USE OF RECLAIMED ASPHALT PAVEMENT (RAP)
AS A BITUMINOUS BASE COURSE

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ABSTRACT

USE OF RECLAIMED ASPHALT PAVEMENT (RAP) AS A BITUMINOUS BASE COURSE

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The main objective of this study is to provide the reuse of the material (RAP) which is scarified from the wearing course of KGM test road section between Ankara and Eskisehir as a part of bituminous base course material.

Marshall Stability is taken as a criteria in determining the optimum rate of RAP material which will provide the most economical reuse.

In the first part of the study, the general information is given about recycling, recycling processes and the mix design of recycled materials.

In the second part, a sequence of Marshall Stability test is performed on the specimens prepared according to the hot-mix recycling process at different composition of old and new material with different asphalt contents.

As a result, the rates of RAP and new materials, and asphalt content which will provide the most economical reuse of RAP are given.

Key Words: Recycling, RAP, RAM, Marshall Stability, Hot-mix

Science Code: 624 04 01

ÖZET

DÖNÜŞTÜRÜLMÜŞ ASFALT KARIŞIMLARIN (RAP)

BİTÜMLÜ TEMEL TABAKASI OLARAK KULLANILMASI

ÇUBUK, M.Kürşat

Yüksek Lısans Tezi, İnş. Müh. Bölümü

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Bu çalışmanın amacı, Ankara-Eskişehir karayolunun otuzuncu kılometresınde, aşınma tabakasından sökülmüş malzemenin (RAP), bıtümlü temel malzemesinin bir kısmı olarak tekrar kullanımının araştırılmasıdır.

RAP malzemesinin en yüksek ekonomik verimi sağlayacak optimum oranının saptanmasında Marshall Stabılıtesi kriter olarak alınmıştır.

Çalışmanın ilk kısmında, dönüşüm, dönüşüm işlemleri ve dönüştürülmüş malzemenin karışım dizaynı hakkında genel bilgiler verilmiştir.

İkinci kısımda ise eski ve yeni malzemelerin degişik oranlarda sıcak karışım yöntemi ile karıştırılması ile elde edilen numuneler üzerinde, farklı asfalt yüzdeleri için bir dizi Marshall Stabilite deneyi gerçekleştirilmiştir.

Sonuç olarak, RAP malzemesinin en ekonomik kullanımını sağlayacak olan yüzdesi ile yeni aggrega ve asfalt oranları saptanmıştır.

Anahtar Kelimeler: Dönüşüm, Marshall Stabilite, Eski malzeme, Yeni malzeme, Sıcak Karışım

Bilim Kodu: 624 04 01

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The author is indepted to his family for their help,encouragement and moral support.

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LIST OF SYMBOLS

RAP : Reclaimed Asphalt Pavement

RAM : Recycling Aggregate Material

Dt : Theoretical Specific Gravity

Vh : Void Content

Vf : Void Filled with Asphalt

P.U.W.: Practical Unit Weight

A/C : Asphalt Content

CHAPTER 1

INTRODUCTION

1.1. General

Recycling is the reuse of material which has already served its first-intended purpose. Material removed from the surface of pavements as part of a maintenance program offers a source of cheap bitumen and aggregate since it is usually dumped or sold as fill material.

The need to reuse of recycled existing pavement materials for the reconstruction and rehabilitation of asphalt and Portland cement concrete pavements is of increasing importance. Recycling can help both to optimize the use of available materials and energy supplies, and to decrease the cost of maintaining our highways, roads, and streets.

In the U.S.A the Federal Highway Administration(FHWA) estimates the pavement industry generated $105.5 million in savings using recycled materials in 1985. And FHWA reports that 34 states have accepted some form of asphalt recycling in their specifications.(1) Other major benefits of recycling are conservation of aggregates, binders, and energy, as well as preservation of the environment and existing highway geometric.

Recycling is not a new process. As early as 1915, asphalt paving surfaces had been recycled. However, the quantity of pavement materials recycled from 1915 to 1975 is small compared to the amount of recycling that has been taken place and is expected to occur between 1975 and 1990.

In the past ten years there has been increasing emphasis on the need to reduce pavement rehabilitation costs and to conserve energy. Because of these twin emphases, many authorities have reexamined and recognized the importance of recycling techniques. Recycling can reduce not only cost and energy savings, but also the demand for asphalt during supply interruptions.(1)

1.2. Field of Investigations

This study covers the stages recycling processes and investigates the behavior of recycled material by means of some conventional material testings.

CHAPTER 2

GENERAL INFORMATION ABOUT RECYCLING AND RECYCLING PROCESS, LABORATORY AND DESIGN PROCEDURE

Pavement recycling operations can be applied on two types of pavement materials which are asphaltic and Portland cement concrete pavements.

It is possible to categorize the recycling operations further according to the particular procedure used as illustrated in Figure 2.1.

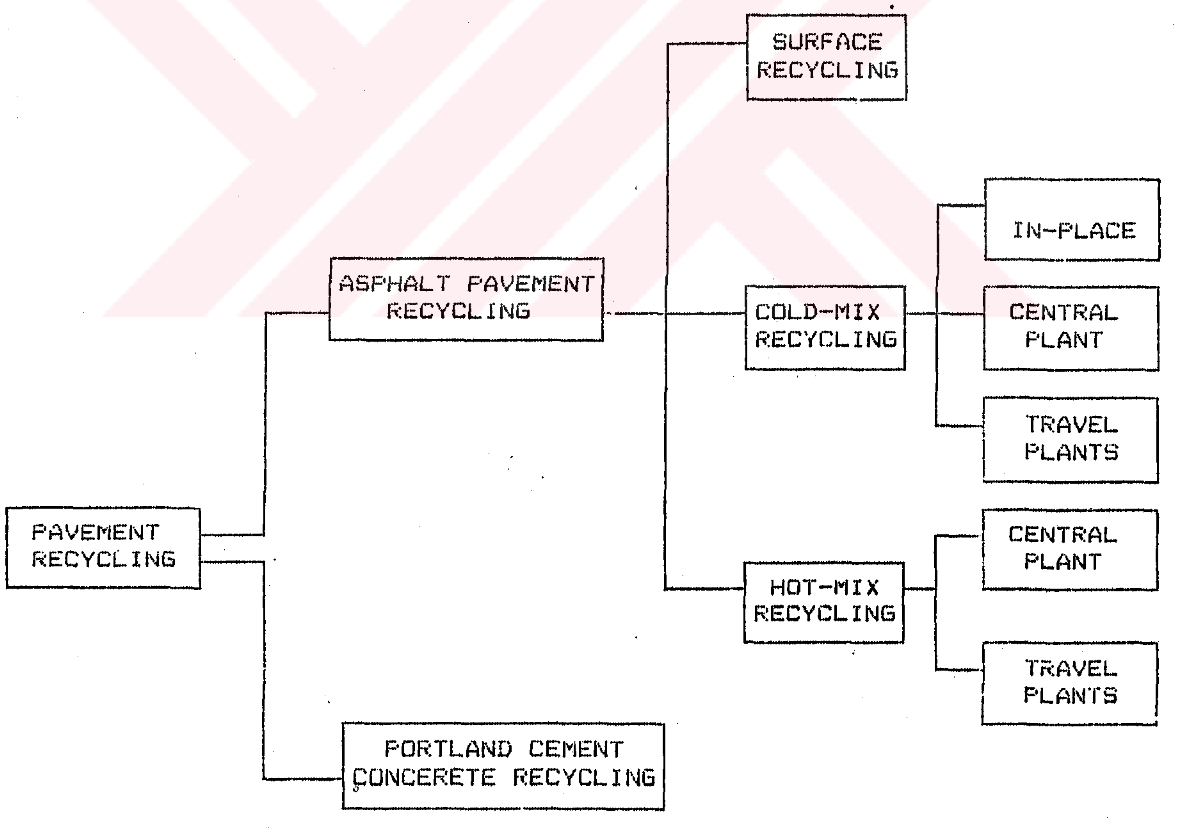


Figure 2.1. Recycling operation chart

2.1. Basic Knowledge About Each Main Type of Recycling

2.1.1. Asphalt pavement recycling

The reuse of an existing asphalt pavement is possible by employing one of three recycling procedures: Surface recycling, cold-mix recycling, or hot-mix recycling.

2.1.1.1. Surface recycling

The reworking in-place of the surface of an asphalt pavement to a depth of less than about two inches by the use of any suitable machinery available. This operation is a single- or multi-step process that may involve the use of added materials, including aggregate, modifiers, or asphalt mixtures.

2.1.1.2. Cold-mix asphalt pavement recycling

The reuse of untreated base materials and/or asphalt concrete pavement that is either processed in-place or at a central plant with the addition of asphalt emulsions, cutbacks, portland cement, lime and/or other materials as required to achieve the desired mix quality, followed by placement and compaction.

2.1.1.3. Hot-mix asphalt pavement recycling

The removal of more than the top one inches of an asphalt pavement with or without removal of underlying pavement layers (e.g.,untreated base materials) that is processed by sizing, heating, and mixing in a central plant with additional components such as aggregate, bitumen, or recycling agents and then relied and compacted according to standard specification for conventional hot mixtures such as asphalt concrete base, binder, and asphalt concrete leveling or surface course.

2.1.1.4. Portland cement concrete pavement recycling

The reuse of existing Portland cement concrete pavement by processing it into aggregate and sand sizes and then using it in-place or in some instances, with additions of conventional aggregate and sand into a new portland cement or asphalt concrete mixture or used as aggregate for a stabilized or unstabilized base.

Additional definition associated with asphalt pavement recycling are given in sections 2.1.1.5. and 2.1.1.6.

2.1.1.5. Asphalt modifier

A generic term describing any compound or material that is used as an admixture to alter or improve the properties of the asphalt binder in the recycled asphalt mixture included are asphalt cements, cutback asphalt, emulsified asphalt, and recycling agents.(2)

2.1.1.6. Asphalt recycling agent

A petroleum product additive with a combination of chemical and physical properties designed to restore aged asphalt to desired specification. The recycling agent should conform to the specifications contained in ASTM D 4552, 'standard practices for classifying hot-mix recycling agents '. (2)

2.2. Asphalt Pavement Recycling Processes

2.2.1. Surface recycling

Asphalt pavement surface recycling is limited to less than about two inches. Surface recycling is only suitable for correcting surface non-structural surface distress, not due to pavement structure are subgrade deficiencies, such as minor raveling, nonload associated cracking, minor corrugations, minor flushing or bleeding, poor construction practices, and poor drainage profile.

A wide variety of pavement surface removal equipment has been developed and several innovative techniques can be categorized into cold-planers, heater-planers, cold millers, and heaters-scarifiers. The first three types of equipment are generally used for pavement removal only and therefore are not technically part of a surface recycling process, though the removed material can be recycled in a separate operations. (2)

The most common surface recycling process is heater scarifying, which involves the heating and scarification of an asphalt pavement surface. The operation may include the addition of asphalt or other modifier scarification is usually limited to a depth of 3/4 in. to 1 in. in a single pass, though some equipment can penetrate deeper. The basic recycling operation using the heater-scarifying approach consist of preparing, heating, and scarifying the surface, adding additional materials, if required, compacting and making final adjustments to manholes and drainage structures.

To be suitable for the heaterscarifier process, the pavement section should contain at least 3 in. of an asphalt mixture and the surface course should not contained aggregate larger than 1 in. in the case of portland cement concrete pavements with and asphalt overlay there should be a minimum of 2 in. of asphalt over the PCC. Heater scarifiers are large pieces of equipment and may be impractical for step and curing mountain roads.

The equipment required for the heaterscarifier surface-recycling process generally consists of heaterscarifier, roller, distributor truck, and usually a paver.

The depth of scarification is the most critical element. The deeper the scarification, the better the finished product will be. In some circumstances, surface recycling with an overlay. Since the recycling process uses in-place material in the leveling procedure, there can be a reduction in the thickness of overlay required and ,in some cases, no overlay is required.(3)

Air quality problems may result when surface recycling old pavements that contain mixtures with cutback asphalts.(maintenance patches, seal coats, etc.)

2.2.2. Cold-mix asphalt recycling

Cold-mix asphalt recycling is a process in which reclaimed asphalt pavement materials, new aggregate and/or reclaimed aggregate materials, or both, are mixed with new asphalt and/or recycling agents to produce cold-mix base mixtures. The mixing may be done in-place or at a central plant, and the process does not require the addition of heat. The cold recycling base is usually covered with a hot-mix wearing surface or asphalt surface treatment to provide a water and abrasion resistant surface.(3)

Cold recycling can also involve the reworking of foundation materials and roadways without surfaces (i.e., untreated soils and aggregate) by means of mechanical or chemical stabilization. Available stabilizers include asphaltic materials, lime, portland cement, and fly ash in combination with lime, portland cement, and flue dust. The choice of stabilizer depends on the characteristics of the soil or aggregates.

There are several procedures that can be used for cold recycling. Figure 2.2 gives a summary flow chart of available procedures for cold in-place surface and base recycling.

Five basic steps in the construction of a cold recycled asphalt pavement are: 1) pavement removal and size reduction, 2) addition of new asphalt, recycling agent and mixing, 3) laydown and airation, 4) compaction and curing, and 5) application of wearing surface.

The initial step for any type of cold recycling process is to rip, scarify, pulverize, or mill the existing pavement to a specified depth.

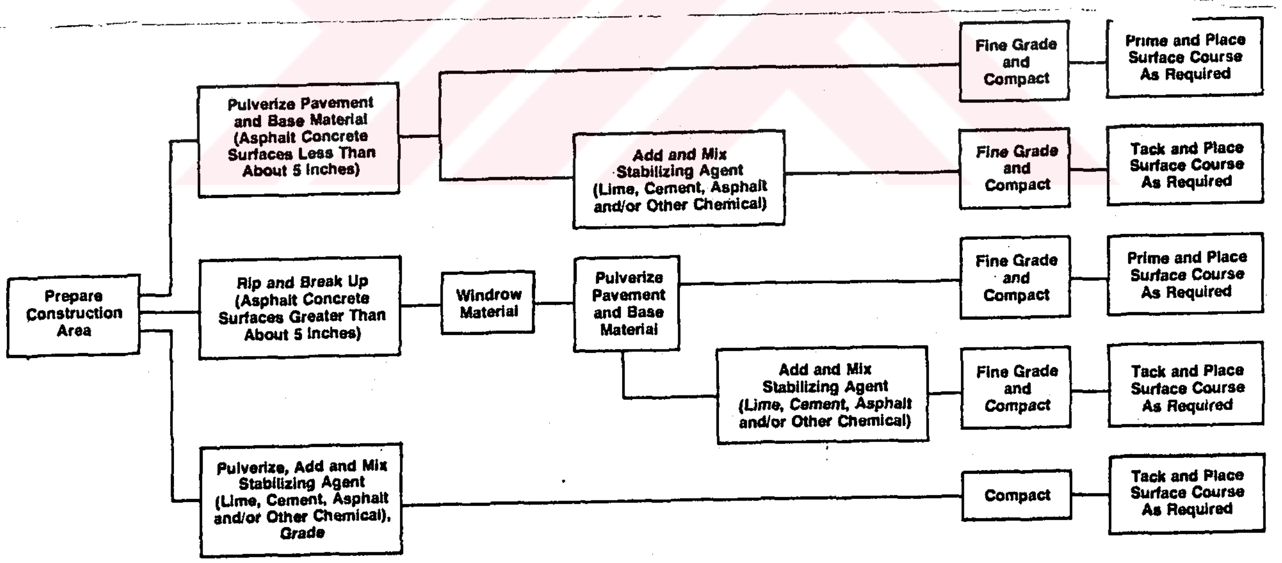


FIGURE 2. Procedures available for cold in-place surface and base recycling.

The broken-up material can than be further reduced in size (if necessary) and mixed with new asphalt and/or recycling agent in-place, or it can be hauled to a central plant location where it is crushed (if necessary), stockpiled, fed into a conventional batch or drum plant for mixing, and hauled back to the job site for laydown and compaction. The choice of which method to use will depend on several factors such as equipment availability, condition of the existing roadway, and economics.For example, in-place recycling is especially applicable to secondary low-volume roads that are located at a considerable distance from a central plant. On the other hand, central-plant mixing allows better quality control and affords the best opportunity to produce a uniform recycled mix, since the reclaimed material can be segregated into various stockpiles, based on property variation and then reblended. (4)

2.2.3. Hot-mix asphalt recycling

Hot-mix recycling is a process in which reclaimed asphalt pavement (RAP) materials, reclaimed aggregate materials (RAM), or both, are combined with new aggregate and/or asphalt, and/or recycling agents, as necessary, in a central plant blending and mixing operation to produce hot-mix paving mixtures. The finished product,is generally required to meet standard materials specifications and construction requirements for the type of asphalt concrete mixture being produced. With equipment now available, all hot-mix producers can recycle using relatively inexpensive additions or modifications to their existing plants, or using plants designed specifically for recycling, without violating air quality regulations.(4) Hot-mix recycling can be a standard procedure in road maintenance and rehabilitation practices if it is satisfies the following economical, technical, and environmental needs of the highway engineer:

* Achieve productivity levels similar to conventional hot-mixes
* produce stable mixes equivalent to new asphalt mixes. Both the aggregate and asphalt in the recycled mix must need the same requirements as new materials.
* Be an environmentally acceptable system (i.e., that limits 'blue smoke' during production).

Hot-mix recycling, although relatively new, is a proven technology and is much less experimental in nature than many of the cold-recycling techniques, with the increased use of the drum-mix plant and it adaptability for recycling, the amount of hot recycled material being produced each year has increased. It was estimated in 1980 that about ten percent of the asphalt concrete hot-mix market would be supplied by hot central plant recycling operations in the next three to five years. In 1985 the estimate ran to 15 percent or higher. (5)

In comparing cold recycling with hot recycling, there are several advantages of hot central plant operations. Excellent quality control can be obtained in terms of particle sizing, modifier and total binder content, blending percentages of new and recycled aggregate, and mixture homogeneity. The process can be used to repair all types of pavement including high traffic volume facilities.

