THE EFFECT OF CRUMB RUBBER ADDITIVE INTO HOT MIX ASPHALT PERFORMANCE

THESIS

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By

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CERTIFICATION OF ORIGINALITY

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, this study contains no material previously published or written by another person or material which to substantial extent has been accepted for the award of any other degree or diploma of a university or other institutes of higher learning, except where due acknowledgement is made in the text of the thesis.

Semarang March, 2011

WALID SALEM ALI ALTAMZWI

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DEDICATION

My family members and who love me and whom I loved.

ABSTRACT

Many researches have been conducted in finding alternative materials in order to be used as a modifier in asphalt mixture for the purpose of improving its properties. This thesis presents a study of laboratory evaluation on the performance of hot-mixed asphalt (HMA) using crumb rubber as an additive. It is noted that crumb rubber was identified to have potency as a modifier in HMA due to the elastic behavior exposed by the rubber particles, especially in reducing the rutting potential. In this research, fine crumb rubber passing sieve no 200 obtained by ambient-temperature grinding process from discarded truck tires, was used to modify asphalt cement. The fine crumb rubber with different contents, i.e. 3%, 5% and 15%, was incorporated into the mixture by using wet process method. The samples of asphalt mixtures were prepared and tested by following Marshall design procedure. The results showed that the addition of crumb rubber in asphalt cement made the modified asphalt became less temperature-susceptible. The use of crumb rubber asphalt in asphalt mixture, especially for 3% crumb rubber content, could produce more and less comparable performance to mixture with virgin asphalt, in terms of load-deflection and volumetric properties. One drawback of the use of crumb rubber in the mixture is that it is required more asphalt content than that of mixture without crumb rubber. This is contributed by the nature of crumb rubber material that has high water or asphalt absorption.

Keywords: crumb rubber, wet process, hot-mixed asphalt, Marshall design procedure

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NOMENCLATURE

AASHTO	:	American Association of State Highway and Transportation Officials.
AC	:	Concrete.
ASTM	:	American Society for Testing and Materials
A-R	:	Rubber.
BM	:	Bina Marga.
CA	:	Coarse Aggregate.
CCL4	:	Carbon Tetrachloride.
CRM	:	Crumb Rubber Modifier.
EPA	:	Environmental Protection Agency.
FA	:	Filler Aggregate.
HMA	:	Hot Mixes.
HRS	:	Hot Rolled Sheet.
IRS	:	International Road of Standard.
LOH	:	Loss On Heating.
MQ	:	Marshall Quotient.
OAC	:	Optimum Content.
OBC	:	Optimum Bitumen Content.
RAP	:	Reclaimed Pavement.
SNI	:	Standard National Indonesia.
SSD	:	Saturated Surface Dry.
VFA	:	Void Filled with.
VIM	:	Void in Mixture
VMA	:	Void Mineral Aggregate.
WC	:	Wearing Course.

CHAPTER I
INTRODUCTION

1.1 Background

A lot of research has been conducted in order to investigate other alternative material as modifier in asphalt mixes. The concept of modifying asphalt mixes is not new. In fact, since years ago there have been numerous efforts to modify asphalt mixes in order to get a better performance and quality of hot asphalt mixes.

Nowadays, the use of scrap tire rubber or crumb rubber as modifier in asphalt mixes start to get more attention among asphalt paving agencies and department of transportation, especially in Europe and the United States. In the middle of 1980s California has performed the most extensive amount of field research where more than 100 projects were constructed in the past twenty years.

However, In Indonesia, the application of crumb rubber as a modifying agent in hot mix asphalt is still rare. This is due to the less number of researches being conducted in evaluating the potential of crumb rubber as an alternative material to improve the performance of asphalt mixes according to Indonesia condition. Hence, there is a need to conduct a detailed study on the performance of Indonesia hot mix asphalt using crumb rubber as a modifier. Besides, the use of crumb rubber in asphalt cement could improve significantly the performance of asphalt mixture, it could be a potential for crumb rubber to be used as a modifier in hot asphalt mixes.

1.2 Problem Statement

Pavement damage is a continuous problem faced by road users. New road tend to damage after only two or three years, due to traffic movement even though they have been designed to last longer. Repeated application of traffic loads causes structural damage to asphalt pavement in a form of rutting which occurs along the wheel track. This kind of damage becomes quite worst especially in hot climatic condition like Indonesia. Development of modified asphalt mixes has been explored over the past few decades in order to improve the performance of pavement mixes. Crumb rubber obtained from used tires has been the focus on several research efforts with purpose to overcome those pavement problems and also helps in recycling mountainous dumping tires at landfill.

However, the degree of improvement and the cost effectiveness of using crumb rubber in asphalt mixes have not been firmly established. Most of developed countries, such as the United States, also encounter the same problem because of the limited information available on the effectiveness of using crumb rubber in asphalt mixes and they are not well documented. Although many studies have been performed to investigate the effectiveness of using crumb rubber in modifying the hot mix asphalt mixes, conflict results have been discovered. These could be due to difference devices used, testing environments, and also the size of the experiment conducted. Thus, there is a need to conduct a study to evaluate the performance of hot mixes asphalt (HMA) composed of asphalt cement that being modified using crumb rubber.

1.3 Objective

This study aims to investigate the effect of adding crumb rubber with certain proportion into asphalt cement of hot mix asphalt mixture by using wet process.

1.4 Scope of Study

The scope of this study is as follows.

a. To evaluate the properties of materials using crumb rubber into hot mix asphalt.
b. To evaluate the properties of mixtures (using virgin asphalt and crumb rubber into hot mix asphalt).

The size of fine crumb rubber that is use in modifying asphalt mixes used passing sieve no 200mm. For each type of mixes, that numbers of samples prepared are divided into four categories. These categories include unmodified samples added with 3 percent crumb rubber, samples added with 5 percent crumb rubber and samples added 15 percent crumb rubber in order to identify which mixes that meet the desired performance.

1.5 Limitation of Study

This study covers on the topic of modified HMA mixes with crumb rubber by using the method of wet process. This study covers one type of aggregate gradation, that is, dense graded aggregate. The preparation of HMA samples and tests is following Marshall Design Procedures and the results of the tests should comply with Indonesian specification, that is, Bina Marga (Directorate General of Highway) standards.

1.6 Organization of Thesis

The Thesis is organized into five chapters as follows:

Chapter 1 Introduction

This chapter consists of background, aim and limitation of study.

Chapter 2 Literature review

This chapter describes the history of the crumb rubber usage in the mixture, the types of crumb rubber and procedures to obtain crumb rubber. It also identifies various standards for preparing of crumb rubber using wet and dry processes. The evaluation of the performance of modified asphalt mixture with crumb rubber as additive, as well as review of several previous researches about the use of any kind of rubber in the asphalt mixture also will be presented.

Chapter 3 Research Design and Methodology

At this chapter, descriptions of general procedures used in this study and steps to be undertaken during the implementation of research are presented. In this chapter, it is specified the specification that should be fulfill by all materials (aggregate, asphalt and crumb rubber) before they can be used as components of the mixtures. The type of the tests for the materials and the mixtures based on Marshall parameters are also described.

Chapter 4 Results and Discussion

This chapter presents the results of material tests and the mixture performance measurement. Evaluation was conducted on the results to ensure that all materials and the mixture could fulfill the requirements as specified in the standards used.

Chapter 5 Conclusions and Recommendations

This chapter consists of the summary of research findings and recommendations for further research works.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Roadways are important in our daily. A lot of money is spent annually by the government on the construction and maintenance of roadways. It would greatly benefit to the nation's economy if we could extend the service life of the roads could. In order to enhance pavement performance, it is essential to understand the material involved in pavement construction. Therefore, crumb rubber could be an alternative material in improving the quality of hot mix asphalt.

2.2 Background of Crumb Rubber

Scrap tires are part of the solid waste management problem. Each year a lot of tires are discarded and many countries are facing the same problem in managing scrap tires. Figure 2.1 shows many tires discarded in the way, because it is not useful. The Environmental Protection Agency (EPA) estimated that 285 million tires are discarded annually in the United States and only 97 millions are being recycled (Chehovits, 1989).

Generally crumb rubber is manufactured from automotive and truck scrap tires. From an engineering point of view, crumb rubber has a number of special thermo-mechanical and chemico-physical properties. Crumb rubber is made by shredding scrap tire, that it is a particulate material free of fiber and steel. The size of the rubber particles is graded and can be found in many shapes and sizes (see Figure 2.2). The finest one can be as small as about 0.2 mm and below. The gradation commonly used in rubberized asphalt pavement is between about 2.0 mm to 0.5 mm. Crumb rubber is light in weight and also durable. It can last for a long period of time in a natural environment. From safety aspect, crumb rubber can be categorized as a non-toxic and inert material.

Figure 2.1: Discarded truck tires

Figure 2.2: Different sizes of crumb rubber

Now crumb rubber can be added into asphalt concrete whether to function as 'rubber-filler', 'asphalt-rubber' or as an additive. Modified asphalt pavement containing high air porosity due to crumb rubber that take place in the mixture will certainly increase the sound absorption capability in comparison with conventional asphalt pavement.

2.3 Crumb Rubber for Civil Engineering Applications

Because of the scale and required material properties, crumb rubber has been considered as suitable for the use in civil engineering applications. The strength and physical properties of crumb rubber make this material attractive for these types of applications. In most cases, crumb rubber is used as a raw material to improve the required properties of the product.

Among the wide variety of commercial applications, the following applications have exhibited a growing market potential:

a. Flooring for pavements, athletic fields and industrial facilities.
b. Acoustic barriers.
c. Rail crossings, ties and buffers.

Instead of crumb rubber is inexpensive filler in this application, it also has been chosen for its properties. However, several studies have shown that even if the initial cost are increased by using crumb rubber, the improved function and life of the product would significantly reduce the maintenance cost, and consequently the total cost of product.

2.4 Crumb Rubber Modified Asphalt Concrete Technology

Crumb rubber is the recycled rubber obtained by mechanical shearing or grinding of tires into small particles. The use of crumb-rubber modifier (CRM) in hot mix asphalt can be traced back to the 1840s when natural rubber was introduced into Asphalt to increase its engineering performance (Heitzman, 1992). Since the 1960s, researchers and engineers have used shredded automobile tires in hot mix asphalt mixes for pavements. However, it was not thoroughly discovered until the late of 1980s when people start to realize about the need to improve the conventional asphalt mixes and recycled tire crumb rubber become one of the alternative materials (Epps, 1994).

With a lot of researches being done in this field, there are many terminologies associated with tire rubber modified asphalt concrete mixes. Some of the terminologies that are commonly used as filler crumb rubber, because it is not new, rubber modified asphalt mixes and rubberized asphalt. These terms refer to the use of rubber in asphalt mixes that are different in their mix composition, method of production or preparation and their physical and structural properties.

Crumb rubber modifier is a general term used to identify concepts that incorporate scrap tire rubber into paving materials. Crumb rubber can be introduced into asphalt mixes by either reacting crumb rubber with asphalt at temperature where it is sufficient to cause physical and chemical changes that result as a modified binder or by blending the crumb rubber with hot aggregates before mixing with asphalt produce a rubber modified mixes. As a result, the consideration in using the crumb rubber will be different according to the terminologies whether it is associated with rubber modified binders or mixes.

