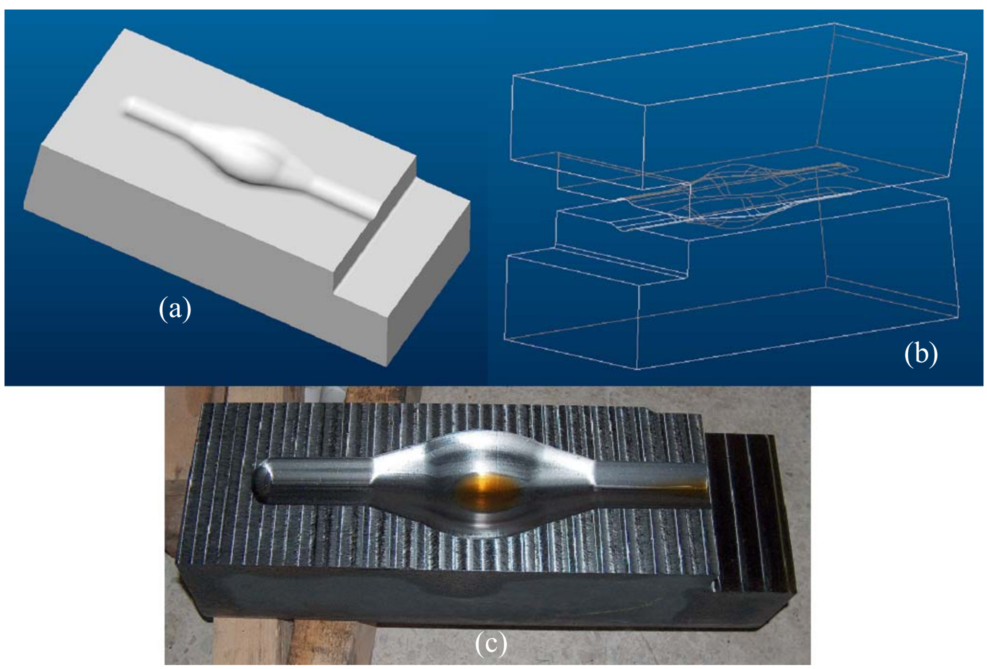


Figure 5.37 – (a) Created Model of the 2nd Preform (Fullering) Operation Die; (b) Assembly Model of the Dies; (c) One of the Manufactured Die

Die blocks of 2nd Preform (Fullering) and 4th Preform (Blocking) operation dies (Fig. 5.37 and Fig. 5.38, respectively) are also designed and manufactured.