Four basic construction activities are required in the hot-mix recycling process: 1) removing existing asphalt pavement; 2) preparing reclaimed pavement for hot-mix recycling, stockpiling, and crushing; 3) processing the blend of old and new materials in a hot-mix plant and; 4) placing the material on the roadway.

Much of the same equipment used for pavement removal and size reduction in cold-recycling can be used for hot recycling, several procedures have been developed that allow the use of RAP in a central-plant hot-mix process. Both batch plants and drum-mix plants have been successfully modified to produce hot recycled mixtures. Plants specifically designed for recycling are also available.(5)

2.3. Design of Recycled Mixes

2.3.1. Cold-mix recycling

There are certain basic steps that must be included in the mix-design procedure. These can be generalized as follows:

* Obtain representative field samples from the pavement or from stockpiles of the reclaimed materials.

* Perform laboratory analysis: determine composition and properties of the reclaimed materials, evaluate the deficiencies of the reclaimed material and determine the need for additional aggregate, select the type and amount of asphalt modifier, and mix, compact, and test trial mixtures.

* Select the optimum combination of mix components as initial target value and adjust in the field as necessary.

Figure 2.3.shows a generalized flow chart of the basic steps in the mix design procedure for cold asphalt pavement recycling.

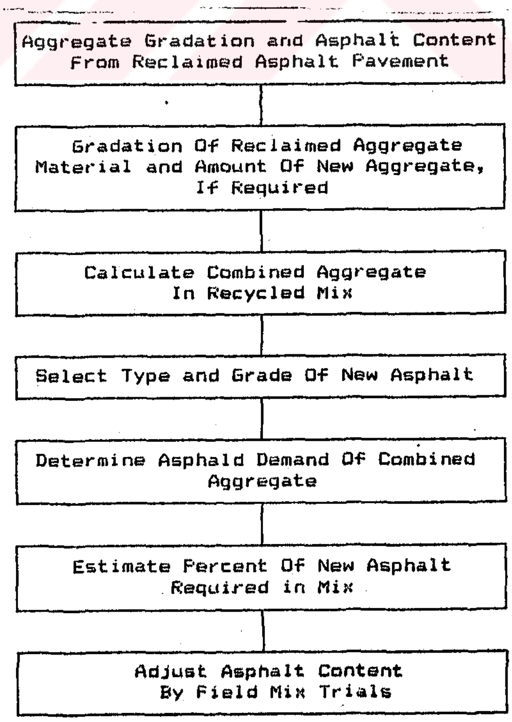


Figure 2.3. Mix Design Flow Chart For Cold -Mix Recycling Procedure.

Although there are many similarities between the mix design procedures for hot-recycled and cold-recycled asphalt mixtures, there are certain differences between the two mix types that must be considered. These involve primarily the time-temperature effects associated with the presence of water and the slower binder softening rate in cold-recycled mixes. Consequently, changes in mixture properties with time, in addition to target redications in aged binder consistency of the RAP, are important considerations in cold-recycled mix design.

2.3.2. Hot-mix recycling

All hot-mix recycling of reclaimed asphalt pavements is done by the heat-transfer method. Recycled mixtures can and have been successfully produced in both batch and drum-mix plants.

In batch plants the heat-transfer method comprises the use of super-heated aggregate (new and/or reclaimed) to increase the temperature of reclaimed asphalt pavement.

In the drum-mix process also takes place. Three major approaches have been used. One process depended entirely on indirect heating by the exhaust gases. The second process uses convection heating by containing the complete combustion process and by turbulent air mixing action which develops a uniform gas temperature distribution.(3)

The third process heats the new or reclaimed aggregate in the front of the drum, introduces the reclaimed asphalt pavement at approximately the center of the drum and heats (by convection and conduction), and mixes through the remainder of the drum.(3)

The resulting mixture from either batch or drum-mix plants, at conventional mix temperatures is discharged into a surge bin or houl trucks. he recycled material is placed on the roadway using conventional paving and compaction equipment.

In the laboratory work for hot-mix recycling, the followings should be covered:

* Evaluation of the RAP

a. Determine the asphalt content (ASTM D-2172 Extraction)

This is done to certain amount of asphalt in the RAP which could be regained by recycling. If it is less than 1%, it cannot be recovered and the RAP will be considered as untreated aggregate.

b. Determine the gradation of the extracted aggregate (ASTM C-136)

The gradation of the existing aggregate in the RAP should be determined so that untreated aggregate of appropriate size can be added in order to bring it to desired gradation and hardness.

c. Recover the asphalt from the solution of trichloroethylene (ASTM D-1856)

In this step, the mix is heated until the ethylene evaporates and is collected with the condensation for reuse. The residue is kept in a tray for later use.

d. Determine viscosity at 60 °C (ASTM D-2171) or viscosity at 135 C (ASTM D-2170) plus penetration at 25°C (ASTM D-5)

Usually, since the recovered asphalt is very hard, the second option yields a more promising solution.

* Select the desired viscosity of the final binder

Depending upon the climate and thickness of the recycled pavement to be laid, the viscosity of the final binder is decided. Usually in areas like Ankara, AC-10 with 1000 P. viscosity at 60°C is used.

* Select the gradation of new aggregate according to specification compliance

a. Determine the gradation of new aggregate (ASTM C-136)

b. Calculate the required binder percentage to meet grading specifications

The above would also be used in regulating the openings of the bins in plants.

* Estimate binder demand

The CKE test is used to obtain the optimum binder demand.

* Determine mix proportions for trial mixes

* Make and test trial mixes

For this step either the Marshall or Hveem methods can be used.

* Select the job-mix formula

This will give the result of the laboratory work in a short statements for the type of hot-mix recycling technique being used for a particular job.

The essential factor in achieving optimum output and success in any of the recycling techniques, is the close following and effective control of the laboratory work.

A comprehensive study of hot recycling mix-design was conducted for FHWA by The Asphalt Institute. Figure 2.4. is a flow chart of the basic steps in the Institute's recommended design procedure.(5)

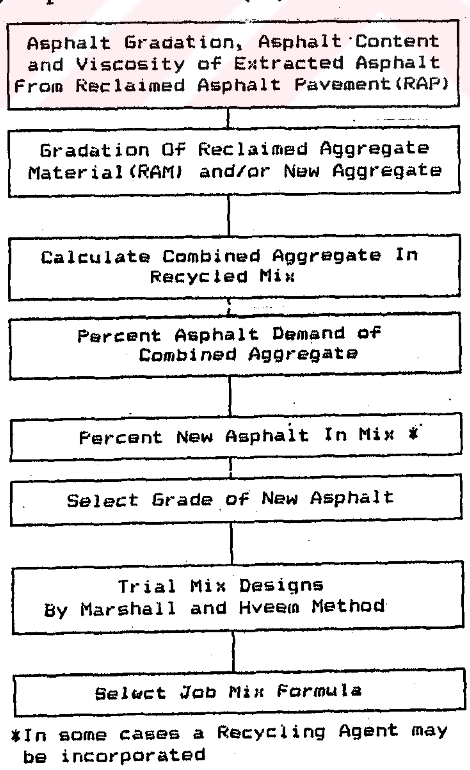


Figure 2.4. Mix Design Flow Chart For Hot -Mix Recycling Procedure.

CHAPTER 3

MATERIAL PROPERTIES

3.1. General

Physical properties of the materials used in the asphaltic concrete which is prepared in the laboratory are presented in this chapter.

3.2. Bitumen

The bitumen used in the mixtures was 67 pen. and obtained from the General Directorate of Turkish Highways.

The properties of the bitumen were determined by a series of laboratory asphalt tests in METU Transportation laboratory. These properties are shown on the Table 3.1.

Table 3.1. Physical Properties of Bitumen

Penetration	67
Specific Gravity	1.02
Ring & Ball Softening Point (°C)	54
Temperature Succeptibility	
A=(Log800 - LogP25) / T r&b - 25°C	0.037
Penetration Index	0.5

3.3. Mineral Aggregates

Lime stone used in the mixes were brought from ENKA-BECHTEL motorway site. They were crushed both to make them angular and to fit to the selected gradation specification.

The selected gradation specification was Type A Bituminous Base course of Turkish Highway Department.

The specific gravity of coarse, fine and filler part of the aggregates and the specification ranges were shown on the Tables 3.2. and 3.3 respectively.

Table 3.2. Physical Properties of Mineral Aggregates

PROPERTY	COARSE	FINE	FILLER
Specific Gravity	2.717	2.723	2.713

Table 3.3. Type A Bitumious Base Course Gradation Specification

Sieve Size	% Passing
1 1/2	100
1	72-100
3/4	60-90
1/2	50-78
3/8	43-70
No.4	30-55
No.10	18-42
No.40	6-21
No.80	2-13
No. 200	0-7

3.4. Mixture Properties

The existing asphalt content of the reclaimed asphalt pavement taken from the test road between Ankara and Eskisehir was found as 5.75 % by means of the Exraction test performed in METU Transportation Laboratory.

The optimum asphalt content of the bituminous base course was found as 3 % by means of the Marshall test performed at KGM asphalt laboratory.

The specimens prepared from the reclaimed asphalt pavement were used without adding anything and they were compacted by applying 50 blow efforts on each side.

The recycled specimens were prepared by the addition of asphalt and aggregate to the reclaimed material at certain amounts according to the predetermined reclaimed and new material percentages.These percentages and related asphalt and aggregate amounts are given in Chapter 4.

CHAPTER 4

EXPERIMENTAL PROCEDURES

4.1. General

Since the aim of this study is to determine the optimum percentages of reclaimed and new materials, the experiments were performed on these reclaimed and recycled materials.

Firstly, it was necessary to determine the existing asphalt content and aggregate gradation of RAP material in order to determine the additional amounts of these materials. Therefore, an extraction and sieve analysis tests were performed on six samples.

4.2. Preparation of Specimens

4.2.1. Reclaimed Specimens

The material taken from the scarified pavement was heated to 150°C, mixed and compacted with 50 blow effords on each side by using Marshall test equipments in the laboratory. The results are shown in Tables 4.1. and 4.2.

4.2.2. Recycled Specimens

In order to prepare the recycled bituminous base course specimens, it was necessary to determine the amounts of asphalt and aggregate to be added to the RAP

Table 4.1. Heights of Marshall Specimens for RAP

SAMPLE	HEIG.1	HEIG.2	HEIG.3	AVE.	Wair	Wwat
1	60.6	60.4	60.7	60.56	1107.0	637.0
2	58.8	58.6	58.4	58.60	1094.0	634.0
3	59.4	59.4	59.6	59.46	1100.0	637.0
4	60.0	60.4	60.0	60.13	1115.0	644.0
5	60.2	60.0	60.3	60.16	1111.0	640.0
6	60.3	61.0	60.5	60.6	1110.5	638.0

Table 4.2. Marshall Tests Result for RAP

SAMPLE	STABILITY	FACTOR	STABILITY**	FLOW
1	1271.84	1.079	1372.32	6-7
2	1275.83	1.143	1458.28	7
3	1328.93	1.114	1480.43	6
4	1121.35	1.094	1226.76	6
5	1218.11	1.090	1327.74	9
6	1387.38	1.079	1496.98	10

material according to the varying asphalt contents and aggregate gradation specification (Type A) of the bituminous base course.

These percentages of RAP and new materials, and corresponding aggregate and asphalt requirements are shown in Tables 4.3., 4.4., 4.5., 4.6., 4.7., 4.8., 4.9., 4.10., 4.11., 4.12., 4.13. and 4.14.

The asphalt and aggregate were added to the RAP material according to these calculated amounts and the laboratory hot-mix procedure was applied to this mixed material with 50 blow efforts. Three specimens were prepared for each asphalt content.

After the removal of the specimens from the molds, they were allowed to cool at room temperature at about 24 hours and then they weighted in air and in water. Related properties of both reclaimed and recycled specimens were calculated from these weightings.

Before their stability and flow values were measured by using Marshall apparatus, they were soaked into the 60 C water bath for 30 minutes according to the Marshall Test requirements.

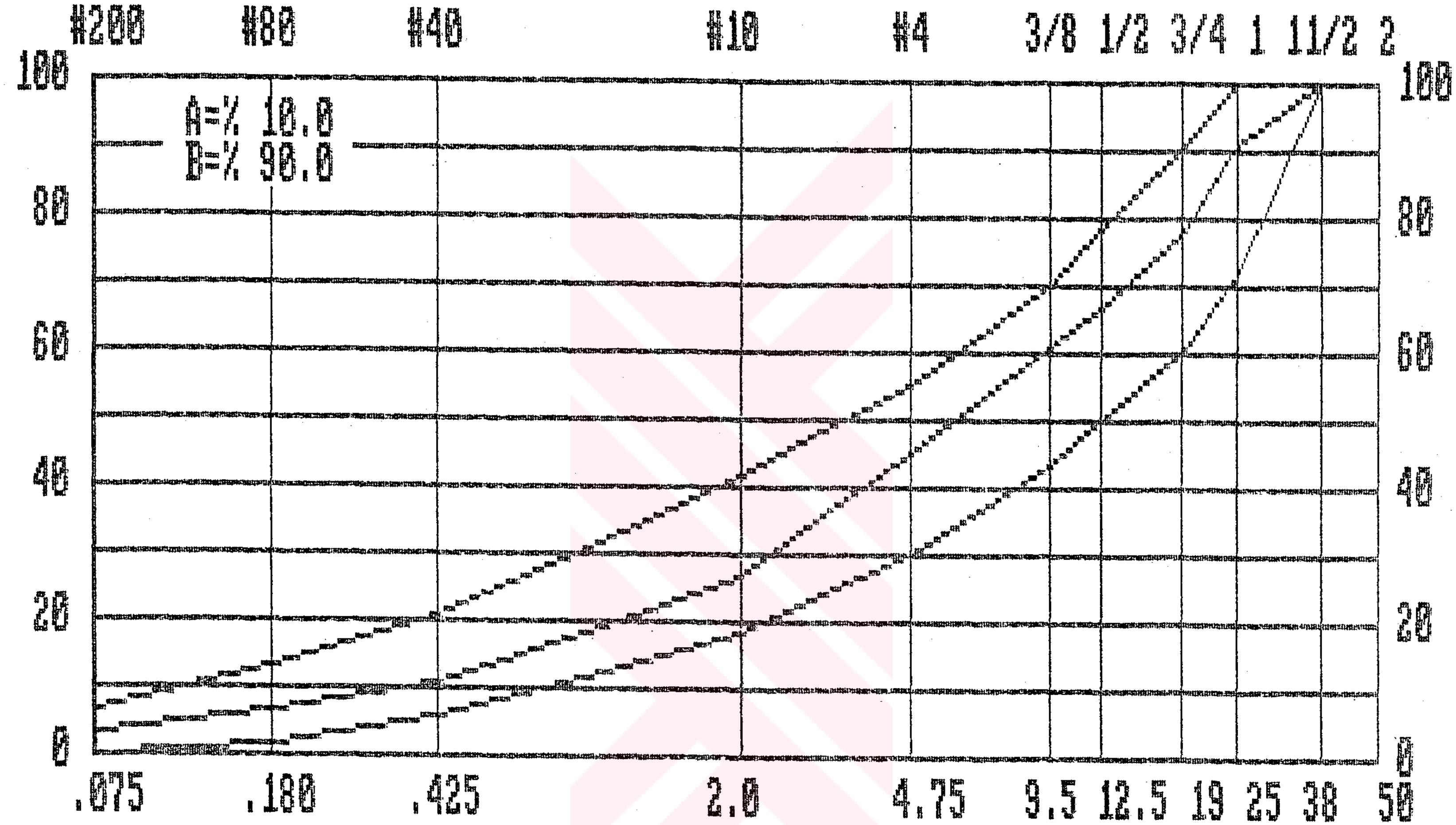
The test results are given in Chapter 5.