Normally the terminologies associated with these CRM mixes are based on the percentage composition of CRM in asphalt or mixes and the mix production process. Currently, these are two technologies used to incorporate crumb rubber in asphalt concrete. The process of mixing the crumb rubber with the asphalt cement prior to mixing it with aggregates is known as wet process (see Figure 2.3). Whereas dry process refers to a method that first blends crumb rubber with hot aggregates prior to mixing it with asphalt binder which the end product called Rubber Modified Asphalt Concrete (RUMAC) mixes (Elliot, 1993) (see Figure 2.4).

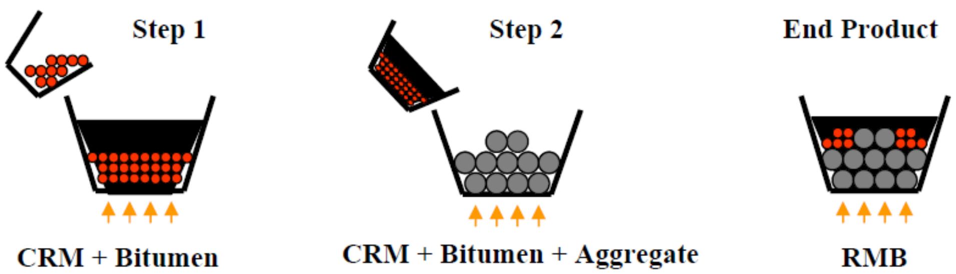

Figure 2.3: Wet process

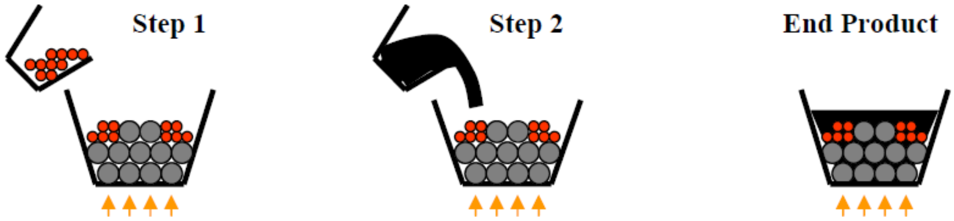

Figure 2.4: Dry process

2.4.1 Asphalt Rubber

Asphalt rubber is a term used to indicate asphalt cement modified with crumb rubber modifier. Schuler et al. (1986) defines asphalt rubber as a modified binder formulated by the physical and chemical bonding of asphalt cement and scrap tire rubber at elevated temperatures. While Green and Tolonen (1997) defines asphalt rubber as an equal blend of rubber and asphalt and asphalt whose response is primarily rubber like although those responses are modified by the presence of asphalt. The mixes prepared using asphalt rubber are referred as Asphalt Rubber (A-R) mixes.

2.4.2 Rubberised Asphalt

Green and Tolonen (1997) define rubberized asphalt as mixture of rubber in asphalt whose response is primarily asphalt like, although the responses are modified by the presence of rubber. An example of rubberized asphalt is a blend containing natural latex rubber.

2.4.3 Rubber Modified Asphalt Mixes

There are basically dense and open graded asphalt concrete mixes to which scrap tire rubber is added as a part of the aggregate component. The percentage of rubber used in these mixes varies from 1 to 3 percent by the total weight of the mix. The mixes are not considered to be asphalt rubber since rubber is not blended with the asphalt cement prior to mixing it with aggregates. The dense and open graded mixes which are produced by first mixing CRM and aggregates followed with an intimate mixing with asphalt cement are referred as 'asphalt concrete rubber filled' or 'rubber modified asphalt concrete mixes (RUMAC)' (Schuler et al., 1986).

2.5 Mix Production

Until recently, the design of CRM mixes was being mainly accomplished by the conventional Marshall method. Even though the Superpave technology has been established, most of the research conducted on CRM mixes is based on Marshall mix design.

As mentioned previously, there are two types of mix productions can be used to incorporate crumb rubber into hot mix asphalt which are wet process and dry process. The wet process has the advantage as the binder properties are better controlled, while the dry process is often easier for an asphalt manufacturer to use. This is because wet process requires asphalt plants with another binder storage tank that can handle more viscous modified binder than conventional asphalt. While the dry process will cost less than the wet process in the long run and for batch plant production it only requires small modification. To date, dry process has been identified as a very effective production method especially when cost of production is put into consideration. Basically, the mixes produced after incorporating rubber into gap gradation prior to mixing with the asphalt cement are called PlusRide RUMAC mixes. Generic/TAK RUMAC. Mixes is referred to end product by reacting crumb rubber into dense gradation.

2.5.1 Preparation of CRM Mixes

Based on past research, it was possible to identify various standards for the preparation of CRM mixes using dry and wet process. Table 2.1 summarizes the specifications adopted for the preparation of CRM mixes in the laboratory according to the design considerations outlined by the Arkansas State Highway and Transportation Department as a compilation of previous research since 1913.

Table 2.1: Specification for the Preparation of Fine Rubber Modified Asphalt Mixes

Procedures Recommended	From Literature Review	Details
Aggregate temperature before mixing with CRM	177 to 218°C	Higher aggregate temperature is said to ensure better reaction between asphalt and CRM.
Duration of aggregates in the oven before dry mixing with CRM	12 hours	Aggregates will be placed in the oven for at least 12 hours before mixing.
CRM temperature before dry mixing with aggregates.	Ambient temperature	CRM is maintained at room temperature will be mixed with hot aggregates.
Asphalt temperature before mixing with aggregates and CRM.	135 to 149°C	Asphalt will be maintained around 135°C to 149°C prior to mixing it with aggregate-CRM blend.
Mould temperature for sample preparation.	135°C, 160°C	The mould temperature must comparable with the mix temperature to prevent the mix from cooling quickly.
Duration of mixing aggregate and CRM.	15 seconds	15 seconds of mixing time.
Duration of mixing aggregate and CRM with asphalt.	2 to 3 minutes	Intimate mixing and mixing temperature of 135°Cand above is essential.
Temperature of compaction hammer and hot plate.	149°Cto 160°C	The compaction hammer face is maintained at 149 to 160°C
Mould treatment before adding the mix	Coat the inside of the mould with grease	Grease is used to coat the inner side of the mould for ease in removing the sample.
Type of compaction	50 blows, 75 blows, Gyratory	Compaction is used to represent the traffic condition.
Curing	160°C, 191°C, no curing	No curing is recommended for TAK mixes. Since fine CRM is used one an hour curing period at 160°Cis recommended for PlusRide mixes.
Sample Extrusion	After setting in the moulds overnight	6 hours or overnight is recommended

2.6 Volumetric Properties Performance

Most of the research conducted on CRM mixes were based on mixes designed using Marshall method. Heitzman (1992) and Epps (1994) stated that crumb rubber was added into dense graded mixes by using dry process (referred as Generic/TAK RUMAC mixes) while PlusRide RUMAC mixes was described for incorporating the crumb rubber with gap graded mixes. The CRM used can range from 1 to 6% by weight of the total mix. However, 1 to 3% CRM was commonly being used (Chehovits et al, 1993).

Initially, only coarse rubber was being used in dry process. However, some experience with the mix indicated that a better durability was obtained with an increase of fine rubber content. Hence, after 1981, 20% of the originally used coarse rubber was replaced with fine rubber passing sieve no 200 (Esch, 1984). Takkalou et al. (1985) reported that the required asphalt content used in CRM mixes was 1.5 to 3% higher than the conventional mixes with similar size and type of aggregates. Koh and Talib (2006) also agreed that RUMAC mixes required higher binder content as the percentage of crumb rubber increased. Elliot (1993) stated that effect of CRM on the optimum Asphalt content (OAC) and volumetric properties was significant for RUMAC mixes with 3% CRM. This could be attributed to the absorption of asphalt by the CRM which increase the asphalt content requirements for the mix to attain the required volumetric properties. Recent research on rubber-Asphalt interaction has demonstrated that during the mixing period, crumb rubber does swell and the amount of Asphalt absorb by crumb rubber was significantly increased which causes the residual Asphalt become stiffer, elastic and consequently affect the performance of the asphalt mixes (Singleton et al, 2000 and Airey et al, 2004).

Besides, the addition of crumb rubber seems to reduce the stiffness as indicated by a reduction in the Marshall stability. Studies by Troy, et al (1996) discovered that gap graded CRM mixes had lower Marshall stability than dense-grade CRM mixes. However, Takkalou et al. (1985) stressed out that performance evaluation on Marshall properties was significantly dependent on the crumb rubber gradation, air voids, aggregate gradation, mixing temperatureand curing conditions.

2.7 Evaluation of CRM Mixes Performance

A major consideration for this evaluation was performance related to rutting and fatigue resistance. The primary purpose of using rubber modifiers in hot mix asphalt (HMA) was to obtain a stiffer HMA at high service temperatures, a more elastic HMA to resist fatigue cracking at intermediate service temperatures, and a lower or unchanged stiffness at low service temperatures to resist thermal cracking.

Rutting was a flexible pavement distress caused by the accumulation of permanent deformation in the pavement layers due to the repeated application of traffic. Heitzman (1992) and Epps (1994) claimed that incorporation of CRM into asphalt mixes will make the mixes more elastic at higher service temperature thus enhancing their rutting resistance. Stroup, M, and and Krutz, N (1992) discovered that the addition of CRM by using dry process enhance the rutting resistance of the mixes at higher temperature. Similarly, Rebala, S, and Estakhri, C, K (1995) stated the used of CRM in the dry process allows it to serve as discrete particles which may enhance the rutting resistance. While Koh and Talib (2006) found that rutting of asphalt mixes at 2,000 load cycles was reduced by 22% with the addition of 3% crumb rubber. Chehovits et al (1993) indicated through Figure 2.5 that the TAK/Generis mixes offer higher rutting resistance compared to the conventional asphalt mixes.

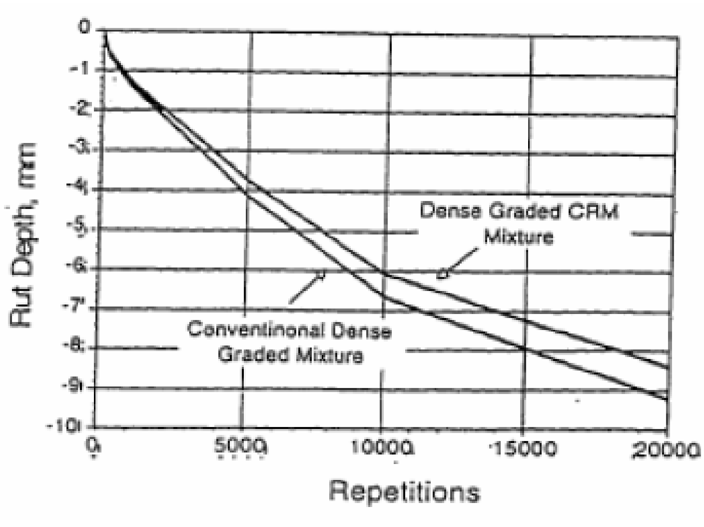

Figure 2.5: Comparison of rutting resistance for conventional

Hanson et al. (1994) evaluated the field cores taken from mix test section in Mississipi, along with the laboratory samples prepared, concluded that the field compacted control mixes deformed more than the field compacted CRM mixes. However, the laboratory compacted samples of the control and CRM mixes did not show any significant different in their rutting resistance. The evaluation of field projects indicated that after 2 years, the amount of rutting in the control and modified section were insignificant.

Most of the previous researches showed a general trend about Marshall mixes, that the dry process of incorporating CRM into asphalt mixes reduced the rutting resistance while wet process of incorporating CRM into the mixes enhanced the rutting resistance. However, another study did by Troy, et al. (1996) discovered CRM pavement sections done in Louisiana exhibit similar or lower rut depth than control sections after five to seven years in service.