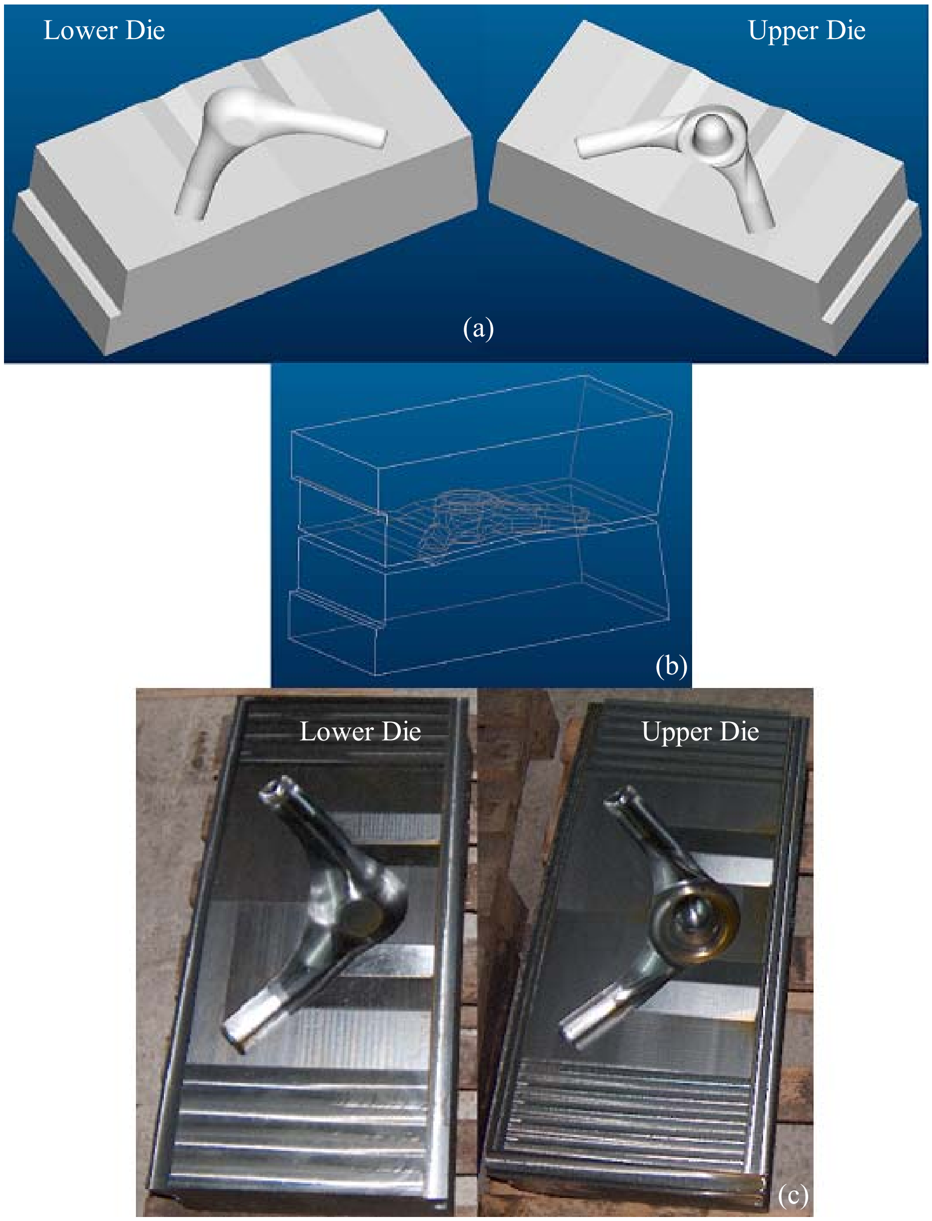


Figure 5.38 – (a) Created Models of the 4th Preform (Blocking) Operation Dies; (b) Assembly Model of the Dies; (c) Manufactured Dies

5.6 Real-Life Experimentation

After the die pairs had been manufactured, they were tested in AKSAN in order to compare the simulation results with the real process results. 10 pieces were taken as sample results with various lengths of billets. The results of these samples can be seen in Table 5.7.

Table 5.7 – Results of the Experiments

Sample No	Billet Diameter (mm)	Billet Length (mm)	Calculated Mass (g)	Calculated Flash Mass (g)	Number of Fullering Strokes	Total Number of Strokes	Die Filling Success
1	60	320	7238	1188	6	11	No
2	60	320	7238	1188	10	15	No
3	60	320	7238	1188	10	15	No
4	60	324	7328	1278	10	15	No
5	60	330	7464	1414	10	15	Yes
6 - 10	**60**	**326**	**7374**	**1324**	**10**	**15**	**Yes**

An initial sample was taken with a length of 320 mm. and the same forging sequence explained in previous section was applied to the billet. For this case, the fullering operation repeated six times; however, complete die fill at the final stage was not obtained, especially at the ends of the part. This part can be seen in Fig 5.39. In this figure, the red circles indicate the unfilled areas of the part. To overcome this problem, the number of fullering operations was increased until the required preform geometry was obtained. For the next two tests (for billets with length of 320 and 324 mm.), ten fullering operations were applied. Although the required preform geometry was almost obtained for both parts after the fullering operations, die fill at the center of the part were not obtained.

Figure 5.39 – Unsatisfactory Sample of the First Experiment

Considering previous results, firstly a billet with a length of 330 mm. was tested. Test of this part resulted with satisfaction in term of complete die fill. To obtain a better result, a billet with a length of 326 mm. was also tested and again complete die fill at the final stage was obtained. In order to confirm the satisfactory result of the process with the billet length of 326 mm., four further tests were also performed and at each case, complete die fill was obtained after the finisher stage. Fig. 5.40 sequentially shows the preforms taken after upsetting, fullering, bending and blocking operations with the billet length of 326 mm. Since the die cavities for the upsetting operation had been manufactured considering the chosen billet with the length of 320 mm., some metal (indicated by red arrow in the figure) were extruded outwards between the die faces. Part after the finishing operation for the same billet can be seen in Fig. 5.41.