Table 4.3. Determination of Additional Asphalt Amount

OLD = % 10		NEW = % 90	
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	15.59	5.98	21.57
2.5	20.85	5.98	26.83
3.0	26.06	5.98	32.04
3.5	31.22	5.98	37.20
4.0	36.33	5.98	42.31

Table 4.4. Determination of Additional Aggregate Amount

SIEVE		% 10	% 90	% 10 OLD (gr)	% 90 NEW (gr)
NO.	DIAM.	OLD	NEW		
3/2	38.1	100	100	----------	----------
1	25.4	100	90	----------	99.00
3/4	19.1	100	75	----------	247.50
1/2	12.7	94	64	----------	356.40
3/8	9.52	86.3	58	15.70	415.80
4	4.76	68	42	35.20	574.20
10	2.00	45.2	25	60.28	742.50
40	0.42	18.3	10	89.87	891.00
80	0.18	11.2	6	97.68	930.60
200	0.074	7	3	102.30	960.30



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	91.0	77.5	67.0	60.8	44.6	27.0	10.8	6.5	3.4

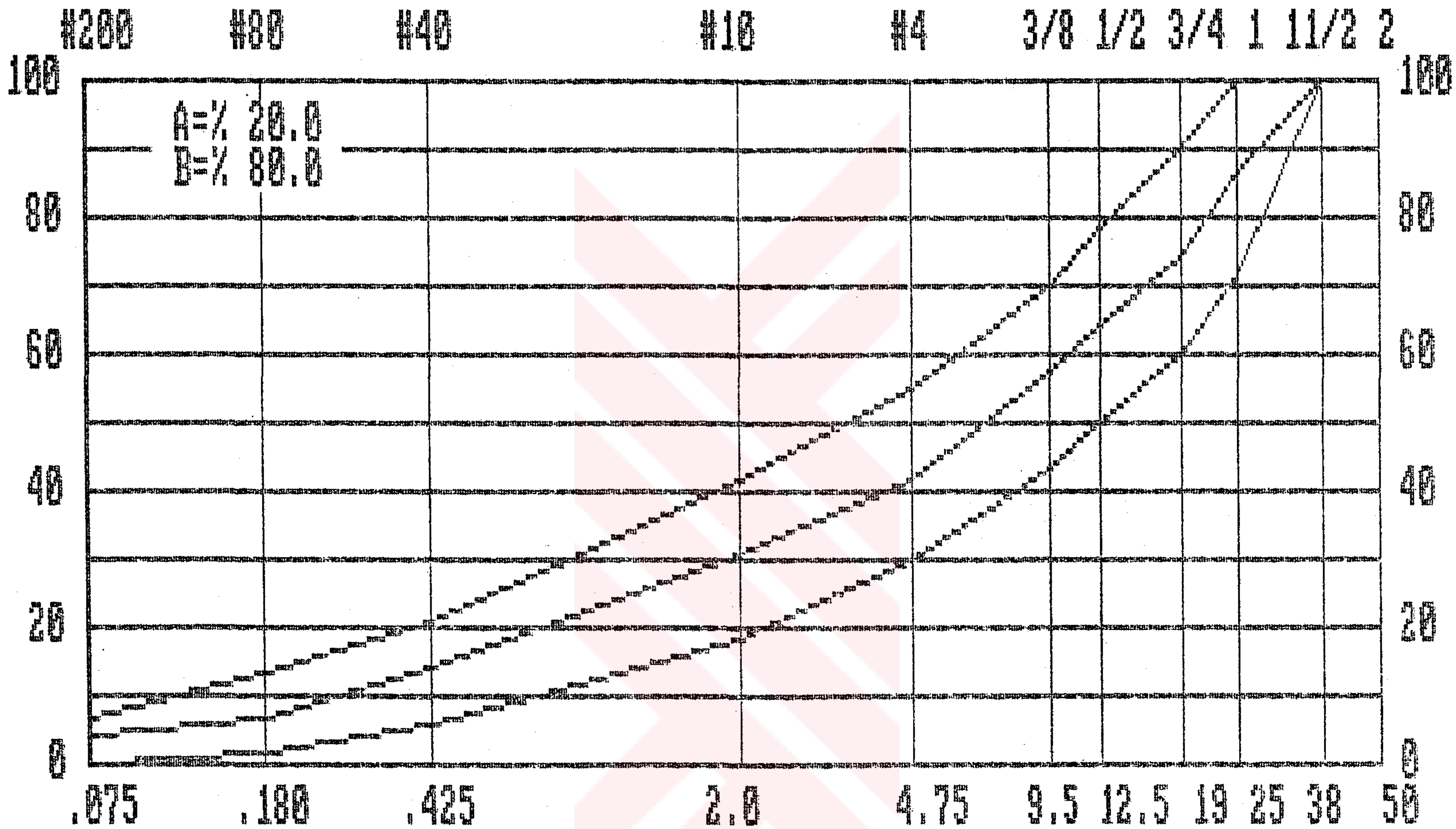
Figure 4.1. Sieve Analysis for 10-90 rates

Table 4.5. Determination of Additional Asphalt Amount

OLD = % 20		NEW = % 80	
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	9.61	11.96	21.57
2.5	14.87	11.96	26.83
3.0	20.08	11.96	32.04
3.5	25.24	11.96	37.20
4.0	30.35	11.96	42.31

Table 4.6. Determination of Additional Aggregate Amount

SIEVE		% 20	% 80	% 20 OLD (gr)	% 80 NEW (gr)
NO.	DIAM. mm	OLD	NEW		
3/2"	38.1	100	100	----------	----------
1"	25.4	100	83	----------	149.6
3/4"	19.1	100	68	----------	281.6
1/2"	12.7	94	57	13.2	378.4
3/8"	9.52	86.3	50	30.1	440.0
4	4.76	68	35	70.4	572.0
10	2.00	45.2	27	120.6	642.4
40	0.42	18.3	13	179.7	765.6
80	0.18	11.2	6	195.4	827.2
200	0.074	7	3	204.6	853.6



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	86.4	74.4	64.4	57.3	41.6	30.6	14.1	7.0	3.8

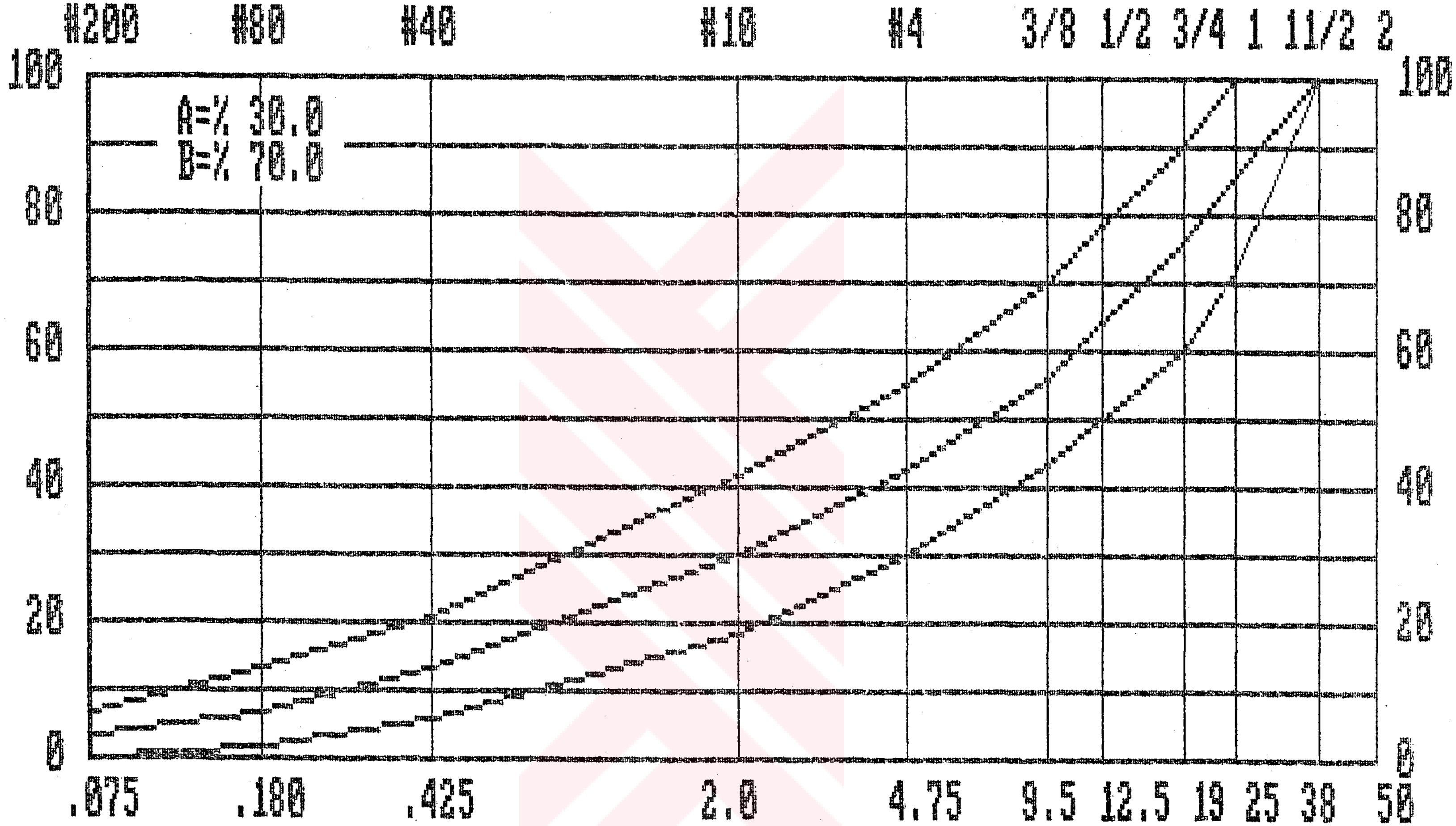
Figure 4.2. Sieve Analysis for 20–80 rates

Table 4.7. Determination of Additional Asphalt Amount

OLD = % 30	NEW = % 70		
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	3.63	17.94	21.57
2.5	8.89	17.94	26.83
3.0	14.10	17.94	32.04
3.5	19.26	17.94	37.20
4.0	24.37	17.94	42.31

Table 4.8. Determination of Additional Aggregate Amount

SIEVE		% 30	% 70	% 30 OLD (gr)	% 70 NEW (gr)
NO.	DIAM.	OLD	NEW		
3/2"	38.1	100	100	----------	----------
1"	25.4	100	90	----------	154.0
3/4"	19.1	100	75	----------	269.5
1/2"	12.7	94	64	19.8	373.3
3/8"	9.52	86.3	58	45.2	438.9
4	4.76	68	42	105.6	523.6
10	2.00	45.2	25	180.8	585.2
40	0.42	18.3	10	269.6	685.3
80	0.18	11.2	6	293.1	731.5
200	0.074	7	3	306.9	754.6



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	86.0	75.5	63.9	56.0	42.8	30.4	13.2	6.9	3.5

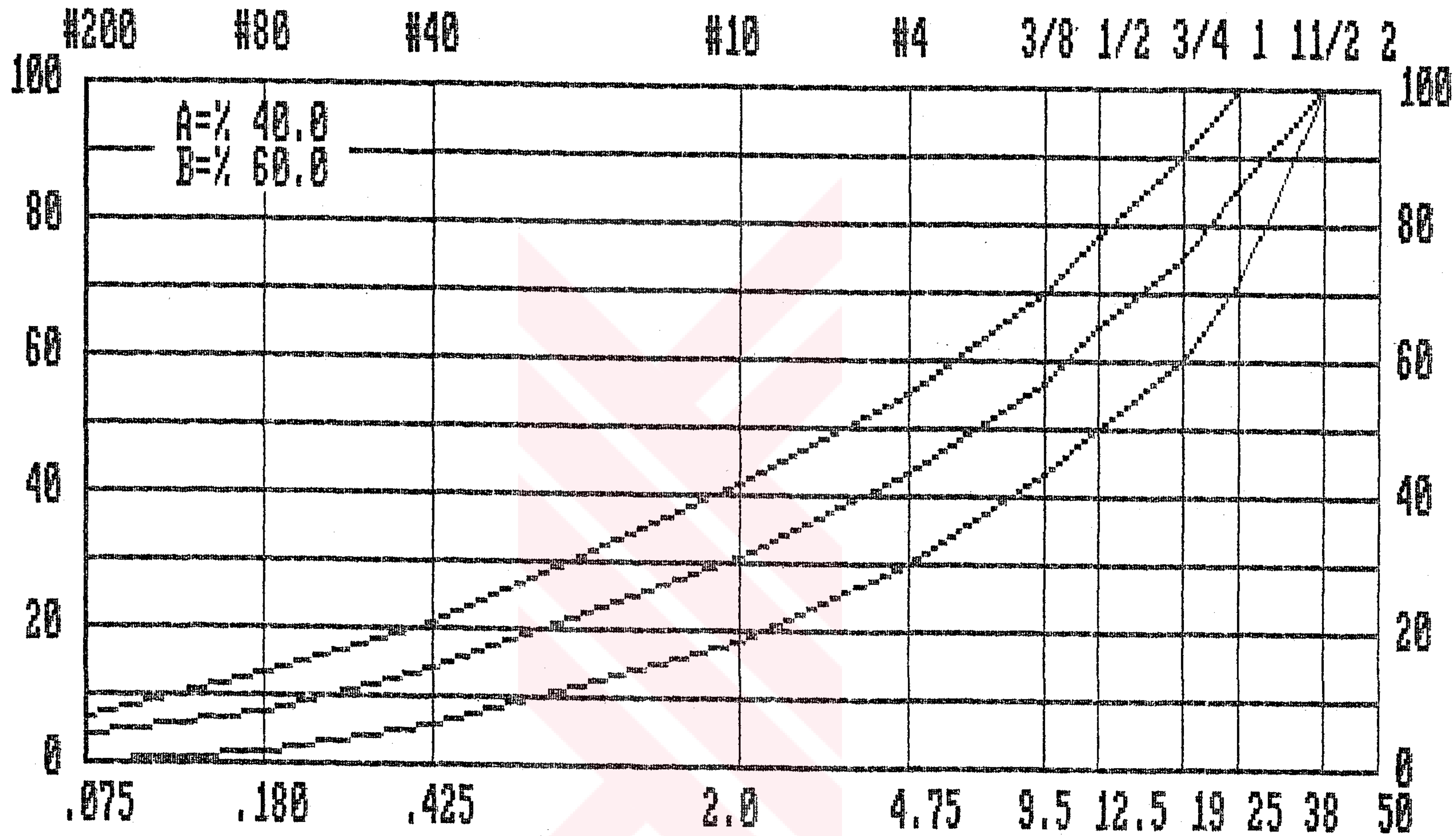
Figure 4.3. Sieve Analysis for 30-70 rates

Table 4.9. Determination of Additional Asphalt Amount

OLD = % 40		NEW = % 60	
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	- 2.35	23.92	21.57
2.5	2.91	23.92	26.83
3.0	8.12	23.92	32.04
3.5	13.29	23.92	37.20
4.0	18.39	23.92	42.31

Table 4.10. Determination of Additional Aggregate Amount

SIEVE		% 40	% 60	% 40 OLD (gr)	% 60 NEW (gr)
NO.	DIAM.	OLD	NEW		
3/2"	38.1	100	100	----------	----------
1"	25.4	100	77	----------	151.80
3/4"	19.1	100	59	----------	270.60
1/2"	12.7	94	45	26.40	363.00
3/8"	9.52	86.3	37	60.28	415.80
4	4.76	68.0	27	140.80	481.80
10	2.00	45.2	21	241.12	521.40
40	0.42	18.3	11	359.48	587.40
80	0.18	11.2	5	390.72	627.00
200	0.074	7	2	490.20	646.80



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	86.2	75.4	64.6	56.7	43.4	30.7	13.9	7.5	4.0

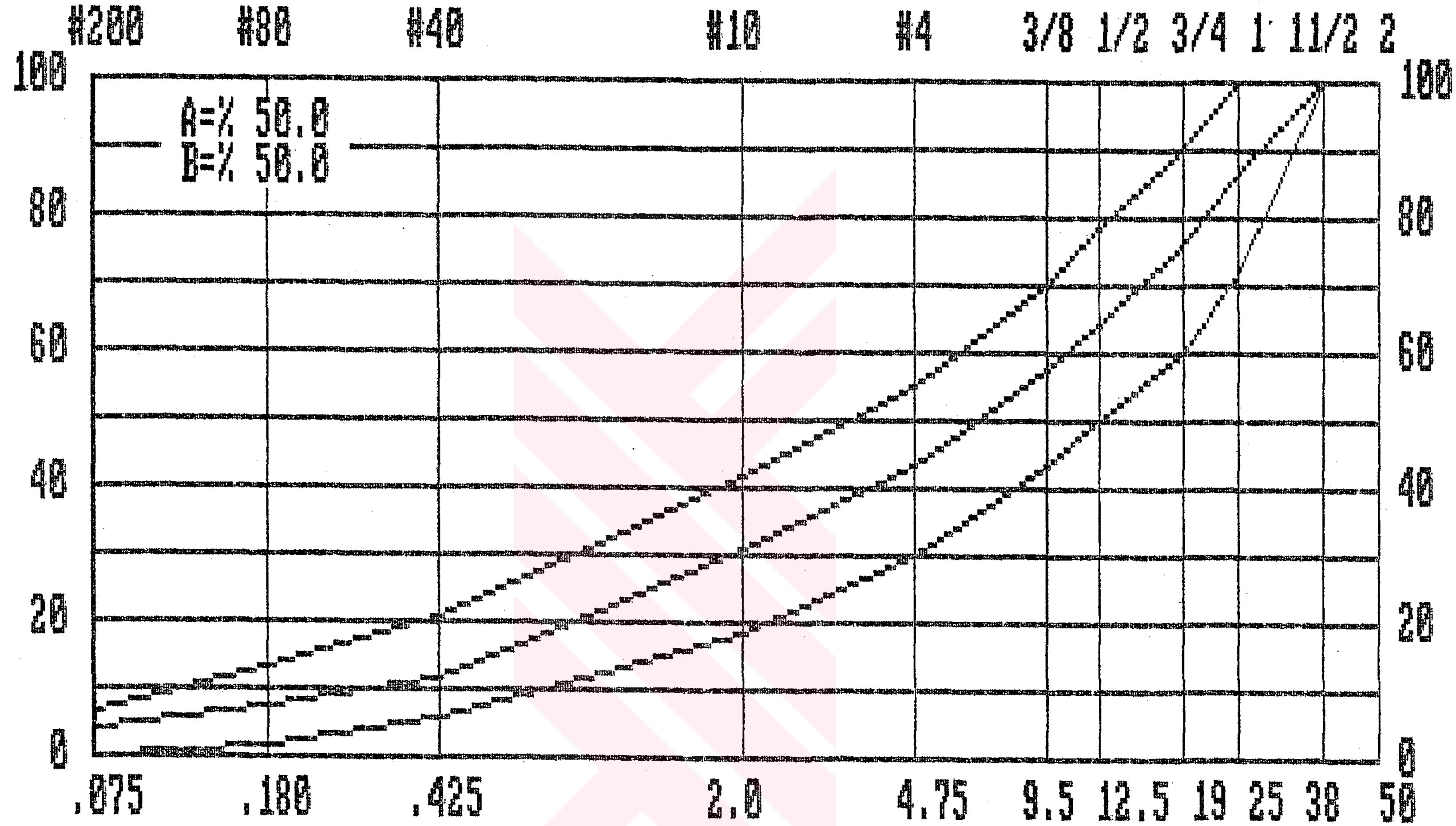
Figure 4.4. Sieve Analysis for 40-60 rates