2. 8 Tests of Material

This stage includes the tests of all materials used in this study; that was, asphalt, coarse aggregate, fine aggregate, filler and crumb rubber.

(a) Tests of Asphalt

There were several testing for asphalt. It has done to check asphalt quality to ensure that it could fulfill the specifications. The testing are as follows:

1. Penetration

Not all uses of asphalt with a large penetration will produce good result, the use of asphalt must be appropriate to conditions, location, and type of pavement that will be used. The Asphalt consists 3 (three) penetration type, namely 60/70, 80/100, and 100/120. The greater of penetration, it means that the asphalt more liquid. This examination was intended to determine the penetration of hard or soft Asphalt (solid or semi-solid) by inserting a needle size, weight, and time into the Asphalt at a certain temperature. Examination procedures refer to the AASHTO T - 49-89 or ASTM D - 5 - 86 or SNI 06-2456-1991 (see the pictures of penetration test in Appendix B).

2. Softening Point

The softening point means the temperature at the steel ball with a certain weight, pressing down a layer of asphalt or tar which stuck in the ring of a certain size, so that the asphalt was touching the base plate located below the ring at a certain height, as a result of a specific heating rate. This examination was intended to determine the softening point ranging from 30℃ to 200℃. Experiments conduct to determine at what temperature the asphalt began softening due to air temperature and traffic load. Examination procedures refer to the AASHTO T - 53-89 or SNI 06-2434-1991. (see the pictures of softening point test in Appendix B).

3. Ductility

The purpose of this inspection was to measure the longest distance that can be drawn between the two molds that contains the hard asphalt before the end at a certain temperature and pull speed. The purpose of this inspection was to determine the ductility of asphalt materials experiments. Examination procedures refer to the AASHTO T - 51-89 or ASTM D - 113-79 or SNI 06-2432-1991. (see the pictures of ductility test in Appendix B).

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4. Asphalt Solubility with Carbon Tetrachloride (CCl_4)

This examination was intended to determine the levels of soluble Asphalt in carbon tetra chloride (CCl_4). The purpose of this inspection was to determine the purity level asphalt. Examination procedures refer to the AASHTO T - 44-70 or ASTM D - 165-42 or SNI M-04-2004.

5. Specific Gravity

The specific gravity of Asphalt or tar was the ratio between the weight of heavy Asphalt or tar and distil water with the same content at a specific temperature. This examination was intend to check the weight of the hard Asphalt or tar. The purpose of this inspection was to get the heavy types of hard Asphalt or tar. Examination procedures refer to the AASHTO T- 228-90 or ASTM D - 70-76 or SNI 06-2441-1991. (see the pictures of specific gravity test in Appendix B).

6. Loss on Heating (LoH)

This examination aims to determine the weight reduction due to evaporation of volatile materials in the asphalt. Examination procedures follow AASHTO T - 79-88 or ASTM D-1754-83 or SNI 06-2440-1991.

a. Sieve Analysis

This examination was intended to determine the gradation, both coarse aggregate and fine aggregates. Examination procedures refer to AASHTO T27 - 88 or SNI 03-1968-1990.

b. Specific Gravity and Absorption

b) Tests of Aggregate

Aggregate tests conduct in this study was to fulfill the requirements of aggregate specification of Bina Marga standard, except for grain shape and surface composition.

1. Coarse Aggregates

The coarse aggregate used should have rough surface, angular sharp and clean from other materials that could interfere with the binding process. Aggregates are used in the form of crush stone in the dry condition. The types of test conduct on aggregates are as follows.

This examination was intended to determine the bulk specific gravity , saturated surface dry gravity (SSD) and apparent specific gravity of coarse aggregate. Bulk specific gravity was the ratio of aggregate dry weight and the weight of the contents of distill water equal to the aggregate in a saturated condition at a certain temperature. The Saturated Surface Dry (SSD) was the ratio between the weight of dry aggregate weight of distill water surface and whose contents equal to aggregate content in the dry state at a certain temperature. Apparent Specific Gravity was the ratio of aggregate dry weight and the weight of distill water whose contents equal to aggregate content in the dry condition at a certain temperature. Absorption was the percentage of water weight that can be absorb by the pores of dry aggregate. Investigation of procedures for coarse aggregate refers to AASHTO T85-88 or SNI 03-1969-1990.

c. Infinity of Aggregate to Asphalt

This examination was intended to determine the aggregate viscidity to asphalt. Stickiness was the percentage of aggregate to asphalt-cover rock surface area to the whole surface of the asphalt aggregate. Examination procedures refer to the SNI 03-2439-1991.

d. Abrasion with Los Angeles Machine

This examination was intended to determine the wear resistance of coarse aggregate to Los Angeles using the machine. Wear was express by the ratio between the weight worn through sieve No.12 to original weight, in percent. Examination procedures refer to the AASHTO T96-87 or SNI 03-2417-1991.

e. Flakiness and Elongation Index

This examination was intended to determine the aggregate of flakiness and elongation. Examination procedures refer to ASTM D-479.

2. Fine aggregate

Fine aggregate consists of clean sand, fine materials results split stone or a combination of both in the dry condition. Inspection types for fine aggregate were as follows:

a. Sieve Analysis

This examination was intended to determine gradation of fine aggregate, so as to determine the percentage of a combination of fine aggregate gradation for the manufacture of a mixture of AC-WC. Mode was used with the filter analysis. Examination procedures refer to the AASHTO T 27-88 or SNI 03-1968-1990.

b. Specific gravity and absorption

Inspection of procedures for fine aggregate refers to AASHTO T84-88 or SNI 03-1970-1990.

3. Filler Inspection

Examination of filler includes:

a. Sieve Analysis

Procedures for checking the sieve analysis for the filler refers to the SNI 03-4142-1996.

b. Specific Gravity and Absorption

Inspection of procedures for filler refers to AASHTO T84-88 or SNI 03-1970-1990.

4. Examination of Crumb Rubber

The examination of specific gravity of crumb rubber using inspection procedures of asphalt, coarse aggregate and fine aggregate. From the third examination, the results were then average. The specific gravity of crumb rubber was used in the calculation of Marshall properties. In this study examination of crumb rubber includes the examination of specific gravity and absorption properties.

2.9 Design of AC-WC Mixture

2.9.1 AC-WC Mixture Gradation

The sieve analysis results of crumb rubber were added to the sieve analysis results of the aggregate and crumb rubber in the mixture that meets the specifications of the aggregate grading examination layer content AC-WC. There were 3 (three) variations of proportion of crumb rubber. Specifications of aggregate gradation of AC-WC mixture can be seen in Table 2.2. (see the pictures of design of AC-WC Mixture test in Appendix B).

Table 2.2: Aggregate Gradation Specification of AC-WC

Sieve Size (mm)	Passed of Weight (%)
19,10 (3/4")	100
12,70 (1/2")	90 – 100
9,52 (3/8")	Maks. 90
4,76 (No.4)	
2,38 (No.8)	28 – 58
1,18 (No.16)	
0,59 (No.30)	
0,279 (No.50)	
0,074 (No.200)	4 – 10
Restricted Zone	
2,38 (No.8)	39.1
1,18 (No.16)	25,6 – 31,6
0,59 (No.30)	19,1 – 23,1
0,279 (No.50)	15,5

Source: Bina Marga (2004)

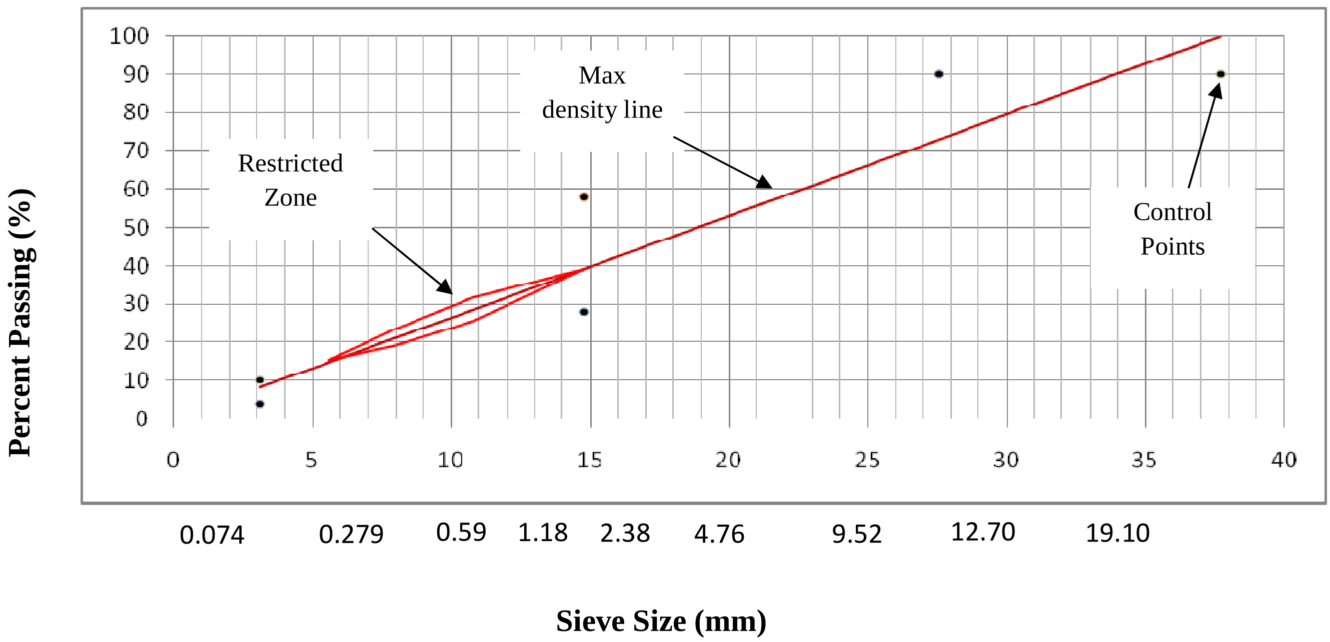

Figure 2.6: Fuller curve for aggregate gradation specification of AC-WC

2.9.2 Initial Estimates of Asphalt Content

Initial Asphalt content was calculated based on the proportion of aggregate gradation the include estimates of asphalt content can be determine using the following equation:

Pb = 0.035 a + 0.045 b + 0.18 F + Constants……………….…………………………(2.1)

where:

Pb	=	% minimum asphalt content
a	=	% of aggregate retained sieve # 8 (% CA)
b	=	% aggregate passed sieve # 200 (% FA)
F	=	% aggregate passed sieve # 200 (60-10%)
Constants	=	value of about 0.5 to 1.0 for AC.

Marshall Characteristics Analysis

The data results were obtained from laboratory test results are:

1. Specimens specific gravity

a. The specific gravity of asphalt was the ratio between the weight of distill Asphalt and heavy water with the same content at a specific temperature.