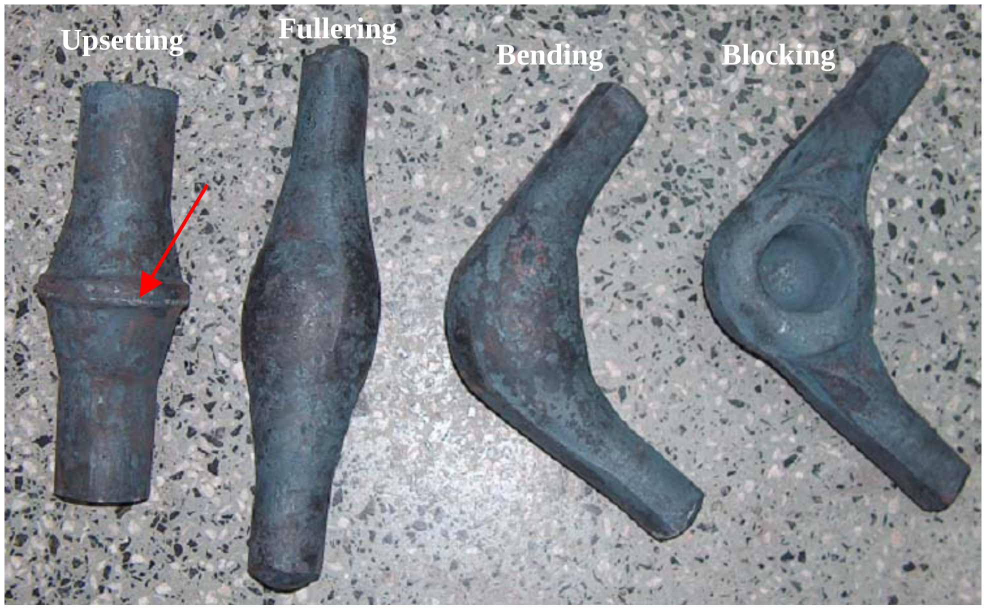


Figure 5.40 – Samples of the Preform Operations

Figure 5.41 – Part After the Finishing Operation

In the current practice of the company, huge amount of flash formed after the blocking operation (See Fig. 5.42). Since, the formation of flash is not desired before the finishing operation, the blocking operation dies were designed for containing all the metal within the die cavities as discussed in Section 5.3.4. This aim has been achieved except a small region labeled by the red line in the figure. A little flash was observed at that region. This flash might be formed due to the wrong placement of the preform by the operator.

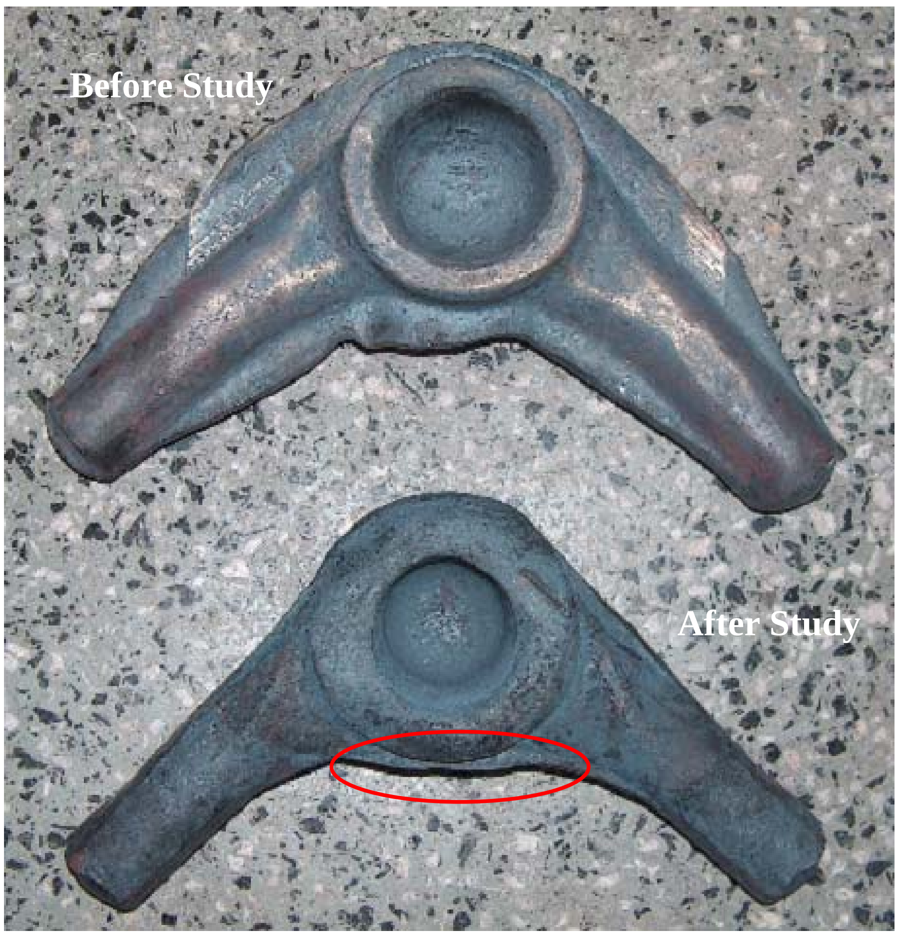


Figure 5.42 – Sample Preform Geometries After the Blocking Operation

Throughout the experiments, the best result was obtained by using a billet with the diameter of 60 mm. and the length of 326 mm. and by a total of fifteen blows of the forging press. Hence, the aim of complete die filling after the finishing stage by using less material, while decreasing the number of blows of the forging press, has been achieved. Table 5.8 gives the results obtained during the study. These results will be discussed in the next chapter.