Table 4.11. Determination of Additional Asphalt Amount

OLD = % 50		NEW = % 50	
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	- 8.34	29.91	21.57
2.5	- 3.08	29.91	26.83
3.0	2.13	29.91	32.04
3.5	7.29	29.91	37.20
4.0	12.04	29.91	42.31

Table 4.12. Determination of Additional Aggregate Amount

SIEVE		% 50	% 50	% 50	% 50
NO.	DIAM.	OLD	NEW	OLD (gr)	NEW (gr)
3/2"	38.1	100	100	----------	----------
1"	25.4	100	73	----------	148.50
3/4"	19.1	100	51	----------	269.50
1/2"	12.7	94	34	33.00	363.00
3/8"	9.52	86.3	28	75.35	369.00
4	4.76	68.0	19	176.00	445.50
10	2.00	45.2	16	301.40	462.00
40	0.42	18.3	5	449.35	522.50
80	0.18	11.2	3	448.40	533.50
200	0.074	7.0	1	511.50	544.50



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	86.5	75.5	64.0	57.2	43.5	30.6	11.7	7.1	4.0

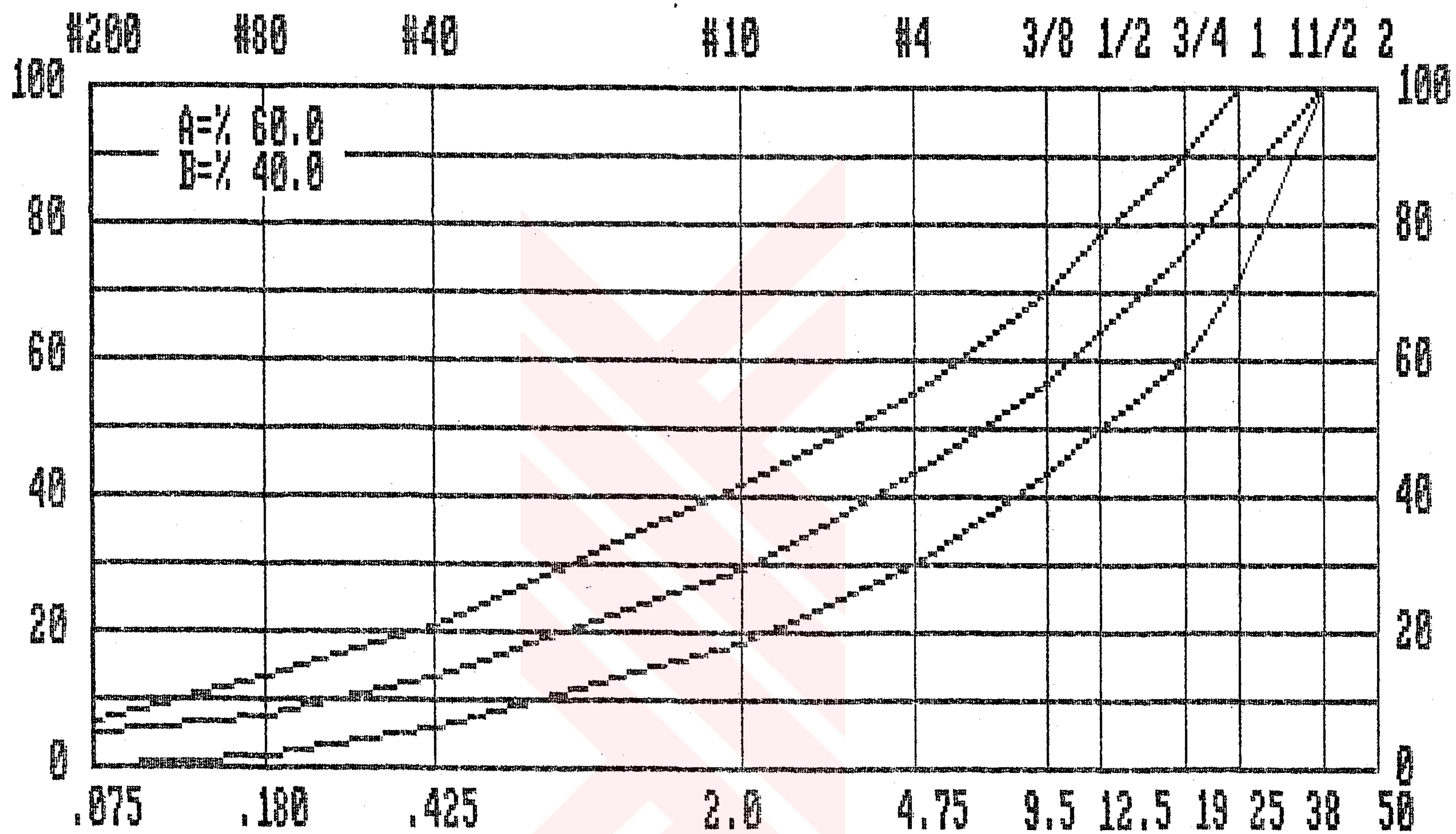
Figure 4.5. Sieve Analysis for 50–50 rates

Table 4.13. Determination of Additional Asphalt Amount

OLD = % 60		NEW = % 40	
A/C	ADDITION (gr)	ASPHALT IN PLACE (gr)	TOTAL ASPHALT (gr)
2.0	- 14.32	35.89	21.57
2.5	- 8.06	35.89	26.83
3.0	- 3.85	35.89	32.04
3.5	1.31	35.89	37.20
4.0	6.42	35.89	42.31

Table 4.14. Determination of Additional Aggregate Amount

SIEVE		% 60	% 40	% 60 OLD (gr)	% 40 NEW (gr)
NO.	DIAM.	OLD	NEW		
3/2"	38.1	100	100	----------	----------
1"	25.4	100	65	----------	154.00
3/4"	19.1	100	39	----------	268.40
1/2"	12.7	94	20	39.60	352.00
3/8"	9.52	86.3	13	90.42	382.80
4	4.76	68.0	7	211.20	409.20
10	2.00	45.2	6	361.68	413.60
40	0.42	18.3	5	539.22	418.00
80	0.18	11.3	2	586.08	431.20
200	7.0	7	1	613.80	435.60



SIEVE SIZE	38	25	19	12.5	9.5	4.75	2	.425	.18	.075
PASS %	100.0	86.0	75.6	64.4	57.0	43.6	29.5	13.0	7.5	4.6

Figure 4.6. Sieve Analysis for 60–40 rates

CHAPTER 5

EVALUATION OF TEST RESULTS

5.1. General

The chapter deal with the evaluation of test results.

It can be seen from the Figures 5.1., 5.2., 5.3., 5.4., 5.5. and 5.6. that as the rate of RAP material increases, the Marshall Stability of the mix increases.

The other properties such as practical unit weight, flow, void content, void filled with asphalt are also in the bituminous base specification ranges. These results can be seen from Figures 5.7. to 5.30.

Determination of optimum asphalt content from these figures by considering the bituminous base course specification is given in Table 5.1.

Table 5.1. Determination of optimum asphalt content

RATES		A/C					
OLD	NEW	STAB.	FLOW	P.U.W.	Vh	Vf	AVE.
10	90	3.25	3.00	3.40	3.50	3.40	3.31
20	80	3.25	3.00	4.00	3.40	3.50	3.43
30	70	3.75	4.00	3.60	3.40	3.40	3.63
40	60	3.25	2.60	3.50	3.30	3.40	3.21
50	50	3.75	3.60	3.70	3.00	3.30	3.47
60	40	3.35	3.80	3.85	3.20	3.20	3.47

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability
1	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
2	2.00	1.96	22.00	60.50	61.50	60.30	60.77	1128.70	659.70	469.00	2.407	11.20	365.00	1.073	392
3	2.00	1.96	22.00	63.50	63.50	64.50	63.83	1101.20	633.80	467.40	2.356	14.00	325.00	0.992	322
							AVERAGE				2.381	12.600			357.022
4	2.50	2.44	26.84	63.50	64.00	64.00	63.83	1086.40	636.30	450.10	2.414	12.80	475.00	0.992	471
5	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
6	2.50	2.44	26.84	62.00	62.30	63.00	62.43	1133.30	664.10	469.20	2.415	13.60	430.00	1.028	442
							AVERAGE				2.415	13.200			456.620
7	3.00	2.91	32.01	63.70	63.10	63.20	63.33	1104.60	654.60	450.00	2.455	16.00	475.00	1.006	478
8	3.00	2.91	32.01	65.00	65.00	64.70	64.90	1113.00	648.00	465.00	2.394	12.80	430.00	0.965	415
9	3.00	2.91	32.01	64.40	64.70	64.00	64.37	1094.40	639.50	454.90	2.406	15.00	490.00	0.978	479
							AVERAGE				2.418	14.600			457.340
10	3.50	3.38	37.18	63.00	63.70	64.50	63.73	1117.20	656.90	460.30	2.427	15.00	430.00	0.995	428
11	3.50	3.38	37.18	63.40	64.00	64.90	64.10	1112.40	651.60	460.80	2.414	14.80	485.00	0.985	478
12	3.50	3.38	37.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				2.421	14.900			452.788
13	4.00	3.85	42.35	64.00	64.00	63.00	63.67	1117.10	654.30	462.80	2.414	15.20	385.00	0.995	383
14	4.00	3.85	42.35	62.00	61.90	62.00	61.97	1114.70	655.10	459.60	2.425	16.00	410.00	1.038	426
15	4.00	3.85	42.35	64.10	64.30	64.60	64.33	1124.60	658.90	465.70	2.415	16.00	425.00	0.980	417
							AVERAGE				2.418	15.733			408.385

Group	DT	Vh	Va	Sb	Sa	Vf
1–3	2.636	9.65	14.15	4.50	85.85	31.79
4–6	2.616	7.70	13.38	5.68	86.62	42.43
7–9	2.597	6.89	13.66	6.78	86.34	49.61
10–12	2.578	6.11	13.99	7.88	86.01	56.33
13–15	2.560	5.54	14.51	8.97	85.49	61.81

Gk = 2.717
Gi = 2.723
Gf = 2.713
Coarse% = 55.400

Gb = 1.038
Fine % = 41.200
Filler% = 3.400

A/C	Vh	P.U.W.	STABILITY	FLOW	Vf
2	9.65	2.381	357	12.6	31.79
2.5	7.70	2.415	456	13.2	42.43
3	6.89	2.418	457	14.6	49.61
3.5	6.11	2.421	452	14.9	56.33
4	5.54	2.418	408	15.7	61.81

Table 5.2. Marshall test results for 10–90 rates

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability		
1	2.00	1.96	22.00	63.30	62.90	64.10	63.43	1111.10	635.80	475.30	2.338	13.60	385.00	1.003	386	GT = 2.635	Sb = 4.38
2	2.00	1.96	22.00	64.00	63.70	64.10	63.93	1123.60	637.90	485.70	2.313	16.80	400.00	0.990	396	Vh = 11.89	Sa = 83.73
3	2.00	1.96	22.00	62.20	61.90	61.40	61.83	1108.50	629.70	478.80	2.315	15.20	410.00	1.044	428	Va = 16.27	VF = 26.94
							AVERAGE				2.322	15.200			403.398		
4	2.50	2.44	26.84	65.00	64.90	64.10	64.67	1096.40	629.00	467.40	2.346	16.80	460.00	0.970	446	GT = 2.616	Sb = 5.48
5	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0	Vh = 10.83	Sa = 83.68
6	2.50	2.44	26.84	65.80	65.80	65.70	65.77	1101.80	626.70	475.10	2.319	14.80	410.00	0.945	387	Va = 16.32	VF = 33.60
							AVERAGE				2.332	15.800			416.825		
7	3.00	2.91	32.01	61.20	61.20	61.80	61.40	1105.20	642.70	462.50	2.390	16.00	440.00	1.056	465	GT = 2.597	Sb = 6.66
8	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0	Vh = 8.48	Sa = 84.86
9	3.00	2.91	32.01	62.40	62.80	62.70	62.63	1103.80	636.70	467.10	2.363	16.80	490.00	1.023	501	Va = 15.14	VF = 43.99
							AVERAGE				2.376	16.400			482.955		
10	3.50	3.38	37.18	63.50	63.10	63.00	63.20	1131.70	667.70	464.00	2.439	16.00	575.00	1.008	580	GT = 2.578	Sb = 7.90
11	3.50	3.38	37.18	61.50	62.20	61.00	61.57	1116.60	655.00	461.60	2.419	13.60	580.00	1.050	609	Vh = 5.85	Sa = 86.25
12	3.50	3.38	37.18	63.00	63.00	63.50	63.17	1109.70	651.80	457.90	2.423	15.20	525.00	1.008	529	Va = 13.75	VF = 57.47
							AVERAGE				2.427	14.933			572.600		
13	4.00	3.85	42.35	65.00	65.50	66.00	65.50	1108.60	652.00	456.60	2.428	15.20	400.00	0.951	380	GT = 2.560	Sb = 8.99
14	4.00	3.85	42.35	64.00	64.00	64.00	64.00	1117.60	657.90	459.70	2.431	14.40	425.00	0.988	420	Vh = 5.33	a = 85.68
15	4.00	3.85	42.35	63.00	62.60	62.10	62.57	1126.80	659.40	467.40	2.411	16.00	415.00	1.023	425	Va = 14.32	VF = 62.78
							AVERAGE				2.423	15.200			408.282		

Gk = 2.717
Gi = 2.723
GF = 2.713
Coarse% = 58.400

Gb = 1.038
Fine % = 37.800
Filler% = 3.800

A/C	Vh
2	11.89
2.5	10.83
3	8.43
3.5	5.85
4	5.33

A/C	P.U.W.
2	2.322
2.5	2.332
3	2.376
3.5	2.427
4	2.423

A/C	STABILITY
2	403
2.5	417
3	483
3.5	573
4	408

A/C	FLOW
2	15.2
2.5	15.8
3	16.4
3.5	14.9
4	15.2

Table 5.3. Marshall test results for 20-80 rates

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability		
1	2.00	1.96	22.00	62.90	63.20	63.00	63.03	1096.10	623.70	472.40	2.320	11.20	475.00	1.013	481	DT = 2.636	Sb = 4.40
2	2.00	1.96	22.00	63.00	62.00	62.00	62.33	1091.50	624.80	466.70	2.339	11.20	575.00	1.031	593	Vh = 11.61	Sa = 83.99
3	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0	Va = 16.01	Vf = 27.48
							AVERAGE				2.330	11.200			537.000		
4	2.50	2.44	26.84	61.00	60.80	60.70	60.83	1100.00	636.80	463.20	2.375	12.00	550.00	1.073	590	DT = 2.616	Sb = 5.60
5	2.50	2.44	26.84	60.20	60.10	60.80	60.37	1089.50	635.70	453.80	2.401	12.00	545.00	1.085	591	Vh = 8.86	Sa = 85.54
6	2.50	2.44	26.84	61.00	60.00	59.70	60.23	1077.30	624.10	453.20	2.377	12.00	540.00	1.090	589	Va = 14.46	Vf = 38.76
							AVERAGE				2.384	12.000			590.025		
7	3.00	2.91	32.01	60.50	60.90	60.80	60.73	1103.30	650.00	453.30	2.434	14.80	615.00	1.076	662	DT = 2.597	Sb = 6.77
8	3.00	2.91	32.01	62.00	60.60	60.40	61.00	1099.40	642.30	457.10	2.405	12.00	515.00	1.067	550	Vh = 6.94	Sa = 86.28
9	3.00	2.91	32.01	62.20	61.20	62.50	61.97	1097.20	642.00	455.20	2.410	11.20	580.00	1.038	602	Va = 13.72	Vf = 49.39
							AVERAGE				2.416	12.667			604.428		
10	3.50	3.38	37.18	59.10	59.80	59.50	59.47	1100.80	656.50	444.30	2.478	12.00	585.00	1.114	652	DT = 2.578	Sb = 7.91
11	3.50	3.38	37.18	60.80	60.50	61.00	60.77	1095.00	637.00	458.00	2.391	14.80	640.00	1.073	687	Vh = 5.81	Sa = 86.29
12	3.50	3.38	37.18	59.00	58.90	60.00	59.30	1098.60	644.00	454.60	2.417	13.60	590.00	1.120	661	Va = 13.71	Vf = 57.67
							AVERAGE				2.428	13.467			666.403		
13	4.00	3.85	42.35	61.00	61.20	61.00	61.07	1119.40	661.30	458.10	2.444	16.00	625.00	1.064	665	DT = 2.560	Sb = 8.95
14	4.00	3.85	42.35	60.00	60.20	60.10	60.10	1114.80	650.60	464.20	2.402	14.00	600.00	1.094	656	Vh = .76	Sa = 85.29
15	4.00	3.85	42.35	58.40	58.20	58.40	58.33	1110.30	646.10	464.20	2.392	12.80	560.00	1.152	645	Va = 14.71	Vf = 60.84
							AVERAGE				2.412	14.267			655.507		