Asphalt Specific Gravity $= \frac{\text{"weight"}}{\text{Volume}}$ at temperature 25°C (gr/cm^3) ……….……......(2.2)

b. Aggregate specific gravity was the result of a combination of gravity of coarse aggregate and fine aggregate. To facilitate the calculation of bulk density of the aggregate total was express in the G_{sb}.

$$G_{sb} = \frac{100}{\frac{\%\,BP_1}{bulk\ specific\ gravity}+\frac{\%\,BP_2}{bulk\ specific\ gravity}+\frac{\%\,Sand}{bulk\ specific\ gravity}+\frac{\%\,dust\ stone}{bulk\ specific\ gravity}}\ (gr/cm3)$$

………………………………………………………………..……….............. (2.3)

Apparent specific gravity of total aggregate which was stated in the G_{sa}.

$$G_{sa} = \frac{100}{\frac{\% BP_1}{apparent\ specific\ gravity} + \frac{\% BP_2}{apparent\ specific\ gravity} + \frac{\% sand}{apparent\ specific\ gravity} + \frac{\% dust\ stone}{apparent\ specific\ gravity}}$$

(gr/cm^3) ……..…………………………………………………………..…....(2.4)

Effective specific gravity of total aggregate:

$$G_{se} = \frac{Gsb + Gsa}{2} \ (gr/cm^3) \quad \text{(2.5)}$$

Maximum Specific Gravity of the mixture:

$$G_{mm} = \frac{100}{\frac{100 - A}{Gse} + \frac{A}{T}} \quad \text{(2.6)}$$

where:

A = Percentage of Asphalt

T = Asphalt specific gravity

2. Density

Density value can be calculated with the formula:

$$\text{Bulk Specific Gravity Mixture} = \frac{\text{Weight on air}}{\text{SSD} - \text{"Weight in Water"}} \ (gr/cm^3) \quad \text{(2.7)}$$

3. Void In Mixture (VIM)

VIM was the percentage of air voids that exist in the mixture obtained by the formula:

$$VIM = \frac{\text{"Max specific gravity mixture"} - \text{Bulk specific gravity mixture}}{\text{BJ Max specific gravity mixture}} \times 100\ \% \quad \text{(2.8)}$$

4. Voids in Mineral Aggregate (VMA)

The value of the VMA can be calculated with the formula:

$$VMA = \frac{\text{Max specific gravity mixture } (100 - \%\text{"Asphalt"})}{\text{Gsb}} \times 100\% \quad \text{...(2.9)}$$

5. Void Filled with Asphalt (VFA)

VFA was the percentage of voids filled with Asphalt effectively obtained from the formula:

$$VFA = \frac{\left(\frac{\%\text{ asphalt x Bulk specific gravity mixture}}{\text{asphalt bulk specific gravity}}\right)}{\left(\frac{\%\text{ asphalt x bulk specific gravity mixture}}{\text{Asphalt specific gravity}}\right) + VIM} \times 100\% \quad \text{...(2.10)}$$

6. Stability

Value stability of specimens obtained from reading the press tool watches of Marshall stability. This figure was corrected with the numbers and figure correction for calibrating the thickness of the specimens. The formula for stability was

S = P x correction thickness of specimens (kg)…………………………….……........(2.12)

Where:

P = Calibration proving ring on O

O = Value of watches reading stability

7. Flow

Flow value (r) obtain from reading the watch stating deformation flow test object in units of 0.01 mm

8. Marshall Quotient

Marshall quotient value calculation was based on the formula:

$$MQ = \frac{\text{Stability}}{1{,}02\ x\ flow\ strip} \text{ (kg/mm)} \quad \text{...(2.13)}$$

2.10 Relevant Research Findings

Until now, several researches pertaining to the use of crumb rubber in asphalt mixtures has been performed, as shown below.

1. Iriansyah (1992), conducted field trials of Rubber Asphalt Mixtures on Cileunyi toll road (Section 50-55). This was an application of the results of laboratory experiment which assessed the benefits asphalt rubber mixture compared to conventional mixtures.

   To mix asphalt cement with crumb rubber, a custom-made mixing device with engine speed 350 radians per minute and stirred for 20 minutes was developed. The use of this device could make rubber asphalt mixture homogeneous. The average temperature used in the mixture reached 155°C.

   The studies produced results that the stability of asphalt rubber mixture showed higher values than the mixture with virgin asphalt. In general, the characteristics of the asphalt rubber mixture were better than using regular asphalt.

2. Daruninifah (2007), conducted a research on HRS-WC with the addition of solid rubber to evaluate the Marshall properties. The study was conducted by comparing several asphalt mixtures that use some variation of rubber content in the asphalt cement (0%, 1%, 2%, 3%, 4%, and 5%). Five asphalt contents were used in determining optimum asphalt content of the HRS-WC there were 6.0%, 6.5%, 7%, 7.5%, and 8%. The mixtures were compacted at standard compaction effort (2x75) and the last collision conducted research for HRS-WC by referring to the optimum asphalt content (OAC) was then varied asphalt content(6.6%, 7.1%, 7.6%, and 8.1%) and rubber pads added to the content variation of each asphalt content (0%,1%, 2%, #5,4% and 5%) pads standard conditions (2x75) impact on the refusal density (2x400) collision.

   The result showed that OAC equals to 7.1% strongly influenced the IRS. HRS-WC mixture with various percentage asphalt content could improve and maintain its density, the bond between the aggregate with asphalt as a binder an increasingly powerful that it can withstand heavy traffic loads without any bleeding, increased durability, elasticity of the asphalt increased and more flexible.

The addition of asphalt rubber daps do not necessarily produce a poor quality of asphalt mixtures. In this study will produce better asphalt mixture properties when it used asphalt content of 7.1% with the addition of 2% rubber on the asphalt.

The difference in this study with previous studies was:

(i) the use of crumb rubber powder passing sieve no. 200 as asphalt modifier.

(ii) the use of AC-WC mixture, refers to the specification of AC-WC, issued by Bina Marga (2004).

CHAPTER III
RESEARCH DESIGN AND METHODOLOGY

3.1 General Overview

In the Chapter Design and methodology of this study, it will be explained about the steps to be undertaken during the implementation of research on "Performance of service course Asphalt Concrete Mixture Wearing Course due to the addition of crumb rubber. The function of methodology as term of reference for doing this research. This research was conducted for the planning of asphalt hot mix, in which the compacting of specimens based on Bina Marga Standard 2004.

3.2 Research Flow Chart

This research was done in several stages, starting from the preparation phase, checks the quality of new materials and crumb rubber to be added to the mix aggregate gradation, mix design stage to implementation stage of testing in the laboratory with the Marshall Test. The steps of this research can be seen in Figure 3.1 below:

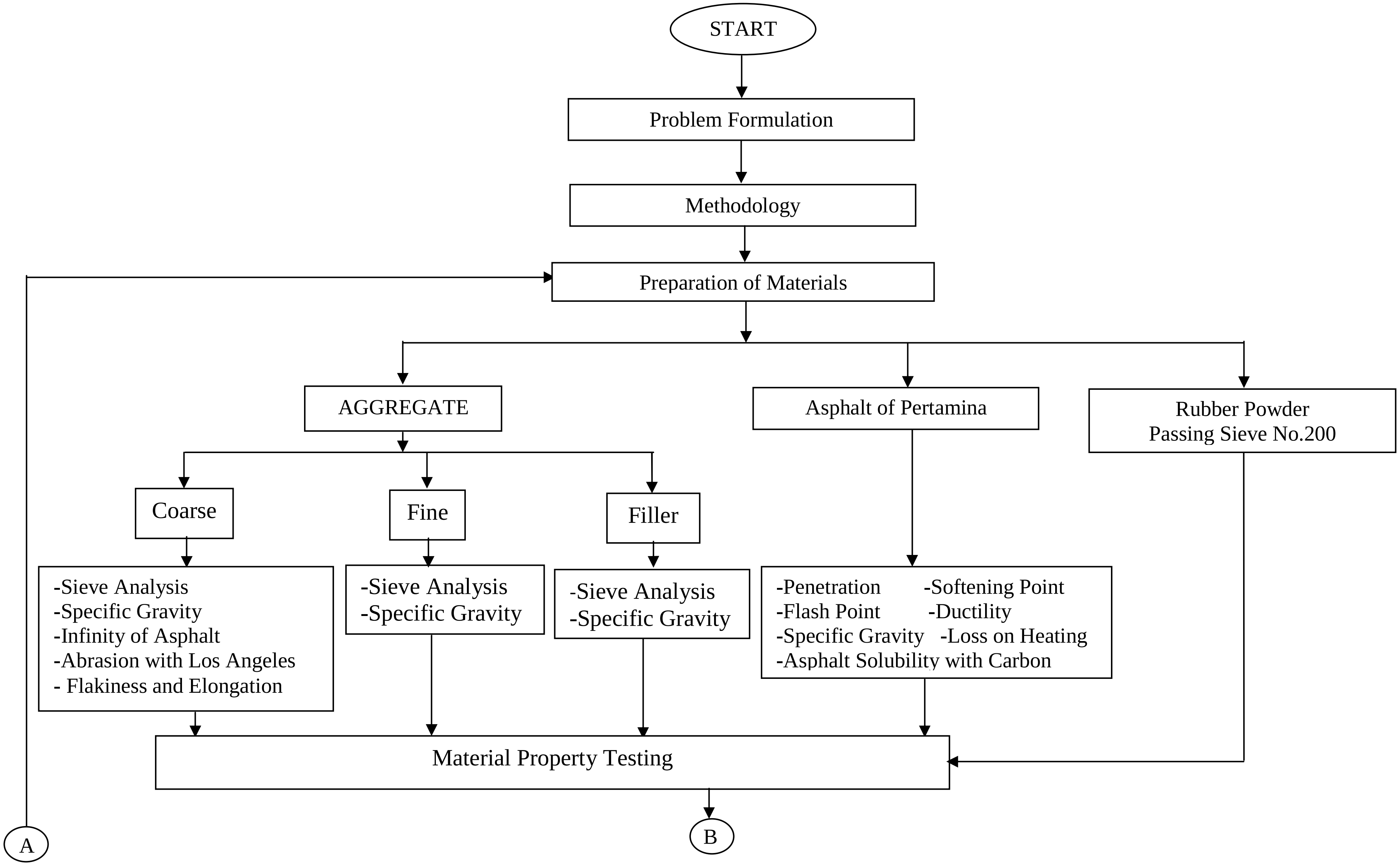

Figure 3.1: Flow Chart for Laboratory Process and Analysis

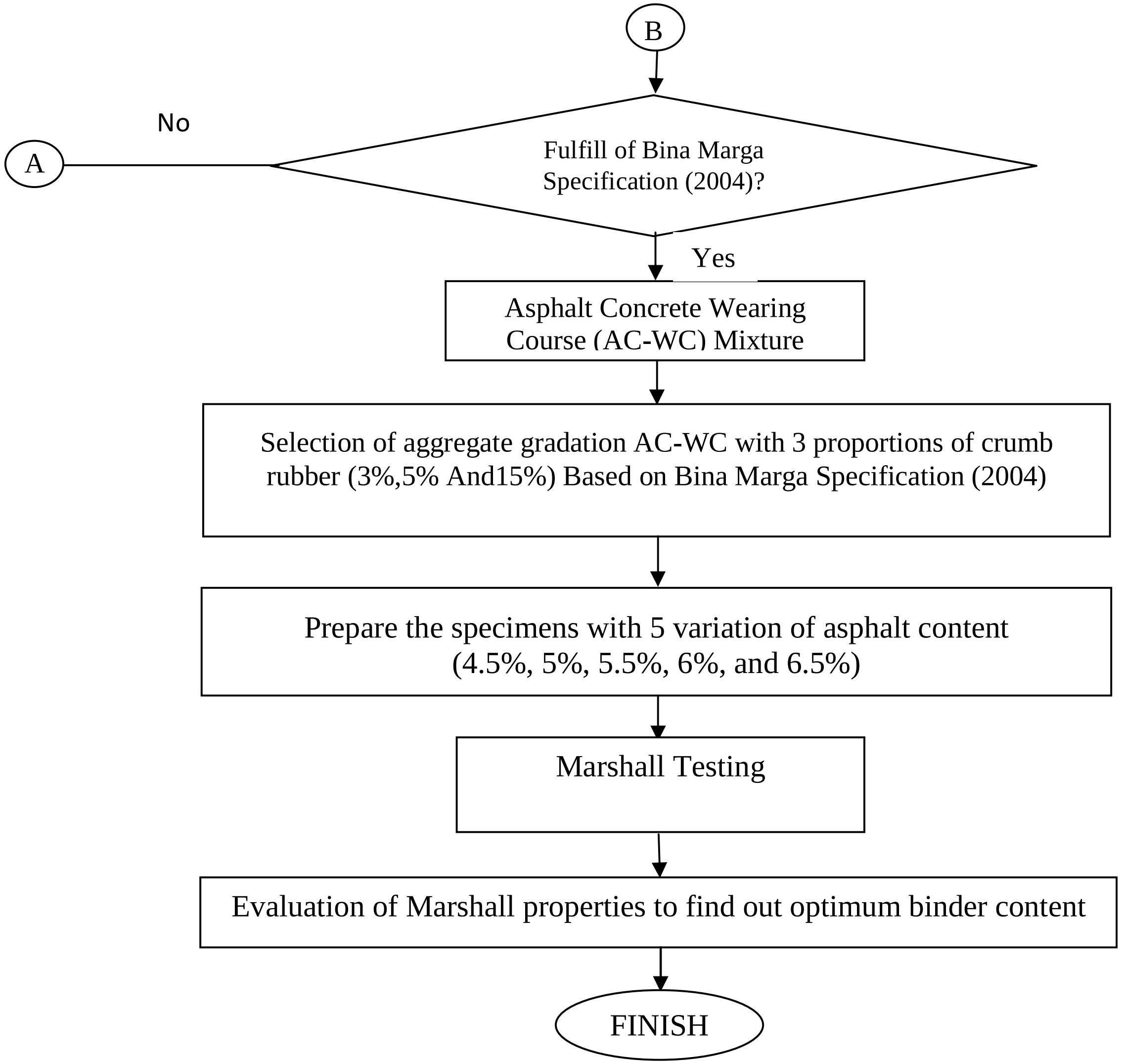

Figure 3.1: Flow Chart for Laboratory Process and Analysis (continuation)

3. 3 Research Procedure

3.3.1 Materials Preparation

Materials that need to be prepared were as follows:

1. Crumb Rubber

Material was taken from tire retreading factory PT. Polirubberindo Perkasa, Jalan Raya Semarang. Scrap tires was converted to crumb rubber with range in size from approximately 5 mm to less than 0.075 mm (sieve no. 200).

2. Aggregate (Coarse, Fine and Filler)

Aggregate come from the Kali Kuto Quarry PT. Adhi Karya. While the fine aggregate come from Muntilan.

3. Asphalt

Using asphalt materials from Pertamina production with penetration 60/70

3.3.2 Material Requirements

The standard and specification used in this study were AASHTO, ASTM and Bina Marga. The specification for asphalt Pen 60/70, aggregate and filler were depicted in Tables 3.1- 3.3.

Table 3.1: Requirements of Asphalt Pen 60-70

Type Examination	Inspection Standards	Requirements		
		Pen. 60/70		Unit
		Min	Max	
Penetration (25 °C, 5 seconds)	AASHTO T 49-89	60	79	0.1 mm
Softening Point (Ring and ball)	AASHTO T 84-88	48	58	^{0}C
Flash point (Elev. Open cup)	AASHTO T 48-89	200	-	^{0}C
Loss on Heating (LOH) (160 °C, 5 h)	AASHTO T 47-83	-	0.8	Wt%
Solubility (CCl4)	AASHTO T 44-90	99	-	Wt%
Ductility (25 °C, 5 cm / sec)	AASHTO T 51-89	100	-	Cm
Penetration after Loss on Heating (LOH)	AASHTO T 47-83	54	-	% in the beginning
Ductility after Loss on Heating (LOH)	AASHTO T 51-49	50	-	% in the beginning
Specific gravity25°C,	AASHTO T 84-88	1	-	Gram/cm

Source: Bina Marga, 2004

Table 3.2: Specification for Coarse and Fine Aggregate

Type Examination	Test Standards	Specification
COARSE AGGREGATE		
1. Sieve Analysis	AASHTO T 27-88	Retained on sieve No.4
2. Infinity with asphalt	AASHTO T19-88	> 95%
3. Abrasion with Los Angeles Machine	AASHTO T 96-87	< 40%
4. Absorption	AASHTO T 84-88	< 3%
5. Apparent Gravity	AASHTO T 84-88	> 2,5 gr/cc
6. Flakiness and Elongation Index	ASTM D-4791	< 25%
FINE AGGREGATE		
1. Absorption	AASHTO T 84-88	< 3%
2. Apparent Specific Gravity	AASHTO T 84-88	> 2,5 gram/cc
3. Sand Equivalent	AASHTO T 176-73	> 50%

Source: Bina Marga, 2004

Table 3.3: Requirements of Filler

Type Examination	% passed of weight
1. Sieve Analysis	
No. 30 (0.59 mm)	100
No. 50 (0.279 mm)	95 – 100
No. 100 (0.149 mm)	90 – 100
No. 200 (0.074 mm)	75 – 100
2. Absorption	< 3 %
3. Apparent gravity	> 2,5 gram/cc

Source :Bina Marga, 2004

3. 3.3 Tests of Material

This stage includes the tests of all materials used in this study, there were, asphalt, coarse aggregate, fine aggregate, filler and crumb rubber.

(a) Tests of Asphalt

There were several testing for asphalt. It has done to check asphalt quality to ensure that it could fulfill the specifications. The tests are as follows (see the detail of the tests in Chapter 2).

1. Penetration

Examination procedures refer to the AASHTO T - 49-89 or ASTM D - 5 - 86 or SNI 06-2456-1991.

2. Softening Point

Examination procedures refer to the AASHTO T - 53-89 or SNI 06-2434-1991.

3. Ductility

Examination procedures refer to the AASHTO T - 51-89 or ASTM D - 113-79 or SNI 06-2432-1991.

4. Asphalt Solubility with Carbon Tetrachloride (CCl_4)

Examination procedures refer to the AASHTO T - 44-70 or ASTM D - 165-42 or SNI M-04-2004.

5. Specific Gravity

Examination procedures refer to the AASHTO T- 228-90 or ASTM D - 70-76 or SNI 06-2441-1991.

6. Loss on Heating (LOH)

Examination procedures follow AASHTO T - 79-88 or ASTM D-1754-83 or SNI 06-2440-1991.

(b) Tests of Aggregate

Aggregate tests conduct in this study was to fulfill the requirements of aggregate specification of Bina Marga standard, except for grain shape and surface composition (see the detail of the tests in Chapter 2).

1. Coarse Aggregates

The coarse aggregate used should have rough surface, angular sharp and clean from other materials that could interfere with the binding process. Aggregates were used in the form of crush stone in the dry condition. The types of test conduct on aggregates are as follows.

a. Sieve Analysis

This examination was intended to determine the gradation, both coarse aggregate and fine aggregates. Examination procedures refer to AASHTO T27 - 88 or SNI 03-1968-1990.

b. Specific Gravity and Absorption

Investigation of procedures for coarse aggregate refers to AASHTO T85-88 or SNI 03-1969-1990.

c. Infinity of Aggregate to Asphalt

Examination procedures refer to the SNI 03-2439-1991.

d. Abrasion with Los Angeles Machine

Examination procedures refer to the AASHTO T96-87 or SNI 03-2417-1991.

e. Flakiness and Elongation Index

This examination was intended to determine the aggregate of flakiness and elongation. Examination procedures refer to ASTM D-479.

2. Fine aggregate

Fine aggregate consists of clean sand, fine materials results split stone or a combination of both in the dry condition. Inspection types for fine aggregate are as follows:

a. Sieve Analysis

Examination procedures refer to the AASHTO T 27-88 or SNI 03-1968-1990.

b. Specific gravity and absorption

Inspection of procedures for fine aggregate refers to AASHTO T84-88 or SNI 03-1970-1990.

3. Filler Inspection

Examination of filler includes:

a. **Sieve Analysis**

Procedures for checking the sieve analysis for the filler refers to the SNI 03-4142-1996.

b. **Specific Gravity and Absorption**

Inspection of procedures for filler refers to AASHTO T84-88 or SNI 03-1970-1990.

4. Examination of Crumb Rubber

Because there is no standard available to examine the properties of crumb rubber, the following tests were adopted: specific gravity and absorption of coarse and fine aggregates, specific gravity of asphalt (with water and kerosene as the medium of the test).

3.3.4 Design of AC-WC Mixture.

3.3.4.1 AC-WC Mixture Gradation

The gradation used in this study is fuller gradation for AC-WC mixture, as shown in Table 2.2 and Figure 2.6.

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3.3.4.2 Initial Estimates of Asphalt Content

Initial asphalt content was calculated based on the proportion of coarse and fine aggregates, and filler in aggregate gradation. The initial estimates of asphalt content can be determined by using equation 2.1.

3.3.4.3 Preparation of Specimens

Two types of specimens were prepared in this study. They are:

1. AC mixture without crumb rubber.
2. AC mixture with crumb rubber.

The procedure of sample preparation is as follows: (i) calculate the initial estimate of asphalt content; (ii) made briquettes with variations in asphalt content, i.e. two points at above and two points at below the initial estimate of asphalt content with 0.5% interval. These briquettes were prepared for asphalt without crumb rubber and for asphalt with crumb rubber.

3.3.4.4 Number of Samples

The number of samples required to find the Optimum Asphalt Content can be seen in Table 3.4.

Table 3.4: Number of samples Test in This Study

Test Objects	Variations of asphalt content	Variations of Crumb Rubber*)	Requirement of Each specimens Variations	Total
The specimens without crumb rubber	5	-	3	15
Specimens with crumb rubber	5	3	3	45
TOTAL				60

Remarks:
*) variations of crumb rubber: 3%, 5% and 15%

3.3.5 Marshall Properties

. The Marshall properties of the briquette were evaluated by checking if the properties fulfill the specification presented in Bina Marga (2004), as seen in Table 3.5.

Table 3.5: Specification of AC Mixture

Properties		Sieve Course		
		WC	BC	Base
Asphalt Absorption (%)	max.	1,2		
The number of collisions per field		75		112
Voids in mixture (VIM) (%)	Min.	4,9		
	Max.	5,9		
Voids in the aggregate (VMA) (%)	Min.	15	14	13
Voids filled with asphalt (VFA) (%)	Min.	65	63	60
Stability (kg)	Min.	800		1500
	Max.	-		-
Flow (mm)	Min.	3		5
Marshall Quotient (kg / mm)	Min.	250		300
Remained Stability Marshall (%) After 24 Hours Immersion, 60Oc	Min.	75		
Voids in mixture (%) on Refusal Density	Min.	2,5		

Source: Bina Marga (2004)

3.3.6 Selection of Optimum Asphalt Content

The results of the Marshall test (stability and flow values) and other mixture properties (VIM (voids in mixture), VMA (voids between the aggregate), VFA (voids filled with asphalt)), and MQ, can be used to identify the optimum asphalt content within the range that meets all the criteria of the design.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Introduction

Generally, typical research on materials conducted so far was to evaluate the use of different materials in the mixture in order to understand the effect of the use of that material to the performance of the mixture. In this study, an evaluation of crumb rubber usage in asphalt mixture was conducted. For this purpose, crumb rubber in three different proportions (3%, 5% and 15%) was mixed with asphalt cement (or called as wet process) to obtain crumb rubber modifier asphalt (CRM asphalt). The performance of asphalt mixture with those CRM asphalts then was evaluated. A comparison between those mixtures with common mixture (aggregate mixed with virgin asphalt) was also presented in this study.