Table 5.8 – Study Results of the ”Ball Joint”

	Billet Type	**Billet Length (mm)**	**Billet Mass (g)**	**Calculated Flash Mass (g)**	**Total # of Forging Stages**	**Flash Mass / Part Mass**
Current Practice	Ø 75 mm	220	7770	1720	20	0.284
Achieved During Simulation (1)	Ø 60 mm	320	7238	1188	11	0.196
Achieved During Simulations (2)	Ø 60 mm	310	7012	962	11	0.159
Achieved During Simulations (3)	Ø 60 mm	300	6786	736	11	0.122
After The Experiments	Ø 60 mm	326	7374	1324	15	0.219

CHAPTER 6

CONCLUSIONS

6.1 Discussions and Conclusions

Today most of the forging companies have been designing their forging processes on the basis of trial and error methods by using their past experiences. Observations in AKSAN [5] show that main reason of the forging errors comes from the wrong design of the preforms, especially for complex forging parts. Improper design of the preforms may result in formation of excess flash, early die wear, long production times, etc., which increase the production costs. For such forgings, process sequence and preforms should be redesigned in order to overcome these problems. In this thesis, the study has been focused on forgings that require bending operation(s) during the preform stage(s).

First study has been conducted on “Chain Bracket” which is a bent forging with the planar parting surface. In the current practice of the company, manual forging by the operator is required after the first bending operation in order to place the preform into the second bending operation dies. However, this manual forging stage causes the problems based on the operator’s skill and increases the process time. To avoid these problems, a new bending operation has been proposed instead of the manual forging operation. Simulation results of the proposed forging sequence has shown that the part can be forged by using three bending operation with more uniform material distribution after the last preforming stage, while eliminating the manual hammering stage.

The second study has been conducted on steering joint used in heavy vehicles, which is a bent forging with the non-planar parting surface. It was observed in AKSAN [5] that the particular forging had extreme problems in terms of material wastage in the form of flash. Before the finishing operation (i.e. after blocking), a huge amount of flash is formed, which is undesirable and may cause rapid die wear. Another important observation is that an average of twenty blows of the forging press are required to forge the particular part, which causes long process time and high equipment usage cost. Having considered these problems, the aim of this study was to design appropriate preforms, which can eliminate these problems.

By examining the experimental results seen in Table 5.7 and the data given in Table 5.8, a minimum amount of flash, which is 1324 g., was observed for the round billet with the diameter of 60 mm. and the length of 326 mm. The flash mass is decreased from 1720 g. to 1324 g., which means about 400 g. of metal has been saved in terms of the flash mass. This means that the flash mass to part mass ratio has been decreased from 0.284 to 0.219. It should be pointed that the recommended flash mass by the NADF, which is 1200 g., is very close to the flash mass obtained after the experiments. This fact shows that the recommendations of NADF can be applicable for similar forging geometries.

In order to complete the forging operation, 15 blows of the forging press have been sufficient during the experiments. Therefore, the required press blows have been decreased from 20 to 15 (Upsetting, 10 Fullering, Bending, Blocking, Finishing and Trimming), although a total of eleven blows have been estimated according to the simulations. With respect to the simulation results, the material flow in the axial direction of the end of the part was observed much less in the real-life experimentation. This characteristic was lead to the need of using a longer billet geometry, while increasing the number of fullering operations. Also the operator dependency should be considered as the reason. During the simulation set-up of the operations, workpiece was placed on the dies exactly at the required position. However, during the experiments, the preforms might have not been placed correctly in the dies. During the simulations, after each fullering operation, the preform was rotated exactly 90^o; however this value might have been deviated up to 15^o during the experiments.

The finite volume simulation results are very similar to the results obtained during the experiments. It should be noted that the number of blows especially in the fullering stage depends on the operator's skill.

The importance of proper volume distribution and the proposed method based on volume distribution curve has been verified by this study. Results of the study show that the aim of reducing the material wastage, while decreasing the number of blows of the forging press have been achieved by designing appropriate process sequence and proper preforms.