Gk = 2.717
Gi = 2.723
Gf = 2.713
Coarse% = 57.200

Gb = 1.038
Fine % = 39.300
Filler% = 3.500

A/C	Vh
2	11.61
2.5	8.89
3	6.94
3.5	5.81
4	5.76

A/C	P.U.W.
2	2.330
2.5	2.384
3	2.416
3.5	2.428
4	2.412

A/C	STABILITY
2	537
2.5	590
3	605
3.5	666
4	656

A/C	FLOW
2	11.2
2.5	12.0
3	12.7
3.5	13.5
4	14.3

Table 5.4. Marshall test results for 30-70 rates

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability
1	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
2	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
3	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
4	2.50	2.44	26.84	59.00	58.40	59.00	58.80	1070.70	622.20	448.50	2.387	15.20	600.00	1.137	682
5	2.50	2.44	26.84	61.50	61.20	61.10	61.27	1091.40	632.70	458.70	2.379	13.60	600.00	1.059	635
6	2.50	2.44	26.84	61.00	61.20	60.80	61.00	1086.80	627.20	459.60	2.365	13.60	615.00	1.067	656
							AVERAGE				2.377	14.133			657.868
7	3.00	2.91	32.01	61.00	62.50	60.40	61.30	1088.60	643.80	444.80	2.447	13.60	625.00	1.059	662
8	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
9	3.00	2.91	32.01	59.00	59.50	59.20	59.23	1087.30	637.00	450.30	2.415	15.60	645.00	1.124	725
							AVERAGE				2.431	14.600			693.428
10	3.50	3.38	37.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
11	3.50	3.38	37.18	60.00	60.10	59.70	59.93	1110.00	651.90	458.10	2.423	16.00	635.00	1.100	699
12	3.50	3.38	37.18	59.20	59.50	58.20	58.97	1096.30	644.90	451.40	2.429	14.00	590.00	1.130	667
							AVERAGE				2.426	15.000			682.600
13	4.00	3.85	42.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
14	4.00	3.85	42.35	60.20	60.30	60.40	60.30	1110.70	651.50	459.20	2.419	14.80	600.00	1.088	653
15	4.00	3.85	42.35	58.70	59.10	59.20	59.00	1108.20	649.60	458.60	2.416	16.60	580.00	1.130	655
							AVERAGE				2.418	15.700			654.100

Group (NO)	DT	Vh	Va	Sb	Sa	Vf
1–3	2.636	ERR	ERR	ERR	ERR	ERR
4–6	2.616	9.13	14.72	5.59	85.28	37.97
7–9	2.597	6.38	13.20	6.82	86.80	51.64
10–12	2.578	5.90	13.80	7.90	86.20	57.24
13–15	2.560	5.55	14.52	8.97	85.48	61.76

Gk = 2.717
Gi = 2.723
Gf = 2.713
Coarse% = 56.600

Gb = 1.038
Fine % = 39.400
Filler% = 4.000

A/C	Vh	P.U.W.	STABILITY	FLOW	VF
2.5	9.13	2.377	658	14.1	37.97
3	6.38	2.431	693	14.6	51.64
3.5	5.90	2.426	682	15.0	57.24
4	5.55	2.418	654	15.7	61.76

Table 5.5. Marshall test results for 40-60 rates

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability
1	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
2	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
3	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
4	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
5	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
6	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
7	3.00	2.91	32.01	59.70	60.00	60.70	60.13	1069.70	626.30	443.40	2.412	12.00	615.00	1.094	673
8	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
9	3.00	2.91	32.01	59.80	59.60	59.80	59.73	1085.70	638.20	447.50	2.426	10.40	615.00	1.107	681
							AVERAGE				2.419	11.200			676.808
10	3.50	3.38	37.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
11	3.50	3.38	37.18	58.50	59.60	59.00	59.03	1101.80	649.30	452.50	2.435	12.40	740.00	1.130	836
12	3.50	3.38	37.18	58.90	59.20	59.10	59.07	1087.00	644.10	442.90	2.454	13.80	730.00	1.127	823
							AVERAGE				2.445	13.100			829.455
13	4.00	3.85	42.35	60.00	58.50	58.70	59.10	1089.40	643.60	445.80	2.444	16.00	700.00	1.127	789
14	4.00	3.85	42.35	59.70	60.20	59.40	59.77	1097.60	646.20	451.40	2.432	21.60	750.00	1.104	828
15	4.00	3.85	42.35	58.00	58.20	58.00	58.07	1103.40	650.10	453.30	2.434	17.60	770.00	1.158	892
							AVERAGE				2.437	18.400			836.229

NO				
1–3	DT = 2.636	Vh = ERR	Va = ERR	Sb = ERR, Sa = ERR, Vf = ERR
4–6	DT = 2.616	Vh = ERR	Va = ERR	Sb = ERR, Sa = ERR, Vf = ERR
7–9	DT = 2.597	Vh = 6.83	Va = 13.61	Sb = 6.78, Sa = 86.39, Vf = 49.82
10–12	DT = 2.578	Vh = 5.17	Va = 13.14	Sb = 7.96, Sa = 86.86, Vf = 60.60
13–15	DT = 2.560	Vh = 4.81	Va = 13.85	Sb = 9.04, Sa = 86.15, Vf = 65.25

Gk = 2.717
Gi = 2.723
Gf = 2.713
Coarse% = 56.500

Gb = 1.038
Fine % = 39.500
Filler% = 4.000

A/C	Vh	A/C	P.U.W.	A/C	STABILITY	A/C	FLOW	A/C	Vf
3	6.83	3	2.419	3	677	3	11.2	3	49.82
3.5	5.17	3.5	2.445	3.5	830	3.5	13.1	3.5	60.60
4	4.81	4	2.437	4	836	4	18.4	4	65.25

Table 5.6. Marshall test results for 50-50 rates

NO	Wa	Wb	Bitumen	Heights 1	Heights 2	Heights 3	Avr. (mm.)	Weight in air (c)	Weight in wat. (d)	Vol. (c - d)	Pratical Unit wait (gr/cm^3)	Flow (mm.)	Stability (kg.)	Correct. Factor	Correct. Stability
1	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
2	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
3	2.00	1.96	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
4	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
5	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
6	2.50	2.44	26.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
7	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
8	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
9	3.00	2.91	32.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.000	0
							AVERAGE				ERR	0.000			0.000
10	3.50	3.38	37.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ERR	0.00	0.00	0.000	0
11	3.50	3.38	37.18	60.00	59.70	59.80	59.83	1102.80	649.10	453.70	2.431	13.20	785.00	1.104	867
12	3.50	3.38	37.18	59.00	58.80	60.00	59.27	1087.10	645.90	441.20	2.464	12.00	865.00	1.120	[illegible]
							AVERAGE				2.447	12.600			917.729
13	4.00	3.85	42.35	61.80	60.70	60.60	61.03	1113.30	661.30	452.00	2.463	14.80	770.00	1.067	822
14	4.00	3.85	42.35	61.30	61.00	61.10	61.13	1108.20	658.50	449.70	2.464	13.40	750.00	1.064	798
15	4.00	3.85	42.35	59.80	58.90	59.30	59.33	1092.30	651.50	440.80	2.478	14.40	765.00	1.130	864
							AVERAGE				2.468	14.200			828.156

NO	DT =	Vh =	Va =	Sb =	Sa =	VF =
1–3	2.635	ERR	ERR	ERR	ERR	ERR
4–6	2.616	ERR	ERR	ERR	ERR	ERR
7–9	2.597	ERR	ERR	ERR	ERR	ERR
10–12	2.578	5.07	13.04	7.47	[illegible]	61.13
13–15	2.560	3.57	12.72	9.16	87.28	71.97

Gk = 2.717
Gi = 2.723
Gf = 2.713
Coarse% = 56.400

Gb = 1.038
Fine % = 39.000
Filler% = 4.600

A/C	Vh
3.5	5.07
4	3.57

A/C	P.U.W.
3.5	2.447
4	2.468

A/C	STABILITY
3.5	918
4	828

A/C	FLOW
3.5	12.6
4	14.2

A/C	VF
3.5	61.13
4	71.97

Table 5.7. Marshall test results for 60-40 rates

Table 5.8. Determination of the physical properties of the recycled mixture according to the optimum asphalt content

%							
%	A/C	3.31	3.43	3.63	3.21	3.47	3.47
	RATES	10	20	30	40	50	60
STABILITY		458	540	645	685	820	920
FLOW		14.8	16.3	13.8	14.9	13.3	12.3
P.U.W.		2.424	2.405	2.425	2.425	2.440	2.445
Vh		6.50	6.80	6.00	6.55	5.50	5.00
Vf		50.0	51.0	55.0	50.0	53.0	55.0