4.2 Properties of Materials

In this study, the main materials used were aggregate, asphalt and crumb rubber. The results of the material tests and their corresponding requirements are presented in the following sections.

4.2.1 Properties of Asphalt

Four properties of both virgin and CRM asphalts were analyzed, that were, specific gravity, penetration, softening point and ductility, and depicted in Table 4.1. The results in the table indicate that in a sufficient proportion, the addition of CRM in asphalt will improve the properties of the asphalt, as seen in the values of penetration and softening point. However, the excessive amount of crumb rubber in asphalt, i.e. 15% in this case, can reduce the performance of the asphalt. As shown in Table 4.1, the addition of such a proportion of crumb rubber may contribute to the results that out of the specified requirements (see the values of softening point and ductility for CRM asphalt with crumb rubber 15%). Another parameter, i.e. specific gravity was very obvious to understand, that the increase of crumb rubber content will increase the specific gravity of the asphalt.

Table 4.1: Properties of CRM Asphalt with Different of Percentage Rubber Mix

No.	Content of Crumb Rubber Passing no. 200	Specific Gravity	Penetration (0.1mm)	Softening Point (°C)	Ductility (m)
1	0%	1.036	64	52	1.00
2	3%	1.038	63	54	1.00
3	5%	1.057	61	52	1.00
4	15%	1.081	62	61	0.90
Specification		Min. 1	60- 70	48 – 59	> 1.00

4.2.2 Properties of Aggregates

At the preliminary stage, aggregate were sieved according to ASTM C 136-84a and separated according to the size of sieves on the selected aggregate gradation. The total weight of aggregates needed was 1200 grams. The aggregate gradation specification for AC-WC and the selected gradation used in this study are shown in Table 2.2 and Figure 4.1.

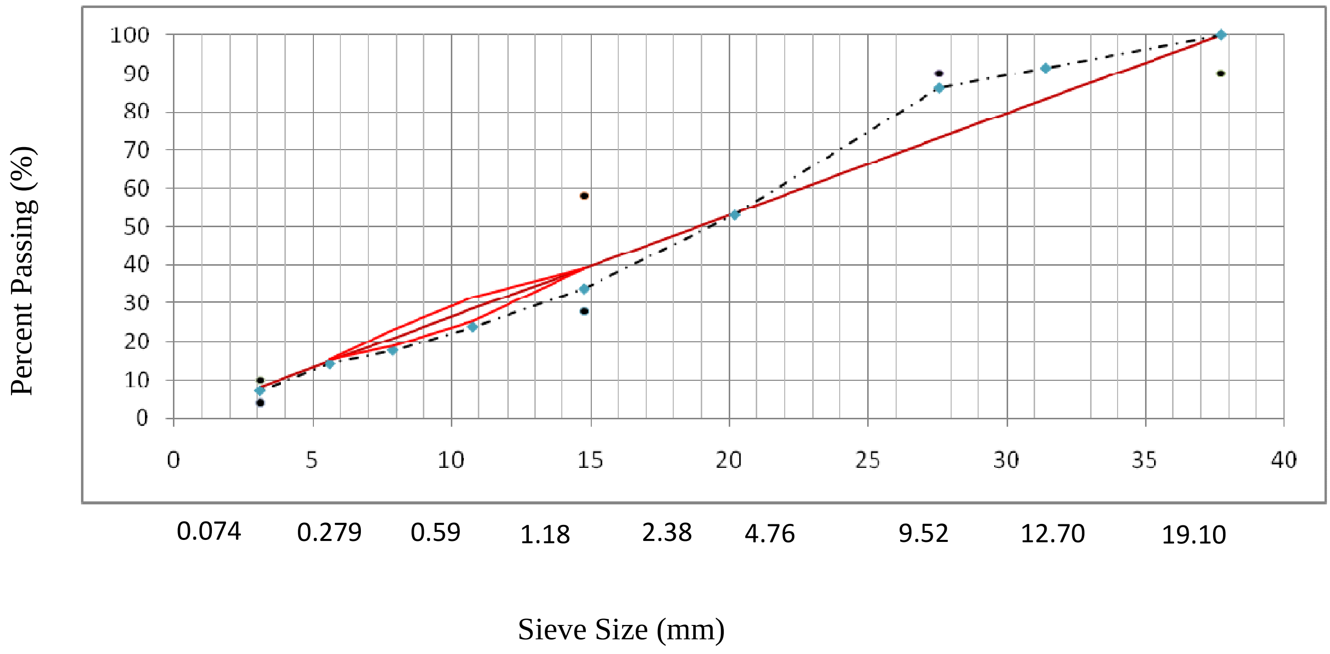

Figure 4.1: Aggregate Gradation Specification of Sieve Course AC-WC

Based on Figure 4.1, it can be concluded that the selected aggregate gradation used in this study can fulfill the gradation requirement specified by Bina Marga (2004).

Similar with asphalt cement, the aggregate materials require to be tested to evaluate whether their properties fulfill the requirements. Several aggregate properties were measured in this study, such as specific gravity, abrasion, flakiness and elongation indices, and so on, to make sure that the aggregates used could be used in making the asphalt mixtures. The results of the aggregate tests are presented in the Tables 4.2 & Table 4.3.

Table 4.2: Properties of coarse aggregate

No	Properties	Requirement	Results	
			CA passing 3/4"	**CA passing 3/8"**
1	Affinity to asphalt	> 95%	98	98
2	Abrasion using LA Test	< 40%	22,36	22,36
3	Absorption	< 3%	2,280	2,482
4	Bulk Specific Gravity	> 2,5 gr/cc	2,679	2,665
5	SSD Specific Gravity	> 2,5 gr/cc	2,740	2,731
6	Apparent Specific Gravity	> 2,5 gr/cc	2,853	2,853
7	Flakiness Index	< 25%	19,10	23,48
8	Elongation Index	< 25%	8,78	9,47

Table 4.3: Properties of fine aggregate and filler

No	Properties	Requirement	Results	
			Fine aggregate	**Filler**
1	Absorption	< 3%	1,626	2,291
2	Bulk Specific Gravity	> 2,5 gr/cc	2,667	2,664
3	SSD Specific Gravity	> 2,5 gr/cc	2,710	2,725
4	Apparent Specific Gravity	> 2,5 gr/cc	2,788	2,837

It can be seen in Tables 4.2 and Table 4.3 show that all properties can fulfill the specification. It is important to note that values of some properties approached their boundaries, such as absorption of coarse aggregate and filler, as well as, flakiness of coarse aggregate. This could affect the performance of the asphalt mixtures.

4.2.3 Properties of Crumb Rubber

In this study, crumb rubber passing sieve no. 200 was used, instead of crumb rubber with larger size. This is because the use of large-size crumb rubber could make the modified asphalt being non-homogenous. Besides, the use of small-size crumb rubber also can make the nature of the bouncy owned by rubber material would be much reduced.

Because of lack test standard for crumb rubber properties, especially its specific gravity and absorption, test procedures for different materials were used, i.e. specific gravity and absorption test procedure for coarse and fine aggregates, and specific gravity test procedure for asphalt cement with water and kerosene as test medium, then the results of all tests were averaged. The results of the test are depicted in the following table.(See Table 4.4 & Table 4.5)

Table 4.4: Specific Gravity of Rubber Powder

No	**Procedures Used**	**Results**	**Unit**
1	Specific gravity of fine aggregates	0,692	gr/cc
2	Specific gravity of coarse aggregate	0,783	gr/cc
3	Specific gravity of asphalt (water as medium)	1,093	gr/cc
4	Specific gravity of asphalt (kerosene as medium)	1,320	gr/cc

Table 4.5: Water absorption of Crumb Rubber

No	Procedures Used	Results	Unit
1	Absorption of Fine Aggregates	6,741	%
2	Absorption of Coarse Aggregate	6,742	%
Average		6,7415	%

It appears in Table 4.4 that the specific gravity of crumb rubber tested using several procedures vary widely. According to visual observation in determining specific gravity of crumb rubber using procedure of determining specific gravity of asphalt with water as medium, it can be concluded that the specific gravity of crumb rubber should be larger than (1). Therefore, in this study, the specific gravity of the crumb rubber was derived from the average value of specific gravity at points 3 and 4 of Table 4.4, that is, equal to 1.2065.

From Table 4.5, it can be concluded that the crumb rubber material has large absorption properties, even beyond the requirement of the absorption value specified for aggregate material, i.e. maximum of 3%.

4.3 Marshall Properties of Asphalt Mixtures

In this study, there were four asphalt mixtures were evaluated, i.e. asphalt mixture with all new materials and three asphalt mixtures with CRM asphalt. The crumb rubber used in CRM asphalt was that passing, sieve no. 200 with three different contents (3%, 5% and 15%). Six Marshall parameters, that were, Marshall Stability, flow, Marshall Quotient (MQ), voids in the mineral aggregate (VMA), voids in the mix (VIM) and voids filled with asphalt (VFA), were analyzed. The results of Marshall parameters evaluated in this study should conform to the requirements of Indonesian specification (Department of Settlement and Regional Infrastructure Republic of Indonesia, 2004), as follows:

(i) Marshall stability min. 800 kg,
(ii) Flow min. 3 mm,
(iii) Marshall Quotient (MQ) min. 250 kg/mm,
(iv) Void in mineral aggregate (VMA) min. 15%,
(v) Voids in the mix (VIM) 4.9%-5.9%, and
(vi) VFA min. 65%.

The results of asphalt mixtures evaluation in terms of Marshall parameters are shown in Table 4.6 and Figure 4.2. More detail about calculation of Marshall volumetric parameters, as well as the load-deformation parameters, can be seen in Appendix A.