6.2 Future Work

The following future studies can be suggested;

- The proposed preform sequence for forging of the "Chain Bracket" may be tested in a forging company after the bending dies will have been manufactured in order to compare the simulation results with experimental results.
- As a result of the experimental study, the placements of the part in the dies are important to have the final desired geometry. Therefore; especially for the fullering operations of the "Ball Joint" some further simulations could be made in order to find out how the placement of the preform in the dies will affect the material distribution.
- Simulations could also be conducted by using different simulation software packages to compare the results.
- The study can be extended for forgings with different geometries.

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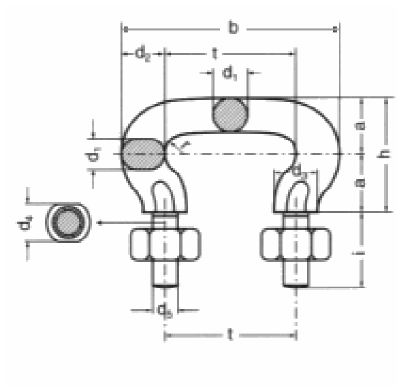
APPENDIX A

TECHNICAL DRAWING OF "CHAIN BRACKET"



Teilung t	Ausladung a	Breite b	d_1	d_2	d_3	d_4	d_5[1] Metr. Gew.	Whitw.-Gew.	Höhe h	Schenkellänge l	r	[4] Gewicht kg ≈	Zugehörige Kettenrädern nach DIN 764 u. 766 für glatte Rollen Nenndicke d	DIN 764 f. verzahnte Rollen Nenndicke d
45	20	73	11,5	14	15	12,5	M 10	—	40	25	7,5	0,17	10	13
56	25	92	15	18	19	16,5	M 12	—	50	32	9,5	0,36	13	16
63	30	105	18	21	23	20	M 16	—	60	40	10,5	0,60	16	18 *
70	34	116	20	23	28	23	M 20	—	68	45	12	0,90	18	20
80	37	132	23	26	31	25	M 20	—	74	45	13	1,13	20	23
91	43	149	26	29	34	29	M 24	7/8" *	86	55	14,5	1,83	23	26
105	50	173	30	34	38	31	M 24	1" *	100	55	17	2,40	26	30
126	59	206	36	40	44	37	M 30	1 1/8" *	118	70	20,5	4,00	30	36
147	68	239	42	46	50	42	M 30	1 1/8" *	136	70	23.5	5.65	36	42

Figure A.1 – Technical Drawing of Chain Bracket [5]

APPENDIX B

MATERIAL PROPERTIES OF STEEL DIN 1.0503

Subcategory: Carbon Steel; AISI 1000 Series Steel; Medium Carbon Steel

Close Analog: AISI 1045H, C45

Composition (%):

C	Fe	P	Mn	S
0.42 - 0.5	98.51 –98.98	Max 0.04	0.6 – 0.9	Max 0.05

Physical Properties:

Density : 7.87 g/cm^3

Hardness : 187 HBr, 90 HRc-B, 10 HRc-C

Mechanical Properties (at room temperature):

Tensile Strength (Ultimate) : 620 MPa

Tensile Strength (Yield) : 550 MPa

Modulus of Elasticity : 200 GPa

Bulk Modulus : 140 GPa

Shear Modulus : 80 GPa

Thermal Properties :

Thermal Conductivity : 51.9 W/m^2-K

Coefficient of Thermal Expansion : 14.6 µm/m-^{o}C

Stress-Strain Curve at High Temperatures and Different Strain Rates:

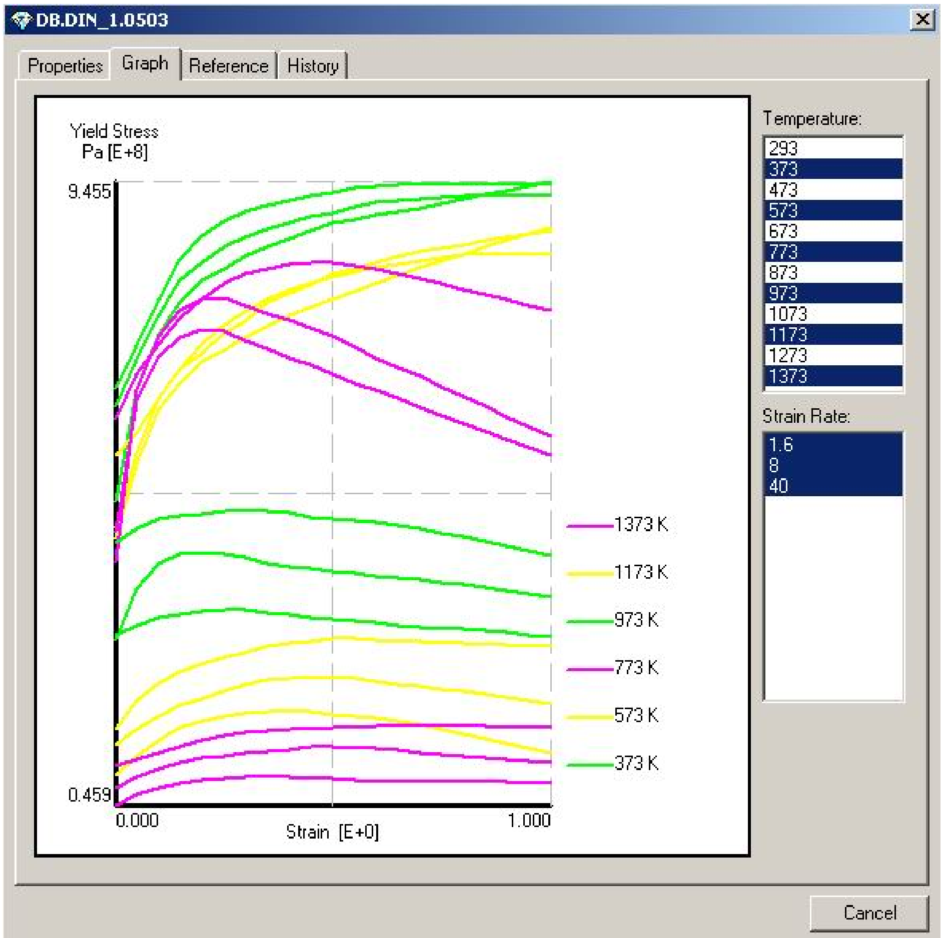


Figure B.1 – Material Properties of DIN 1.0503 Steel [41]

APPENDIX C

TECHNICAL DRAWING OF “BALL JOINT”

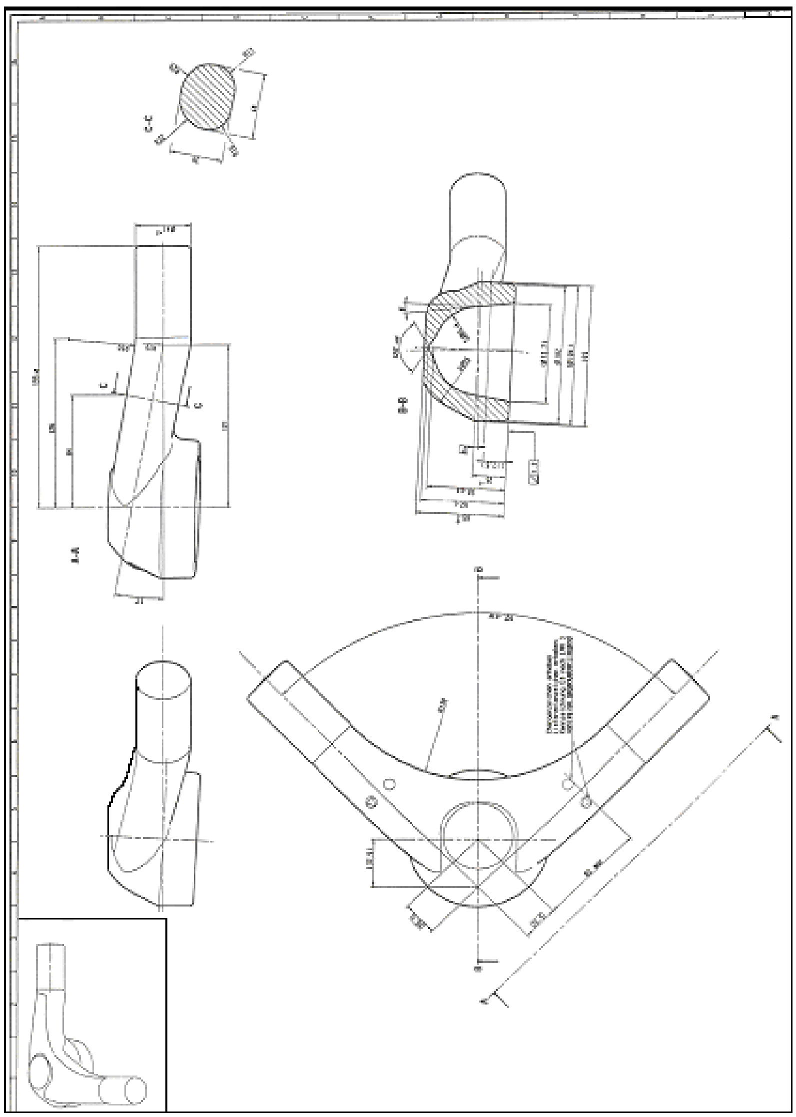


Figure C.1 – Technical Drawing of “Ball Joint” [5]