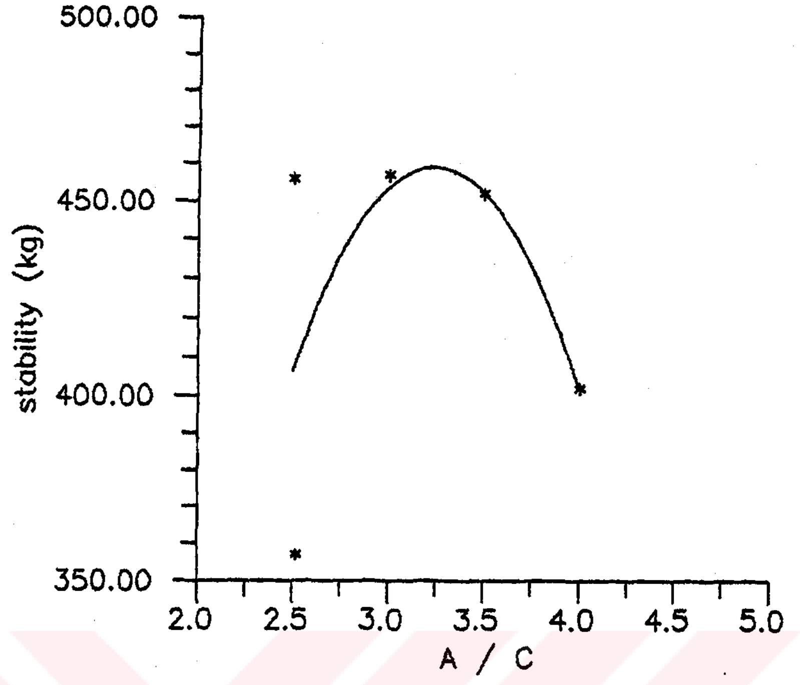


Figure 5.1. Variation in Stability with A/C for 10-90 rates

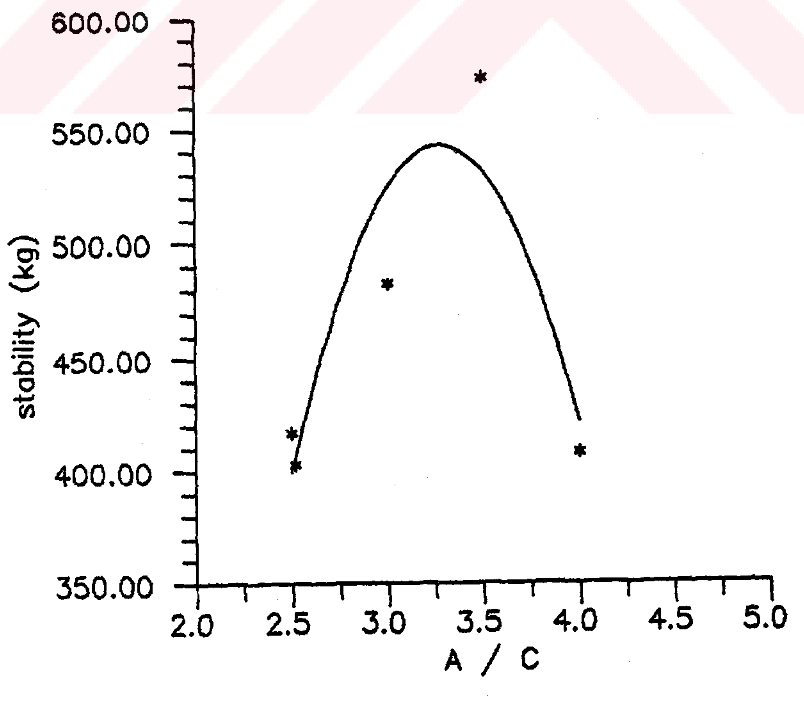


Figure 5.2. Variation in Stability with A/C for 20-80 rates

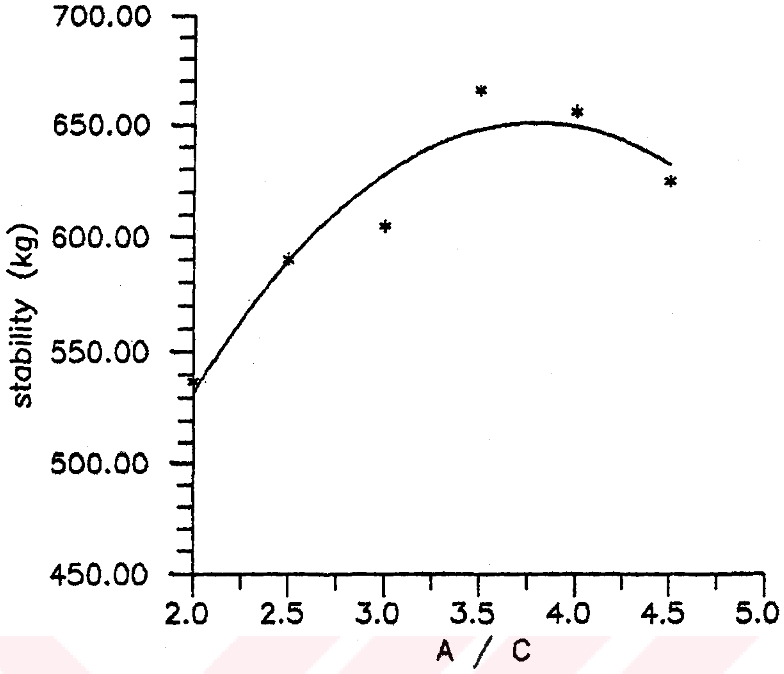


Figure 5.3. Variation in Stability with A/C for 30-70 rates

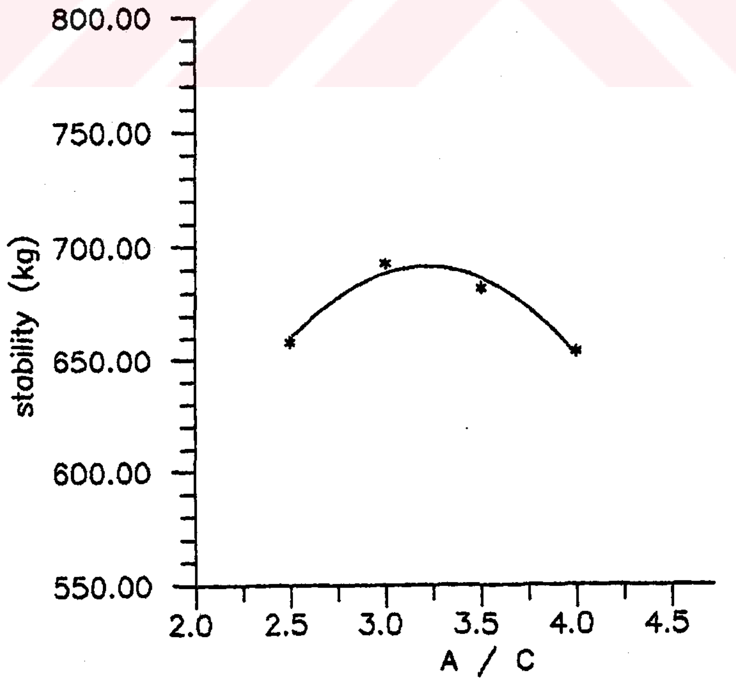


Figure 5.4. Variation in Stability with A/C for 40-60 rates

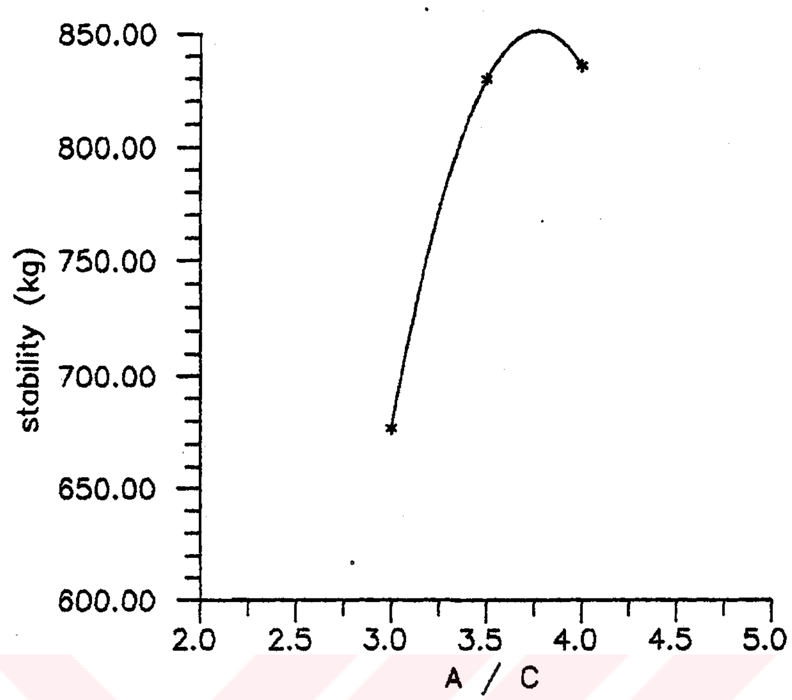


Figure 5.5. Variation in Stability with A/C for 50-50 rates

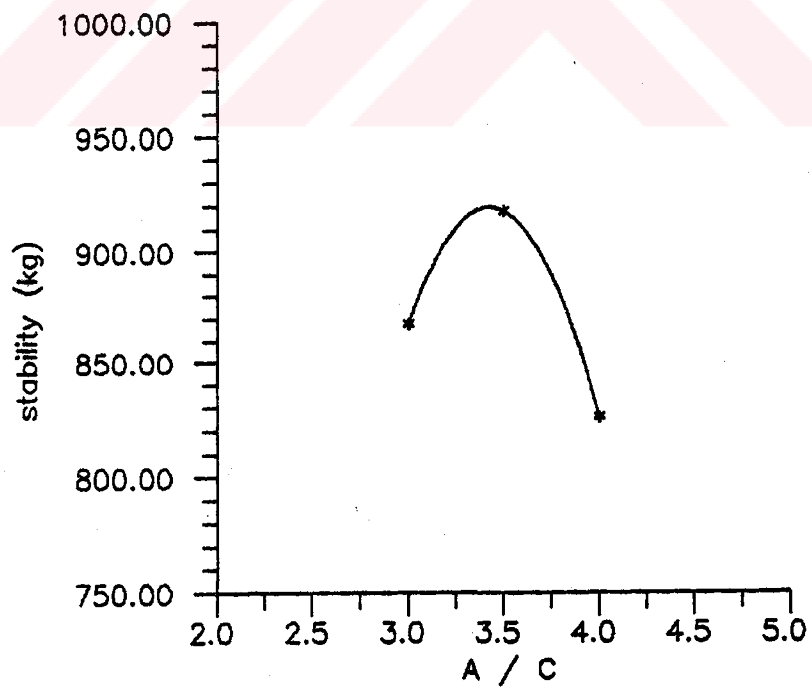


Figure 5.6. Variation in Stability with A/C for 60-40 rates

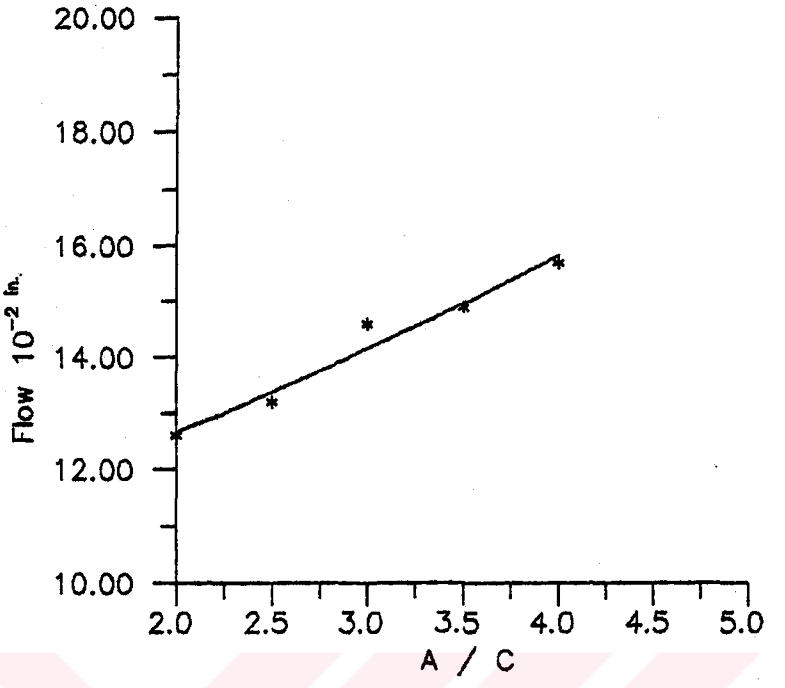


Figure 5.7. Variation in Flow with A/C for 10-90 rates

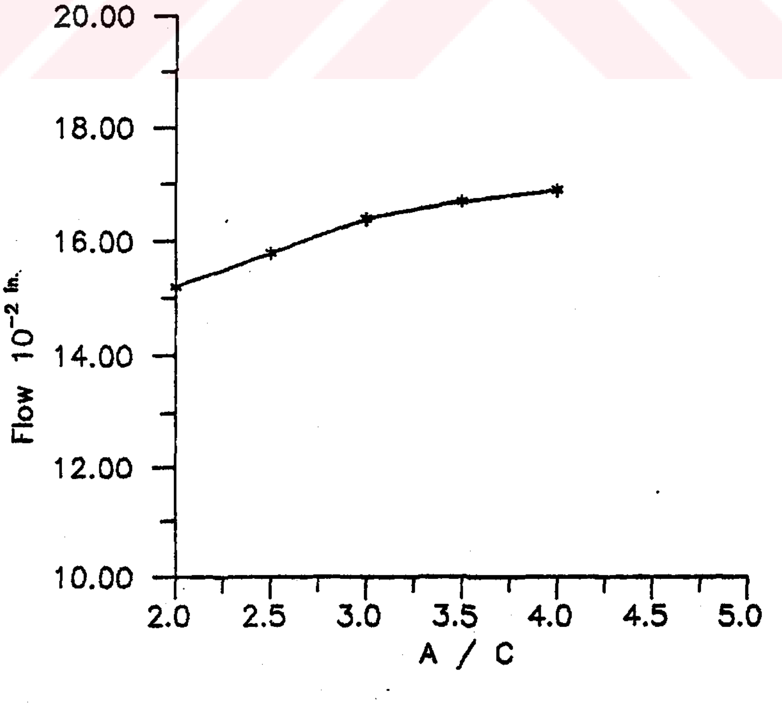


Figure 5.8. Variation in Flow with A/C for 20-80 rates

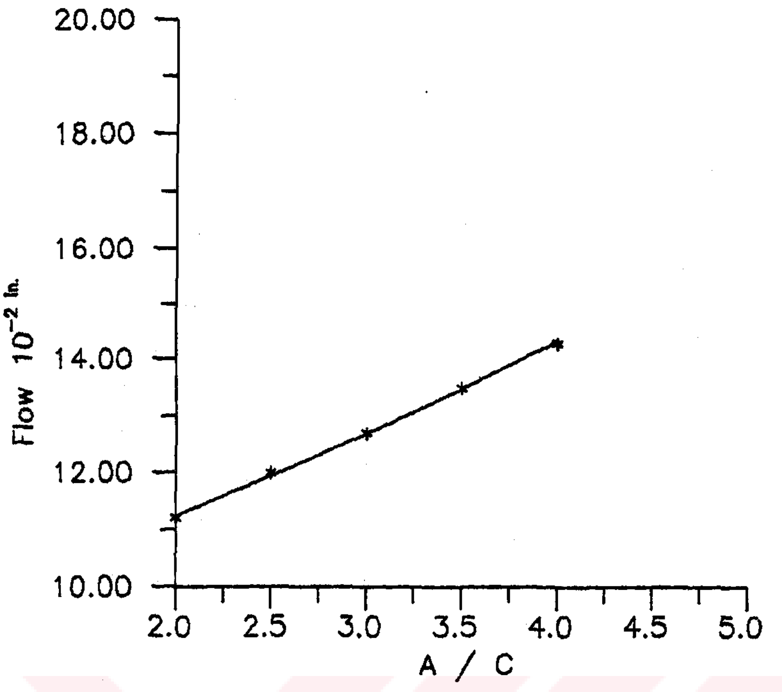


Figure 5.9. Variation in Flow with A/C for 30-70 rates

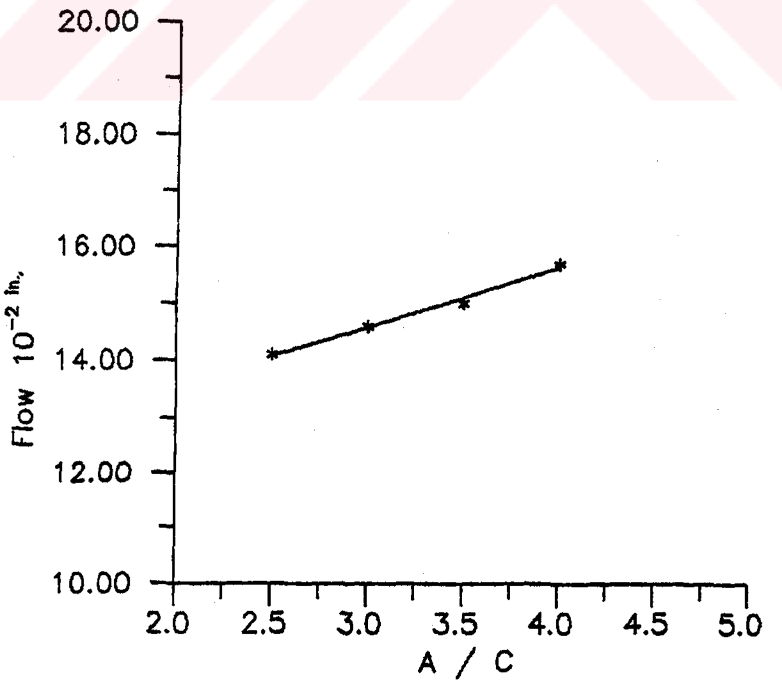


Figure 5.10. Variation in Flow with A/C for 40-60 rates

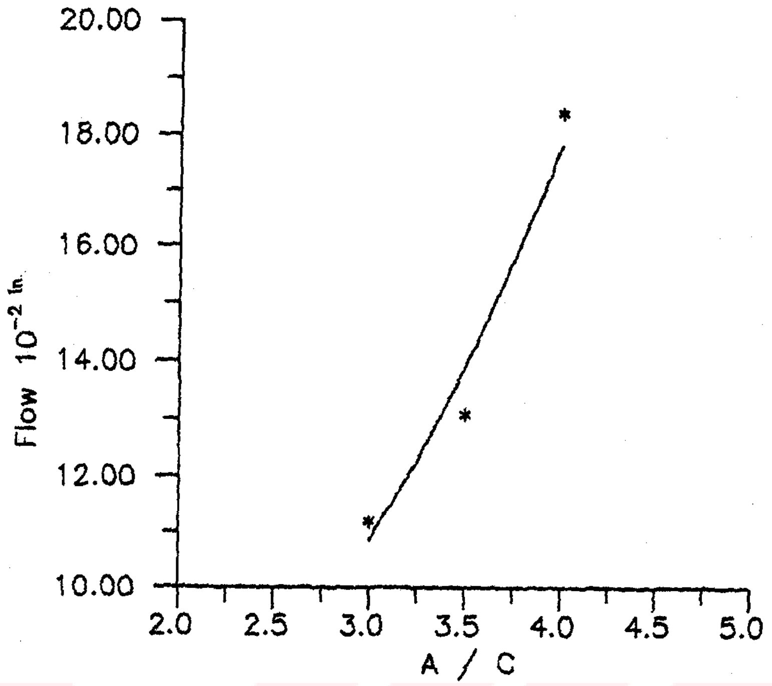


Figure 5.11. Variation in Flow with A/C for 50-50 rates

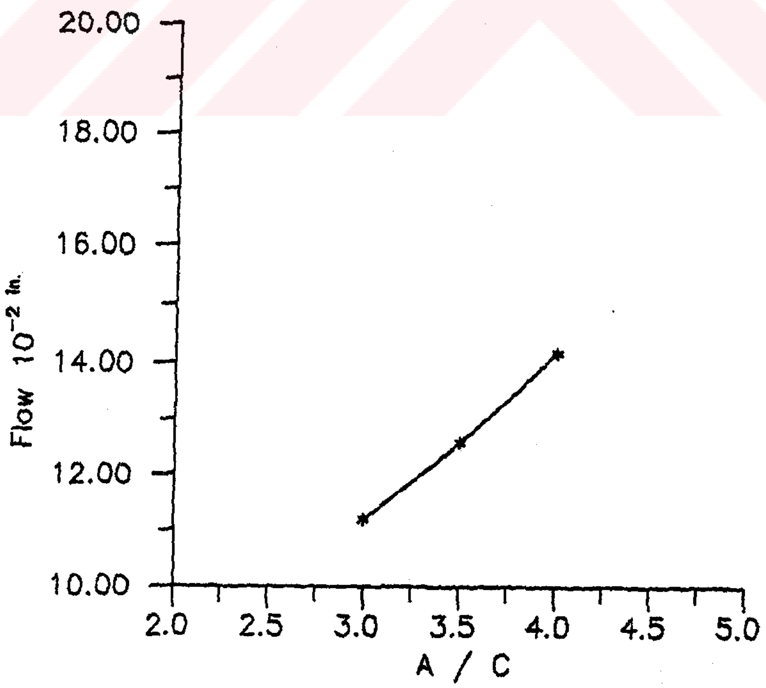


Figure 5.12. Variation in Flow with A/C for 60-40 rates

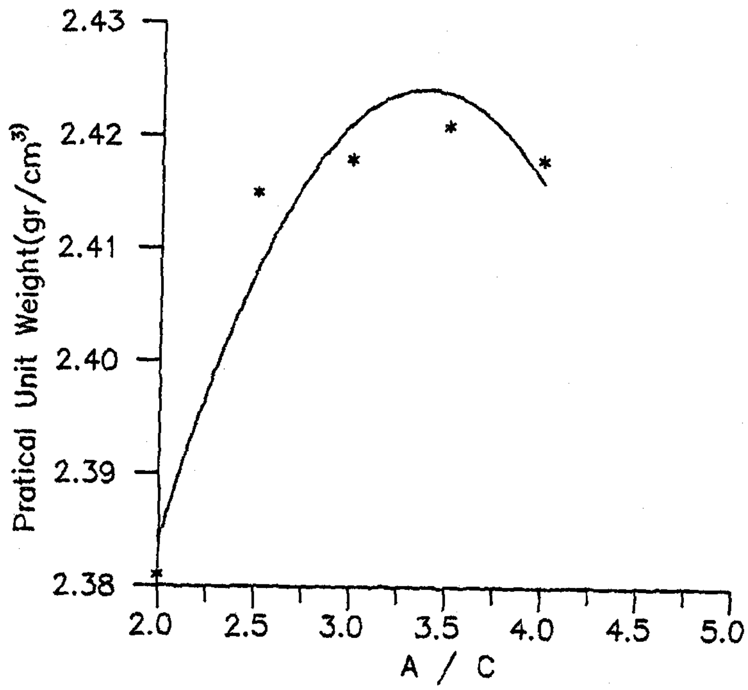


Figure 5.13. Variation in P.U.W. with A/C for 10-90 rates

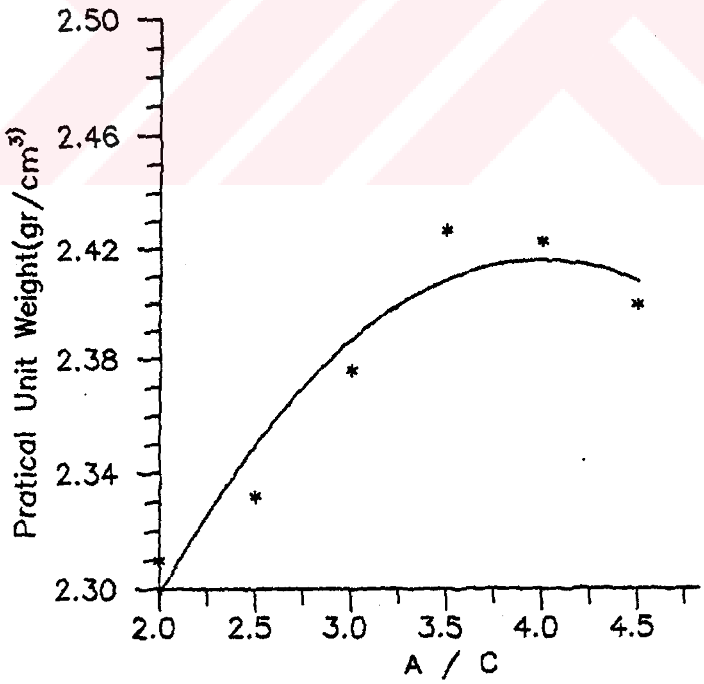


Figure 5.14. Variation in P.U.W. with A/C for 20-80 rates

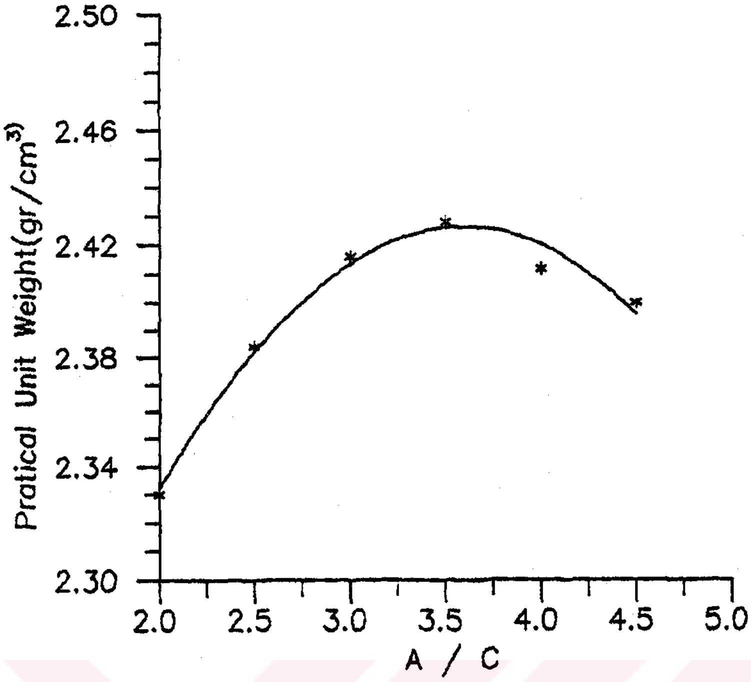


Figure 5.15. Variation in P.U.W. with A/C for 30-70 rates

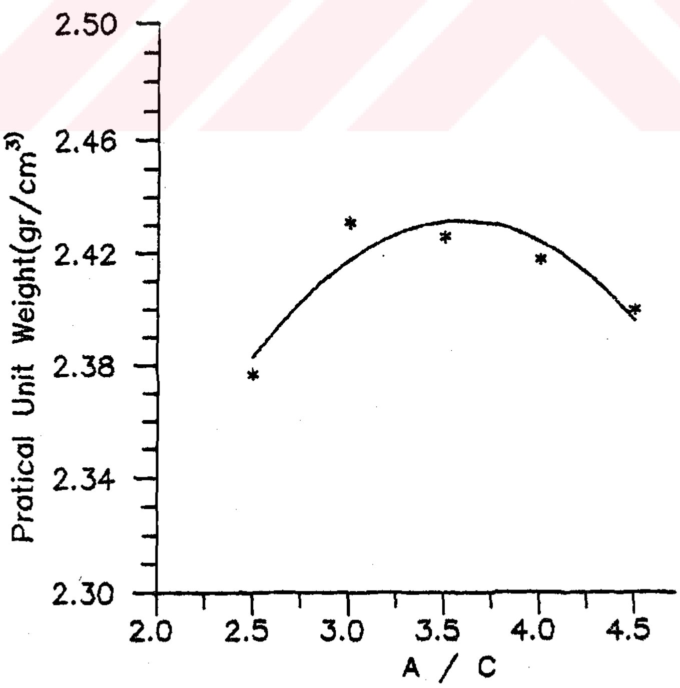


Figure 5.16. Variation in P.U.W. with A/C for 40-60 rates

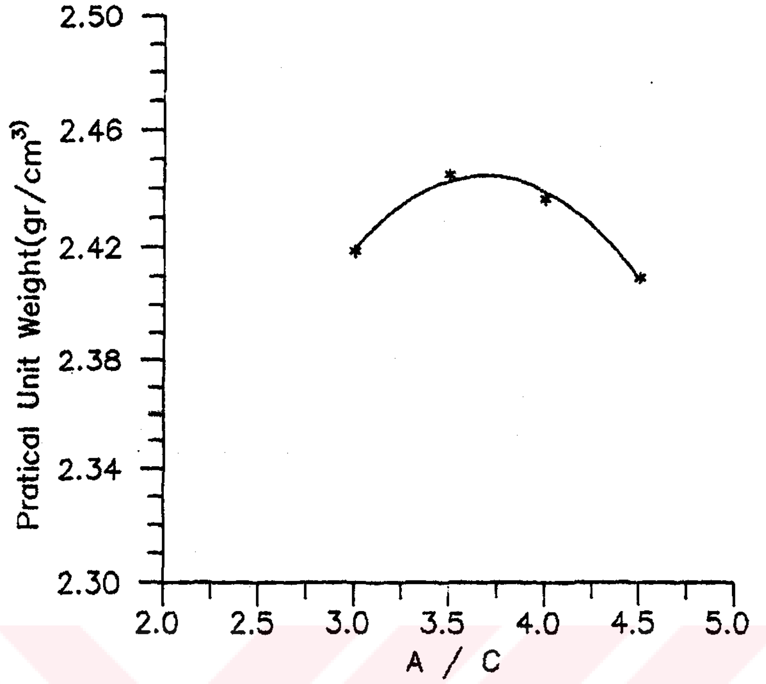


Figure 5.17. Variation in P.U.W. with A/C for 50-50 rates

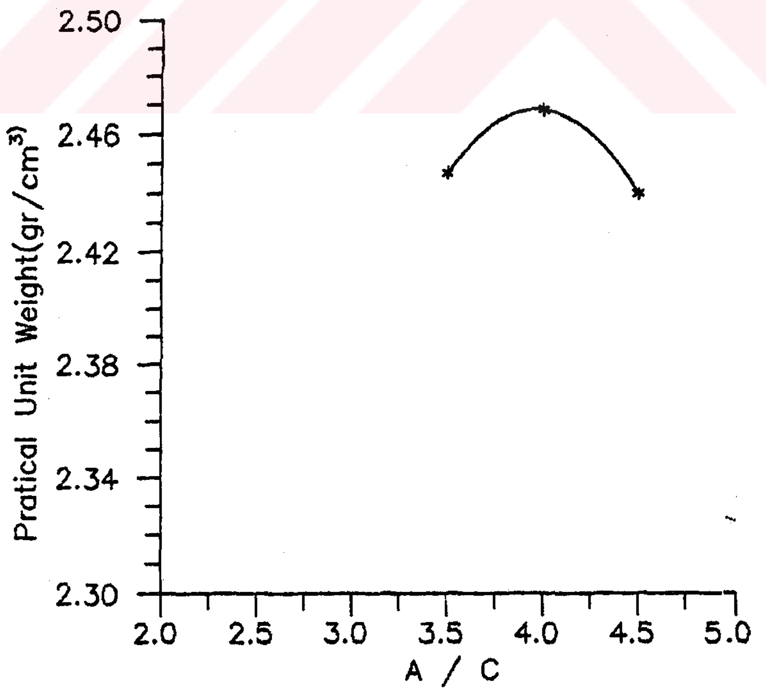


Figure 5.18. Variation in P.U.W. with A/C for 60-40 rates

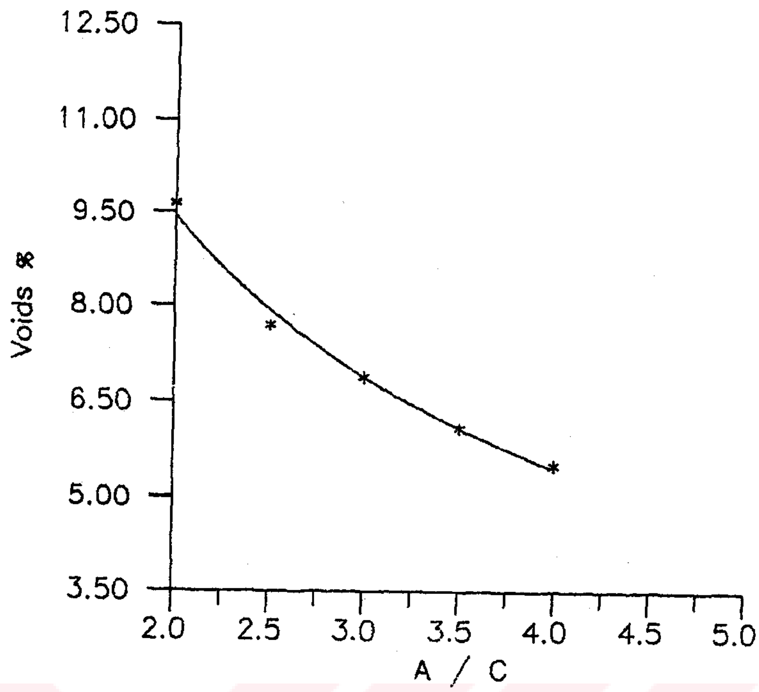


Figure 5.19. Variation in Void Content with A/C for 10-90 rates

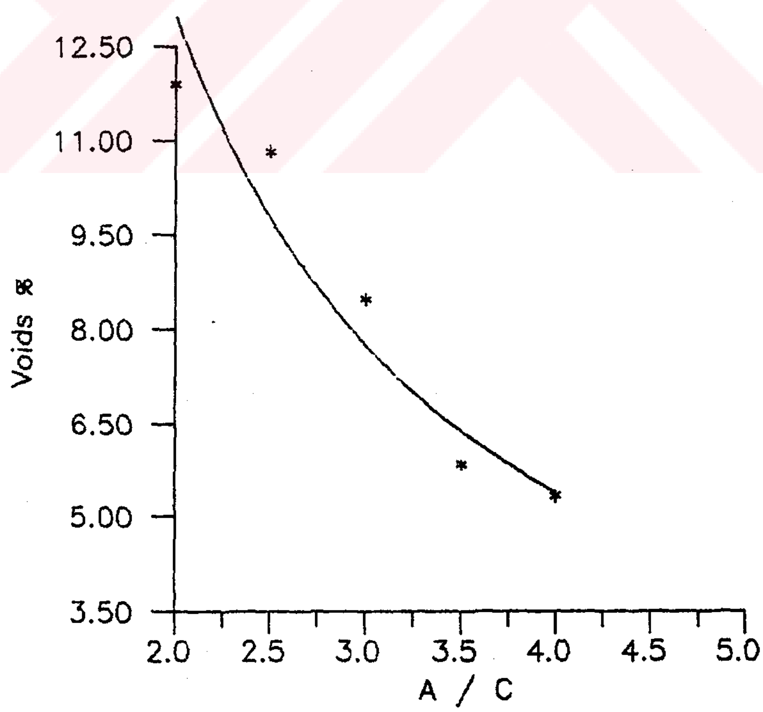


Figure 5.20. Variation in Void Content with A/C for 20-80 rates

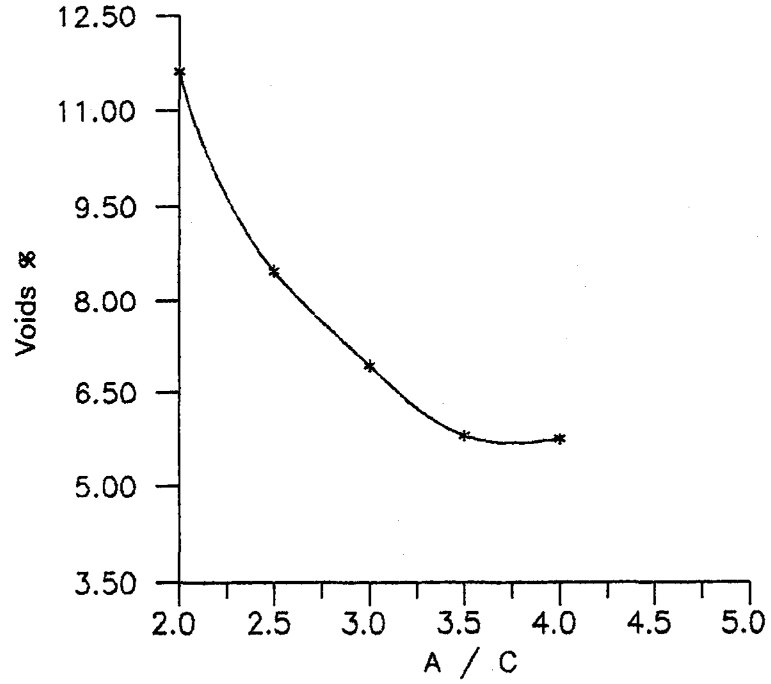


Figure 5.21. Variation in Void Content with A/C for 30-70 rates

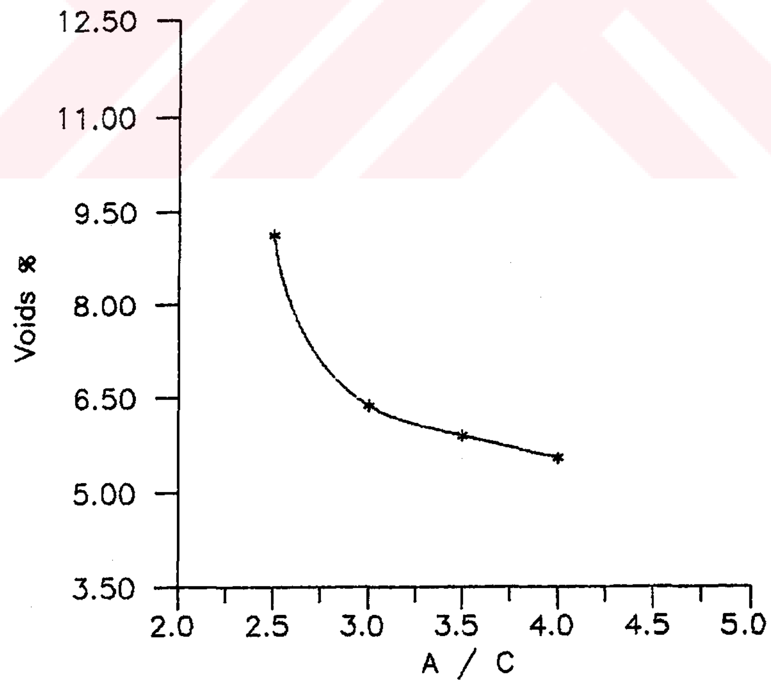


Figure 5.22. Variation ın Void Content with A/C for 40-60 rates

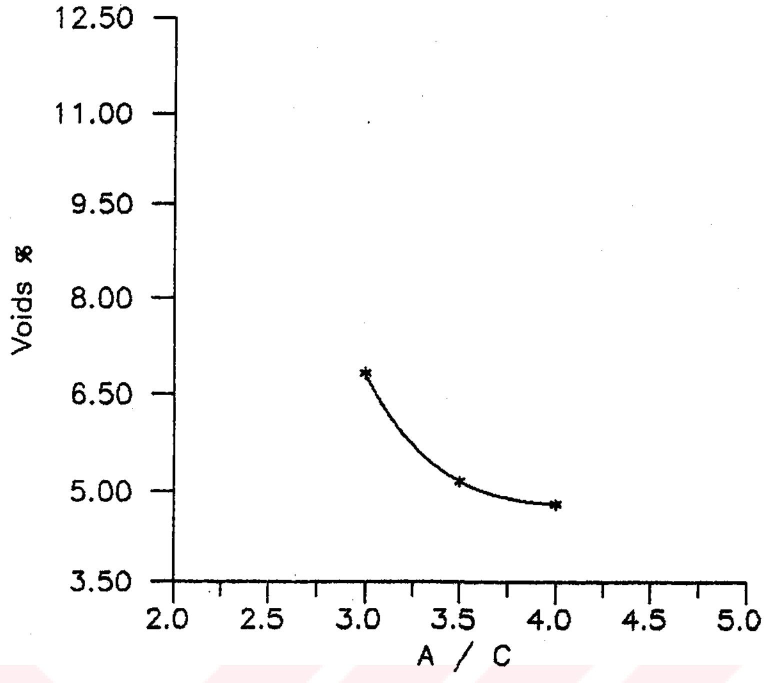


Figure 5.23. Variation in Void Content with A/C for 50-50 rates

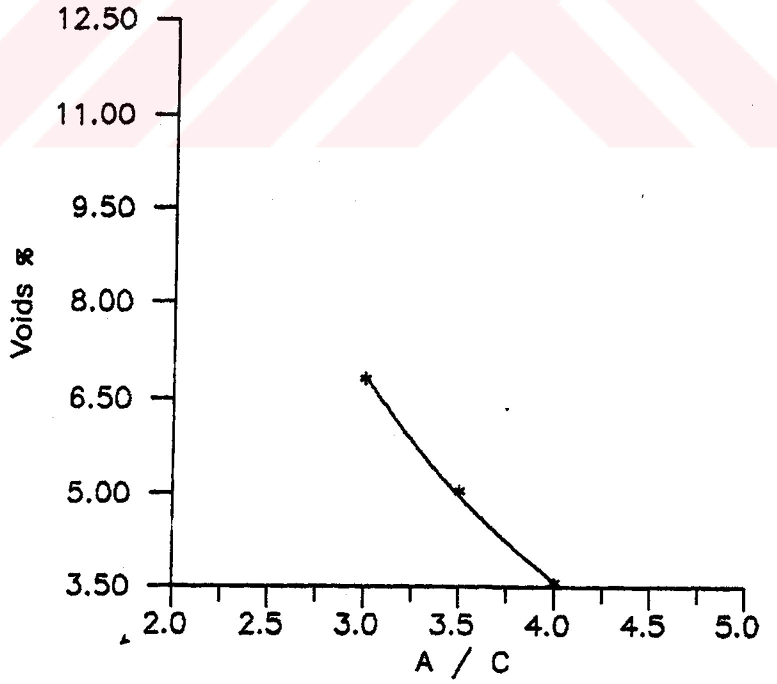


Figure 5.24. Variation in Void Content with A/C for 60-40 rates

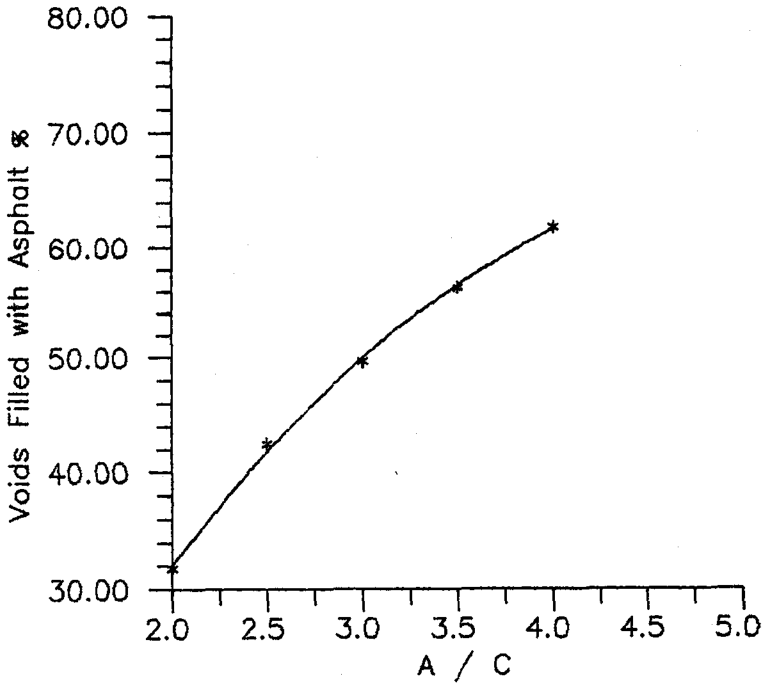


Figure 5.25. Variation in Voids filled with Asphalt with 10-90 rates

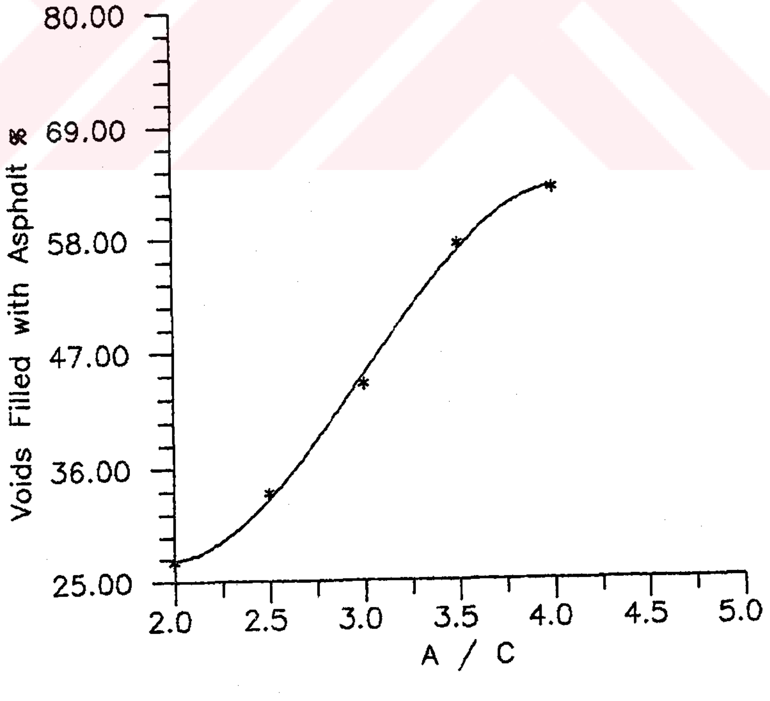


Figure 5.26. Variation in Voids filled with Asphalt with 20-80 rates

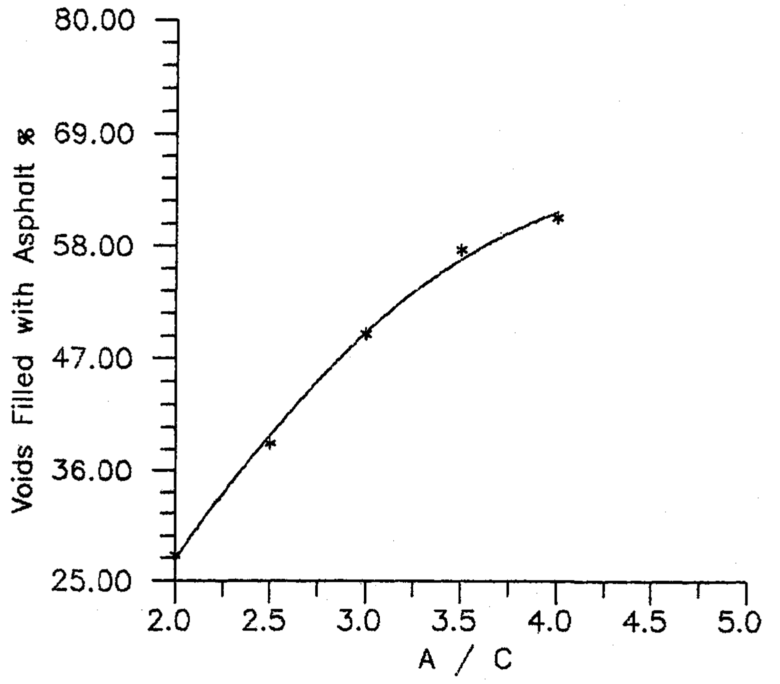


Figure 5.27. Variation in Voids filled with Asphalt with 30-70 rates

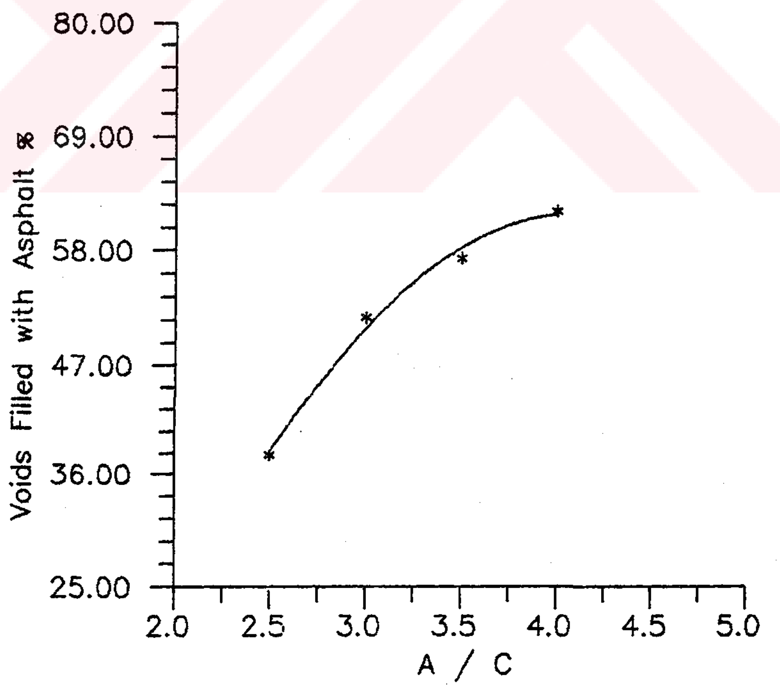


Figure 5.28. Variation in Voids filled with Asphalt with 40-60 rates

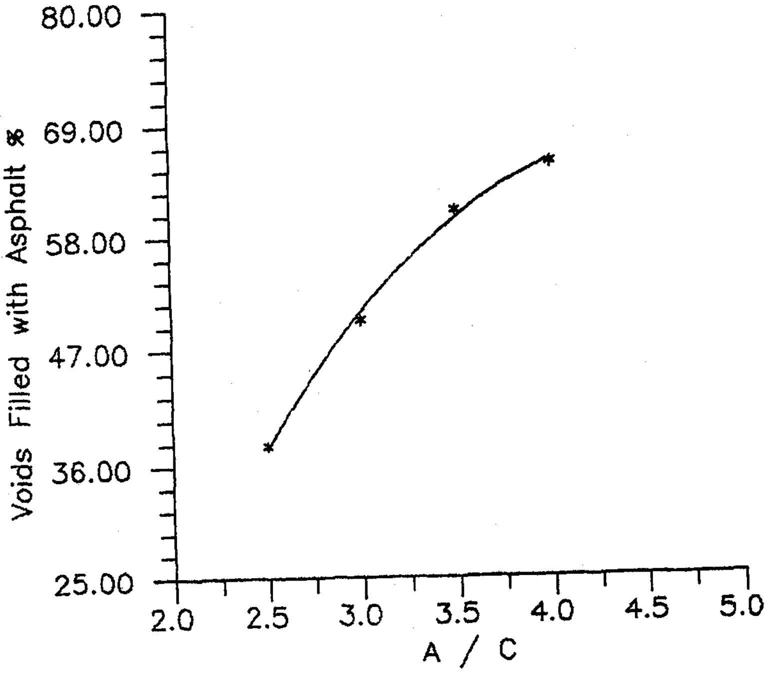