Table 4.6: The Results of Voids-Asphalt Parameters in Mixture with CRM Asphalt

No	Asphalt content (%)	Crumb Rubber Content (%)			
		0%	3%	5%	15%
S.G	4.5	2.338	2.297	2.301	2.313
	5	2.357	2.320	2.321	2.327
	5.5	2.385	2.363	2.353	2.373
	6	2.386	2.373	2.370	2.358
	6.5	2.384	2.364	2.364	2.361
VIM	4.5	8.860	10.488	10.513	10.266
	5	7.425	8.867	9.035	9.059
	5.5	5.600	6.504	7.090	6.579
	6	4.838	5.393	5.749	6.534
	6.5	4.209	5.017	5.298	5.752
VMA	4.5	16.193	17.672	17.530	17.101
	5	15.968	17.257	17.228	17.027
	5.5	15.411	16.199	16.524	15.819
	6	15.820	16.288	16.384	16.818
	6.5	16.346	17.027	17.040	17.156
VFA	4.5	53.405	48.701	48.232	48.394
	5	60.504	55.764	54.859	54.298
	5.5	69.334	65.810	63.330	64.730
	6	74.066	71.776	70.061	66.696
	6.5	78.037	74.689	73.290	71.160
Stability	4.5	856.7	887.7	959.1	981.7
	5	893.1	888.4	929.7	1058.9
	5.5	967.6	915.2	1011.5	1031.5
	6	975.8	923.2	938.8	989.7
	6.5	902	751.1	848.9	903.6
Flow	4.5	2.657	2.150	2.233	2.297
	5	2.840	2.583	2.797	2.673
	5.5	3.710	3.400	3.100	3.033
	6	3.903	3.517	3.347	3.367
	6.5	4.340	2.900	3.657	3.647
MQ	4.5	316.142	404.776	421.045	419.068
	5	308.303	337.164	325.896	388.327
	5.5	255.686	263.901	319.892	333.390
	6	245.081	257.369	275.026	288.201
	6.5	203.752	253.909	227.588	242.935

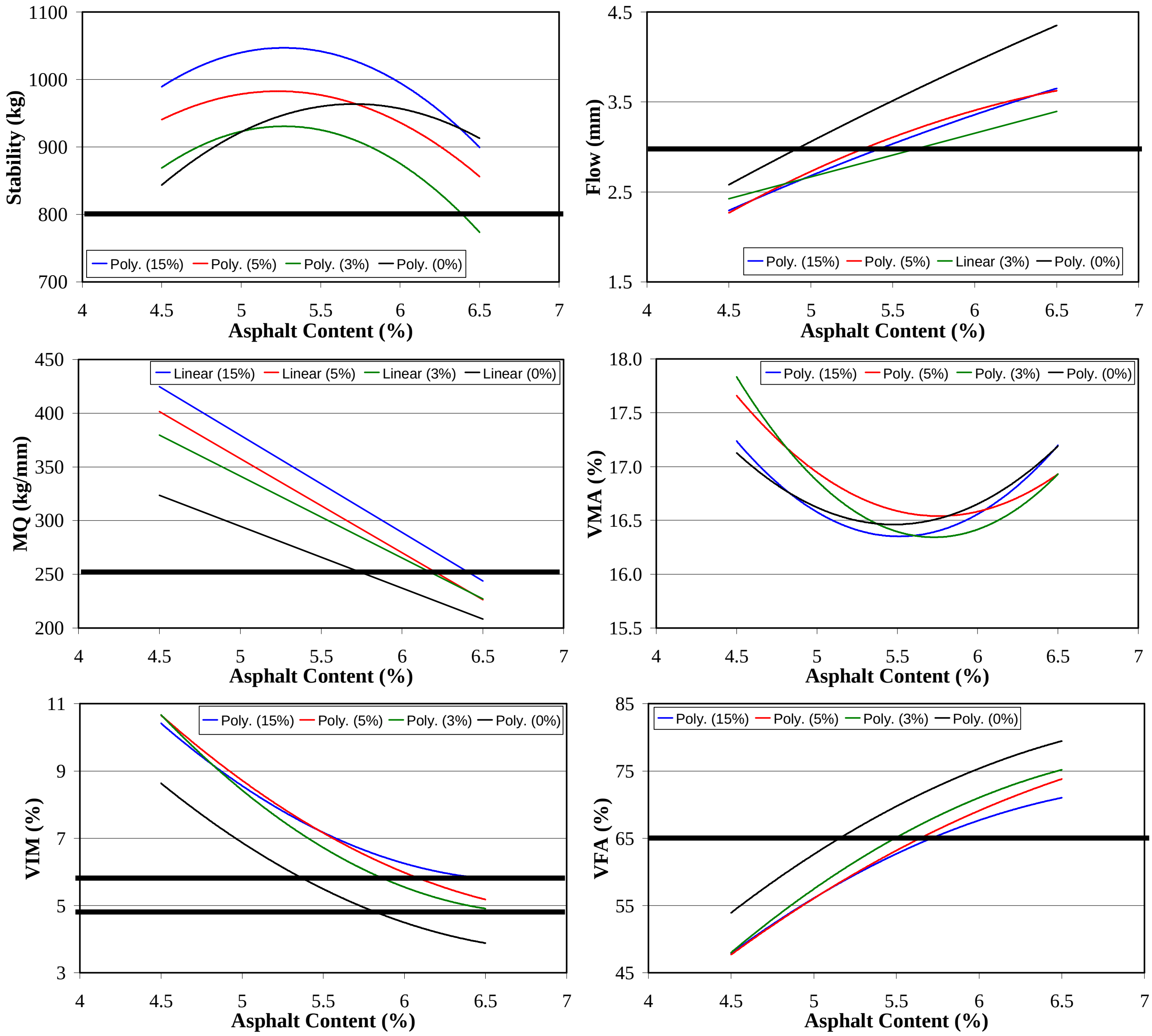

Figure 4.2: Charts of Marshall Properties

Based on the Table 4.6 and Figure 4.2 above, the following observation can be made:

(i) The specific gravity of mixture with all new materials showed higher value than the rest. The use of crumb rubber in the mixture has a tendency to reduce the specific gravity (see Table 4.6). This could be contributed by the fact that crumb rubber has elastic characteristic. This characteristic can cause the mixture being difficult to be denser.

(ii) VMA of mixture with CRM 5% was higher than the rest. However, the results of VIM and VFA parameters indicate that mixture with CRM 3% was more optimal. The high value of VMA of mixture with CRM 5% was contributed by high VIM. It was known that mixture with high VIM was not recommended to be used because it tends to less impermeable and it was susceptible to damage due to ageing process. It was very interesting to know that it is not always valid that the higher the crumb rubber content, the higher the voids will be.

(iii) In Table 4.6 and Figure 4.2, it was interesting to know that the increase of crumb rubber in CRM asphalt will increase the Marshall stability. However, the high values of Marshall stability that was not followed by sufficient flow will result in less flexibility, as represented by Marshall Quotient (MQ) parameter. In this study, the use of 3% crumb rubber in CRM asphalt can show a better result of load-deformation parameter, as compared with the use of higher crumb rubber in CRM asphalt.

(iv) As mentioned previously, all of Marshall parameters values should conform to the requirements of the specification. Among six parameters evaluated, only stability and VMA parameters of all mixture with CRM asphalt could fulfill the requirements. VIM was the parameter with strict requirement, therefore, only short range of asphalt content that could fulfill the requirement.

4.4 Determination of Optimum Asphalt Content (OAC)

Once all Marshall parameters were known, the optimum binder content of the mixtures with different content of crumb rubber can be determined, as follows (see Table 4.7 to Table 4.11).

Table 4.7: Asphalt Content of Marshall Properties for Different Crumb Rubber Content

Marshall Parameter	Standard	Asphalt content for different crumb rubber content			
		0%	3%	5%	15%
Stability	Min 800 kg	4.50-6.50	4.50- 6.40	4.50-6.50	4.50-6.50
Flow	Min 3mm	4.93-6.50	5.11-6.50	4.80-6.50	5.10-6.50
MQ	Min 250 kg	4.50-5.82	4.50-6.50	4.5-6.27	4.50-6.42
VIM	Mix 4.9%-5.9%	5.46-5.94	5.50-6.50	6.04-6.50	6.33-6.50
VFA	Min 65%	5.23-6.50	5.53-6.50	5.62-6.50	5.71-6.50
VMA	Min 15%	4.50-6.50	4.50-6.50	4.50-6.50	4.50-6.50

Table4.8: Determination of OAC of asphalt mixture with 0% crumb rubber

Parameters	Asphalt Content (%)				
	4.5	5.0	5.5	6.0	6.5
Stability					
Flow					
Marshall Quotient					
VMA					
VIM					
VFA					
OAC	**5.640**				

Table4.9: Determination of OAC of asphalt mixture with 3% crumb rubber

Parameters	Asphalt Content (%)				
	4.5	5.0	5.5	6.0	6.5
Stability					
Flow					
Marshall Quotient					
VMA					
VIM					
VFA					
OAC	**5.97**				

Table4.10: Determination of OAC of asphalt mixture with 5% crumb rubber

Parameters	Asphalt Content (%)				
	4.5	5.0	5.5	6.0	6.5
Stability					
Flow					
Marshall Quotient					
VMA					
VIM					
VFA					
OAC	**6.16**				

Table 4.11: Determination of OAC of asphalt mixture with 15% crumb rubber

Parameters	Asphalt Content (%)				
	4.5	5.0	5.5	6.0	6.5
Stability					
Flow					
Marshall Quotient					
VMA					
VIM					
VFA					
OAC	6.26				

As seen in Tables 4.7-4.11, the value of OAC increase with the increase of the percentage of crumb rubber added in asphalt mixture. This could be due to the fact that the crumb rubber has higher water absorption. It wants that the more the crumb rubber in the mixture, the higher asphalt content required to produce a mixture with optimum asphalt content.

Among all crumb rubber contents used in this study, the use of 3% crumb rubber in the asphalt mixture showed better performance compared to the rest, and still comparable with the mixture with virgin materials. However, the performance of asphalt mixture with crumb rubber requires further evaluation as it did not show a significant improvement on the properties of Marshall. Since CRM showed as less temperature-susceptible material, further researches on evaluating this property should be conducted, especially when CRM is used as a material of asphalt mixture.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

On the basis of the results of the laboratory test in this study, the following conclusions were drawn.

1. The penetration values of modified Asphalt were found lower than virgin Asphalt, but the softening values showed higher than virgin Asphalt. This indicated that the addition of crumb rubber in binder can increase penetration index values, which mean it can reduce temperature susceptibility
2. The increase amount of crumb rubber in asphalt mixture will increase the Marshall stability. However, this was not always followed by sufficient flow; therefore, it resulted in less flexibility, as represented by Marshall Quotient (MQ) parameter. In this study, the use of 3% crumb rubber in CRM asphalt can show the best result in terms of load-deformation.
3. The higher the amount of crumb rubber in the asphalt mixture, the higher the VIM and the lower the VFA will be. In this study, asphalt mixture with 3% crumb rubber could produce better result than those of other mixtures with crumb rubber. Overall, asphalt mixture without crumb rubber still showed the best performance.
4. The asphalt mixture with 3% crumb rubber could be used with caution. As the performance of this mixture was still lower than those of mixture without crumb rubber, therefore, it is recommended that this mixture is used as foundation layers, instead of surface layer.
5. The asphalt optimum content (OAC) increased with the increased of crumb rubber. It indicated that the use of crumb rubber in the asphalt mixture will require additional asphalt content, although the fine aggregate used in RAP have contained asphalt already.

5.2 Recommendation

The following points were recommended for improving the results of this study and proposed future works.

1. To produce a recommended rubber content used in asphalt mixture, repeatability of the laboratory works should be performed. To obtain an accurate result, statistic analysis is recommended.

2. It is fact that the use of crumb rubber in asphalt mixture needs additional asphalt content. The requirement of additional asphalt content in the mixture shows that the use of crumb rubber in asphalt mixture is leading in in-efficient manner of producing asphalt mixture. It is necessary to do a research to find out the optimum asphalt content with considering the asphalt content that remains in the surface of milling materials.

3. The crumb rubber used in this study is a result of ambient-temperature grinding process. A comparison between this kind of crumb rubber and crumb rubber as a result of cryogenic grinding process is adviceable.