APPENDIX D

RECOMMENDATIONS FOR UPSETTING OPERATION

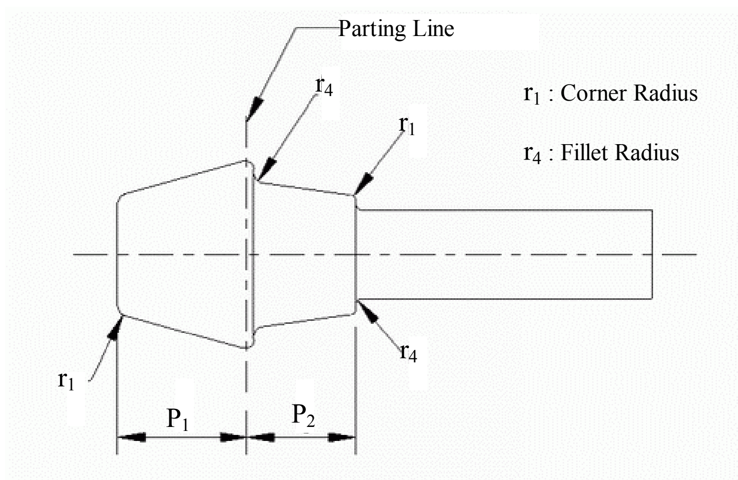


Figure D.1 - Corner and Fillet Radii [15]

Table D.1 - Draft Angle Recommendations [15]

Internal Surfaces			External Surfaces		
Slope	**Angle**	**Application**	**Slope**	**Angle**	**Application**
-	-	-	1 : 20	3^0	In Ram Die
1 : 20	3^0	According to Depth	1 : 50	1^0	Normal Case
1 : 50	0^0 - 3^0	Hole or Recess	-	0^0	On Jaw Surface

Table D.2 Recommendations for Corner Radius [15]

Greatest Distance from Parting Line to the Edge of Upset Region (mm)	**Corner Radius, r_1 (mm) (r_1 in Fig. D.1)**
0 - 25	2
26 - 40	3
41 - 63	4
64 - 100	6
101 - 160	8
161 - 250	10
251 - 400	16
401 - 630	25

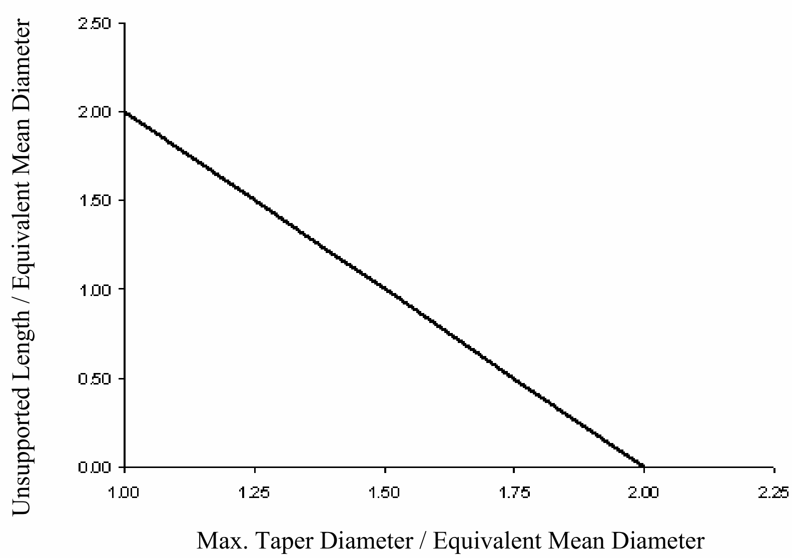


Figure D.2 - Suggested Relationship Between Unsupported Bar Length Beyond Cavity and Maximum Taper Diameter [14]

APPENDIX E

SIMULATION PARAMETERS USED FOR THE ANALYSIS OF THE "BALL JOINT"

In order to verify the designed forging sequence, computer simulations have been done. MSC.Superforge is used as simulation and analysis package. For the analysis of the sequence, some parameters are assigned to define the process. These are Die and Workpiece Geometries, Workpiece Material Properties, Press Properties, Friction Properties, Heat Transfer Properties, and Type of Problem Definition. Steps of definition of these parameters are explained in Chapter 3.