Figure 5.29. Variation in Voids filled with Asphalt with 50-50 rates

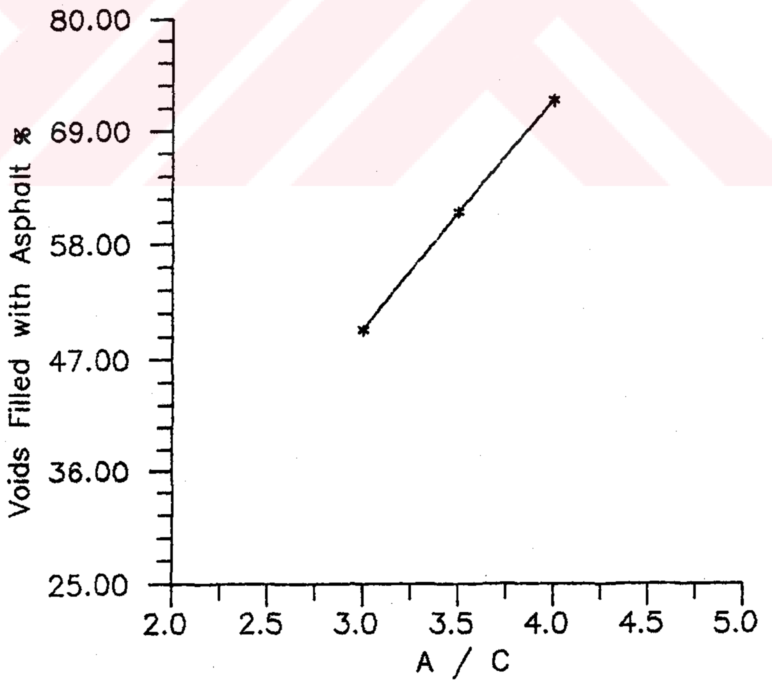


Figure 5.30. Variation in Voids filled with Asphalt with 60-40 rates

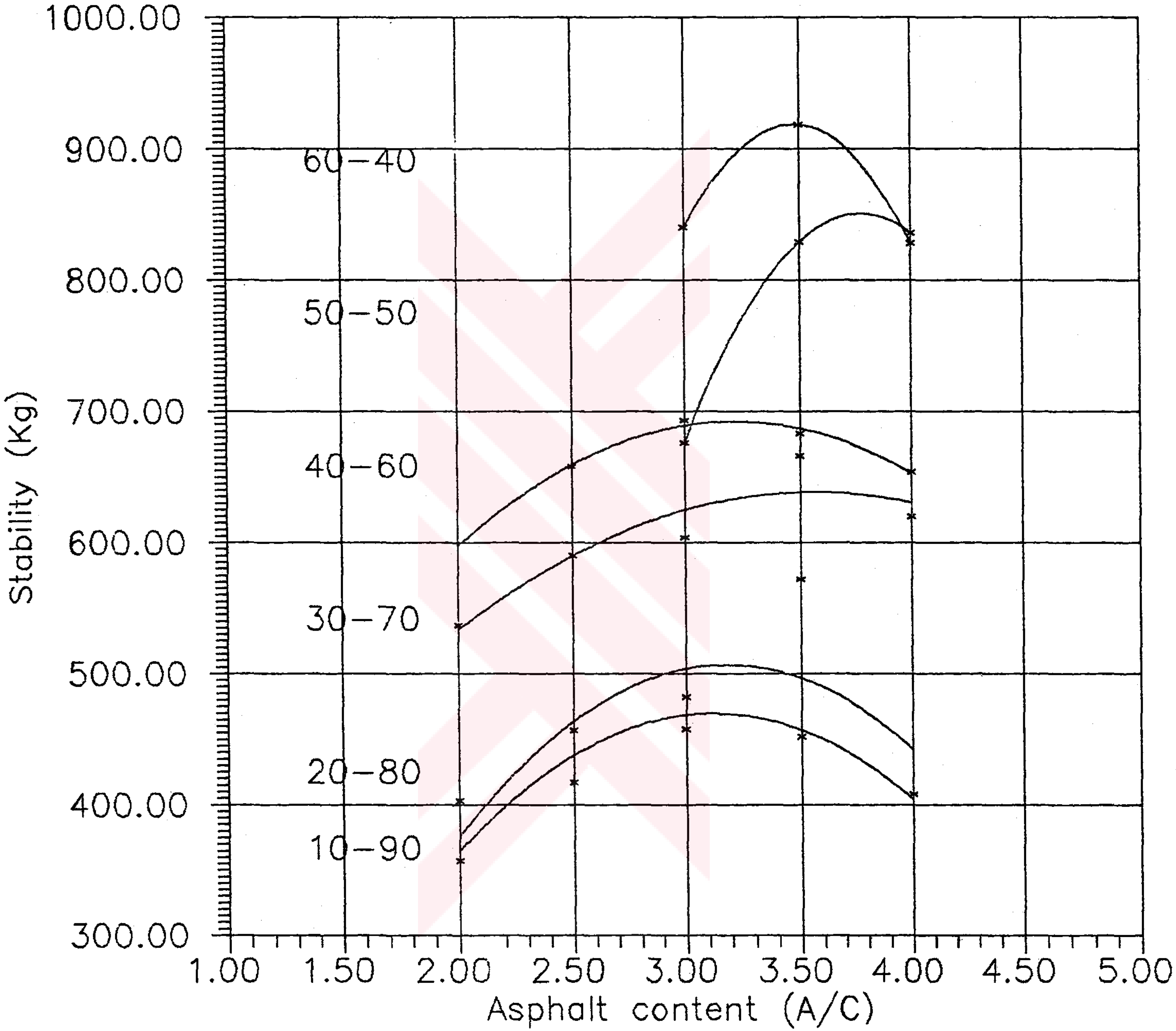


Figure 5.31. Variation in stability with asphalt content

5.2. Economical analysis

The unit price of bituminous base course with the position number 6200 is 34431 TL/ton. as explained below. (7)

The unit price of scarification is 36075 TL/m3.
The unit weight of RAP is 2.415 ton/m3.
So, the unit price of scarification is 14938 TL/ton.
The hauling formula for the scarified material is:

$$F = 1.25*K*(0.0007*M + 0.01)* A$$

A = 1.0 (Pos.No. 07.005/K) (7)
K = 127000 (Pos.No. 07.005/K) (7)
M = 10 km. (assumption)
F = 2699 TL/ton.

The detail of the position number 6200 is as follows:

Pos.No.(7)	Operations	Unit Price TL/TON
4246	Preparation of aggregates	2413
4256	Preparation of aggregates	2847
4265/1	Preparation of aggregates	6139
4365	Storage of bituminous material	54
4358	Heating of bituminous material	530
4366	Transhipment of bituminous material	137

4378	Cleaning of the roads	21
4363/1	Preparation of bitumen	499
4398	Spraying of bitumen	64
4440	Preparation and spreading of the mix in the plant	21699
4269	Weighing of material	28
	TOTAL =	34431

Analysis of the unit price of RAP material:

The cost of the operation of the aggregate drying machine for 0.0125 hours is 456776 TL according to the position number 1910 which appears in pos.no. 4440

An example for 10 % usage of RAP material is given below.

(Scarification + hauling) * 0.10 + (34431 - 5710 + 5976) * 0.90 = 32992 TL/TON.

The cost of preparation of hot mix bituminous base layer is 34431 TL/TON and taken from pos.no. 6200.

The cost of drying of aggregate is 5710 TL/TON and taken from pos.no.1910.

The cost of heating of new aggregate is calculated as follows:

The cost of heating from 25°C to 175°C is 5710 TL.

5710/175-25 = 38 TL/°C for 1 °C increase (assumption).

The cost of heating for raising the temperature of aggregates 157°C (182-25) is : 38 * 157 = 5976 TL/TON.

Heating temparatures are taken from "Hot-Mix recycling manual " (5).

The others were done by the same manner and the results are given in tables 5.12. , 5.13. ,5.14.

The costs of scarification, hauling and heating of the reclaimed materials for different initial moisture contents are as shown in table 5.8., 5.9., 5.10.

The comparison of the costs of conventional and recycled base courses for different initial moisture contents are shown in tables 5.12., 5.13., 5.14.

Table 5.9. Determination of the cost of RAP for 5 % moisture content

OLD %	TEMP. °C	SCARIFICATION TL/TON	HAULING TL/TON	HEATING TL/TON
10	182	14938	2699	5976
20	221	14938	2699	7461
30	274	14938	2699	9479
40	341	14938	2699	12029
50	438	14938	2699	15722
60	500 †	14938	2699	18082

Table 5.10. Determination of the cost of the RAP for 2 % moisture content

OLD %	TEMP. °C	SCARIFICATION TL/TON	HAULING TL/TON	HEATING TL/TON
10	171	14938	2699	5710
20	196	14938	2699	5710
30	232	14938	2699	7880
40	277	14938	2699	9593
50	343	14938	2699	12105
60	405 †	14938	2699	14465

Table 5.11. Determination of the cost of the RAP for 0 % moisture content

OLD %	TEMP. °C	SCARIFICATION TL/TON	HAULING TL/TON	HEATING TL/TON
10	163	14938	2699	5710
20	182	14938	2699	5710
30	207	14938	2699	6928
40	238	14938	2699	8108
50	282	14938	2699	9783
60	341	14938	2699	12029

Table 5.12. Comparison of the costs of conventional and recycled base courses for 5 % moisture content

OLD %	COST OF BITUMINOUS BASE COURSE (TL/TON)	COST OF RECYCLED BASE COURSE (TL/TON)
10	34431	32992
20	34431	32473
30	34431	32031
40	34431	31504
50	34431	31040
60	34431	29303

Table 5.13. Comparison of the costs of conventional and recycled base courses for 2 % moisture content

OLD %	COST OF BITUMINOUS BASE COURSE (TL/TON)	COST OF RECYCLED BASE COURSE (TL/TON)
10	34431	32752
20	34431	31072
30	34431	30912
40	34431	30043
50	34431	29232
60	34431	27857

Table 5.14. Comparison of the costs of conventional and recycled base courses for 0 % moisture content

OLD %	COST OF BITUMINOUS BASE COURSE (TL/TON)	COST OF RECYCLED BASE COURSE (TL/TON)
10	34431	32752
20	34431	31072
30	34431	31542
40	34431	29152
50	34431	28071
60	34431	26882

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

As it is evaluated in chapter 5, the increasing use of RAP material improves stability of the mix. This is the most important result observed in this study.

Although 60 % use of RAP material gives the highest stability and acceptable values for flow, practical unit weight, void content and voids filled with asphalt according to the specifications, it cannot be said that this is the most economical solution. Because there are several other factors influencing the economy of this technique. Therefore, an economical analysis is performed in order to achieve an opinion about the economy of the recycling technique. However, the use of RAP material more than 60 % causes an increase in the existing asphalt content and this means that the RAP material can be used in the recycled mixes requiring higher amount of asphalt such as wearing and binder courses.

In the economical analysis, for 0 % initial moisture content, 60 % use of RAP material provides the most economical solution. Because, the cost of conventinal bituminous base course is 34431 TL/ton. and the cost of recycled bituminous base course is 26882 TL/ton. for this rate of use.

For 2 % and 5 % initial moisture contents, 60 % use of RAP material provides the most economical solution. Because at this rate, although the cost of conventional bituminous base course is 34431 TL/ton, the cost of recycled bituminous base course is 27857 TL/ton. and 29303 TL/ton for 2 % and 5 % respectively.

Increasing usage of RAP material decreases the total cost depending on the unit price which is 38 TL for 1 °C temperature increase. This unit price is an assumption and can be discussed whether it reflects the reality or not.

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