For all forging processes, starting from upsetting to finishing, die sets are modeled by using Pro/E. These files are then transferred to STL format and imported to the analysis package to define the die and workpiece geometries. In order to import a model file to the MSC.Superforge, the surface models must consist of triangular shaped facets only, which is the default in STL files. The STL-Reader in MSC.SuperForge can correct some problems in STL files. STL-Reader will remove facets with zero area (small gaps between the nodes are acceptable). It will try to equivalence with a higher tolerance. However, the STL-Reader can not correct non-matching facets, overlaps and holes occured in STL files. For Pro/E, recommended settings in order to obtain a good STL file are 0.000635 m (0.025 inch) for Chord Length and 0.5 for Angle Control value [41].

Raw material used for the production of the "Ball Joint" is C45 or namely DIN 1.0503. The properties for DIN 1.0503 are given in Appendix C. This particular material type exists in the material library of the analysis package. Therefore, it is selected from this library and assigned to the workpiece.

Because of the load requirements, “4000 tonf” mechanical forging press is used for the production of the part. In order to define the press properties of a mechanical forging press, crank radius, rod length and rotational speed of the crank is needed (these parameters are schematically shown in Fig. E.1. For this type of press, these parameters are specified as in Table E.1.

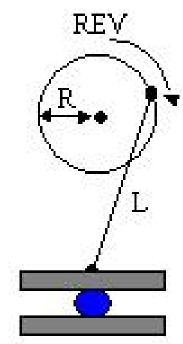


Figure E.1 – Illustration of Mechanical Press Parameters expressed by MSC.Superforge [41]

Table E.1 – “4000 tonf” Press Parameters [23]

Crank Radius (R)	190 mm
Rod Length (L)	1300 mm
Revolution (REV)	60 rpm

Another important point is defining the friction type and parameters. MSC.Superforge provides three different frictional models, which are coulomb and plastic, shear friction, or combined coulomb-plastic shear friction.

For forging operations involving relatively low contact pressure between dry contact surfaces, the Coulomb's friction model is most appropriate [41]. If the frictional shear stress reaches a critical value, the workpiece will slip along the die. According to Coulomb's law of friction, this value is given by:

$$\tau = \mu \cdot \sigma_n \tag{5.2}$$

where, μ is the coefficient of friction and σ_n denotes the normal stress at the workpiece-die interface.

The alternative model to Coulomb's law of friction is Tresca's friction model, which is the law of plastic shear friction. According to this model, if the frictional shear stress, τ, exceeds a constant fraction *m* of the flow stress in shear, τ_{yield}, the workpiece starts to slip [41]:

$$\tau = m \cdot \tau_{yield} \tag{5.3}$$

A value of zero represents perfect sliding, which means there is no shear or friction at the workpiece-die interface. A value of one represents sticking friction, which means that the friction shear stress equals the flow stress of the material in shear. For forging operations involving relatively high contact pressures, it is generally more appropriate to use the law of plastic shear friction [41]

Third model is the combination of both Coulomb and plastic shear friction, which can be used for forging processes where both relatively low and high contact pressures will occur during the process [41]. In that case, the frictional shear stress, τ, is given as:

$$\tau = \min(\mu \cdot \sigma_n, m \cdot \tau_{yield}) \tag{5.4}$$

where, μ is the coefficient of friction, σ_n denotes the normal stress at the workpiece-die interface, *m* is the interface friction factor and τ_{yield}, is the flow stress in shear.

During the analysis of “Ball Joint”, coefficient of friction (μ) 0.3, and interface friction factor (m) 0.05 were used for upsetting, fullering and closed-die simulations. These values were also used by other similar studies [15, 16, 22, 23]. For upsetting simulations, plastic shear friction model is used with a factor of 0.2. Figure E.2 shows the illustrations of these models.

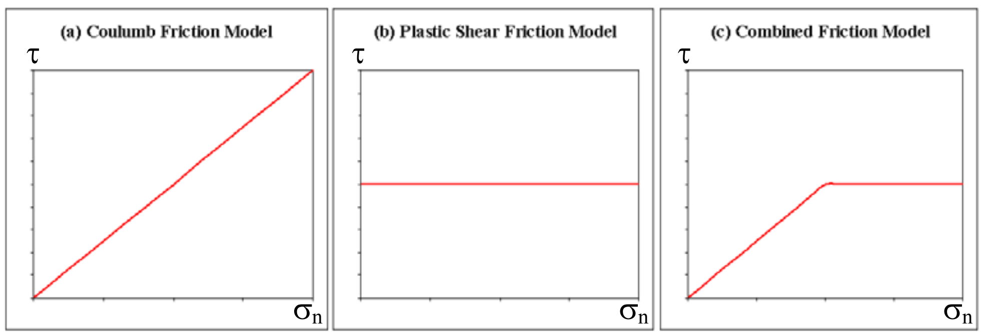


Figure E.2 – Illustrations of Friction Models