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APPENDIX A

Mix Asphalt with Aggregate of Percentage the Crumb Rubber : 0%

ANGKA PENETRASI ASPAL : Pen. 60/70 Ex. Pertamina

Specific Gravity for Asphalt : 1.036

Number Of Sample	Asphalt %	Specific Gravity In The Mix	Volume in the Sample	WEIGHT IN THE GRAM			Specific Gravity	VOID IN THE MIX %	VOID IN THE AGG (%)	VOID IN THE Asphalt (%)	STABILITY		FLOW (MM)	MARSHALL QUOTIN
				Weight in the Air	Weight in the Water	SSD					READ STRIP	IN THE (KG)		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	4.5	2.565	506.3	1184.2	691	1197.3	2.339				75	880.2	2.85	
	4.5	2.565	506.9	1184.1	691.3	1198.2	2.336				68	798.0	2.90	
	4.5	2.565	508.2	1188.7	694	1202.2	2.339				76	891.9	2.22	
		2.565					**2.338**	**8.860**	**16.193**	**53.405**		**856.7**	**2.66**	**316.14**
2	5.0	2.546	503.9	1184.7	690.4	1194.3	2.351				77	947.1	2.97	
	5.0	2.546	505.2	1193.1	695.1	1200.3	2.362				69	809.7	2.80	
	5.0	2.546	502.4	1184.2	691.3	1193.7	2.357				75	922.5	2.75	
		2.546					**2.357**	**7.425**	**15.968**	**60.504**		**893.1**	**2.84**	**308.30**
3	5.5	2.526	497.5	1185.9	692.9	1190.4	2.384				78	959.4	3.63	
	5.5	2.526	499.6	1191.4	696.6	1196.2	2.385				82	1008.6	3.80	
	5.5	2.526	498.9	1190.3	696.3	1195.2	2.386				76	934.8	3.70	
		2.526					**2.385**	**5.600**	**15.411**	**69.334**		**967.6**	**3.71**	**255.69**
4	6.0	2.507	495.7	1182.5	693.1	1188.8	2.386				78	959.4	3.99	
	6.0	2.507	495.6	1183.9	694.2	1189.8	2.389				78	959.4	3.92	
	6.0	2.507	492.2	1173.0	688.6	1180.8	2.383				82	1008.6	3.80	
		2.507					**2.386**	**4.838**	**15.820**	**74.066**		**975.8**	**3.90**	**245.08**
5	6.5	2.488	491.4	1174.4	688.0	1179.4	2.390				73	897.9	4.45	
	6.5	2.488	496.7	1180.9	689.2	1185.9	2.377				73	897.9	4.25	
	6.5	2.488	496.3	1182.9	691.8	1188.1	2.383				74	910.2	4.32	
		2.488					**2.384**	**4.209**	**16.346**	**78.037**		**902.0**	**4.34**	**203.75**

KOMPOSISI AGREGAT		FILLER	SAND
AGGREGATE 3/4"	38	2.679	2.853
AGGREGATE 3/8"	29	2.659	2.853
FILLER	20	2.642	2.881
SAND	13	2.667	2.788

$$Gsb = \frac{100}{\frac{\%\,Agg3/4}{S.G} + \frac{\%\,Agg3/8}{S.G} + \frac{\%\,Filler}{S.G} + \frac{\%\,Sand}{S.G}} = \mathbf{2.664}$$

$$Gse = \frac{Gsb + Gsa}{2} = \mathbf{2.757}$$

$$Gsa = \frac{100}{\frac{\%\,Agg3/4}{S.G} + \frac{\%\,Agg3/8}{S.G} + \frac{\%Filler}{S.G} + \frac{\%\,Sand}{S.G}} = \mathbf{2.850}$$

A: Asphalt (%). **B: Specific Gravity Max in Mix.** **C: Volume in The Sample.**

D: Weight in The Air. **E: Weight in The Water.** **F: Weight in SSD.**

G: Specific Gravity **H: Void in The Mix(%)** **I: Void in the Aggregate (%).**

J: Void in the Asphalt. **K: Stability Read Strip.** **L: Stability in KG.**

M: Flow(mm). **N: Marshall Question.**

Mix Asphalt with Aggregate of Percentage the Crumb Rubber : 3%

ANGKA PENETRASI ASPAL : Pen. 60/70 Ex. Pertamina

Specific Gravity for Asphalt : 1.038

Number of SAMPLE	Asphalt (%)	SPECIFIC GRAVITY MAX IN MIX	VOLUME IN THE SAMPLE	WEIGHT IN THE GRAMS IN THE AIR	DALAM WATER	SSD	Specific Gravity	VOID IN THE MIX %	Void iN AGG (%)	VOID IN Asphalt	STABILITY READ STRIP	IN (KG)	FLOW (MM)	MARSHALL QUETION
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	4.5	2.566	507.4	1178.9	688.5	1195.9	2.323				79	891.4	2.25	
	4.5	2.566	530.3	1198.4	687	1217.3	2.260				76	857.6	2.25	
	4.5	2.566	517.8	1194.5	689.5	1207.3	2.307				81	914.0	1.95	
		2.566					**2.297**	**10.488**	**17.672**	**48.701**		**887.7**	**2.15**	**404.78**
2	5.0	2.546	503.7	1175.6	687.1	1190.8	2.334				79	891.4	2.75	
	5.0	2.546	507.8	1177.6	687.2	1195	2.319				80	938.8	2.90	
	5.0	2.546	509.8	1176.8	682.2	1192	2.308				74	835.0	2.10	
		2.546					**2.320**	**8.867**	**17.257**	**55.764**		**888.4**	**2.58**	**337.16**
3	5.5	2.527	498.4	1173.2	689.5	1187.9	2.354				83	974.0	3.30	
	5.5	2.527	497.0	1179	693.7	1190.7	2.372				75	880.2	3.20	
	5.5	2.527	498.0	1176	688.9	1186.9	2.361				79	891.4	3.70	
		2.527					**2.363**	**6.504**	**16.199**	**65.810**		**915.2**	**3.40**	**263.90**
4	6.0	2.508	504.8	1169.9	676.9	1181.7	2.318				73	856.7	3.80	
	6.0	2.508	492.4	1176.3	693.4	1185.8	2.389				86	1009.2	3.45	
	6.0	2.508	487.2	1174.8	696.2	1183.4	2.411				77	903.6	3.30	
		2.508					**2.373**	**5.393**	**16.288**	**71.776**		**923.2**	**3.52**	**257.37**
5	6.5	2.489	476	1129.2	657.3	1133.3	2.372				60	704.1	2.50	
	6.5	2.489	493.4	1160.5	674.2	1167.6	2.352				67	786.3	3.00	
	6.5	2.489	489.8	1160.0	679.7	1169.5	2.368				65	762.8	3.20	
		2.489					**2.364**	**5.017**	**17.027**	**74.689**		**751.1**	**2.90**	**253.91**

KOMPOSISI AGREGAT		FILLER	SAND
AGGRGATE 3/4"	38	2.679	2.853
AGGREGATE 3/8"	29	2.659	2.853
FILLER	20	2.642	2.881
SAND	13	2.667	2.788

$$Gsb = \frac{100}{\frac{\%\,Agg3/4}{S.G} + \frac{\%\,Agg3/8}{S.G} + \frac{\%\,Filler}{S.G} + \frac{\%\,Sand}{S.G}} \quad \boxed{2.664}$$

$$Gsa = \frac{100}{\frac{\%\,Agg3/4}{S.G} + \frac{\%\,Agg3/8}{S.G} + \frac{\%\,Filler}{S.G} + \frac{\%\,Sand}{S.G}} \quad \boxed{2.850}$$

$$Gse = \frac{Gsb + Gsa}{2} \quad \boxed{2.757}$$

A: Asphalt (%). **B: Specific Gravity Max in Mix.** **C: Volume in The Sample.**

D: Weight in The Air. **E: Weight in The Water.** **F: Weight in SSD.**

G: Specific Gravity **H: Void in The Mix(%)** **I: Void in the Aggregate (%).**

J: Void in the Asphalt. **K: Stability Read Strip.** **L: Stability in KG.**

M: Flow(mm). **N: Marshall Question.**

Mix Asphalt with Aggregate of Percentage the Crumb Rubber : 5%

ANGKA PENETRASI ASPAL : Pen. 60/70 Ex. Pertamina

Specific Gravity for Asphalt : 1.057

Number of SAMPLE	Asphalt (%)	SPECIFIC GRAVITY MAX IN MIX	VOLUME IN THE SAMPLE	WEIGHT IN THE GRAMS IN THE AIR	DALAM WATER	SSD	Specific Gravity	VOID IN THE MIX %	Void IN AGG (%)	VOID IN Asphalt	STABILITY READ STRIP	IN (KG)	FLOW (MM)	MARSHALL BAGI QUETION
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	4.5	2.571	507.5	1173.6	675.1	1182.6	2.313				87	981.7	2.20	
	4.5	2.571	497.2	1147.2	662.7	1159.9	2.307				89	1004.3	1.55	
	4.5	2.571	514.5	1174.2	672.1	1186.6	2.282				79	891.4	2.95	
		2.571					**2.301**	**10.513**	**17.530**	**48.232**		**959.1**	**2.23**	**421.04**
2	5.0	2.552	506	1168.1	676.1	1182.1	2.308				78	880.2	2.95	
	5.0	2.552	504.7	1179.4	685.3	1190	2.337				79	927.1	2.75	
	5.0	2.552	505.9	1172.9	674.9	1180.8	2.318				87	981.7	2.69	
		2.552					**2.321**	**9.035**	**17.228**	**54.859**		**929.7**	**2.80**	**325.90**
3	5.5	2.533	501.7	1171.8	677.8	1179.5	2.336				95	1114.9	3.30	
	5.5	2.533	488.6	1171.2	691.6	1180.2	2.397				78	915.4	2.63	
	5.5	2.533	505.5	1176.5	678.1	1183.6	2.327				89	1004.3	3.37	
		2.533					**2.353**	**7.090**	**16.524**	**63.330**		**1011.5**	**3.10**	**319.89**
4	6.0	2.514	503.8	1181.7	672.4	1176.2	2.346				82	962.3	2.97	
	6.0	2.514	492.8	1180.9	680.5	1173.3	2.396				69	809.7	3.60	
	6.0	2.514	499.9	1183.6	676.6	1176.5	2.368				89	1044.4	3.47	
		2.514					**2.370**	**5.749**	**16.384**	**70.061**		**938.8**	**3.35**	**275.03**
5	6.5	2.496	495.3	1180.5	682.2	1177.5	2.383				70	821.5	3.74	
	6.5	2.496	500.5	1179.7	672.7	1173.2	2.357				75	880.2	3.65	
	6.5	2.496	500.7	1177.2	674.5	1175.2	2.351				72	844.9	3.58	
		2.496					**2.364**	**5.298**	**17.040**	**73.290**		**848.9**	**3.66**	**227.59**

KOMPOSISI AGREGAT		BULK	APP
AGGRGATE 3/4"	38	2.679	2.853
AGGREGATE 3/8"	29	2.659	2.853
FILLER	20	2.642	2.881
SAND	13	2.667	2.788

$$Gsb = \frac{100}{\frac{\% Agg3/4}{S.G} + \frac{\% Agg3/8}{S.G} + \frac{\% Filler}{S.G} + \frac{\% Sand}{S.G}} \quad \boxed{2.664}$$

$$Gsa = \frac{100}{\frac{\% Agg3/4}{S.G} + \frac{\% Agg3/8}{S.G} + \frac{\% Filler}{S.G} + \frac{\% Sand}{S.G}} \quad \boxed{2.850}$$

$$Gse = \frac{Gsb + Gsa}{2} \quad \boxed{2.757}$$

A: Asphalt (%). **B: Specific Gravity Max in Mix.** **C: Volume in The Sample.**

D: Weight in The Air. **E: Weight in The Water.** **F: Weight in SSD.**

G: Specific Gravity **H: Void in The Mix(%)** **I: Void in the Aggregate (%).**

J: Void in the Asphalt. **K: Stability Read Strip.** **L: Stability in KG.**

M: Flow(mm). **N: Marshall Question.**

C

Mix Asphalt with Aggregate of Percentage the Crumb Rubber : 15%

ANGKA PENETRASI ASPAL : Pen. 60/70 Ex. Pertamina

Specific Gravity for Asphalt : 1.081

Number OF SAMPLE	Asphalt (%)	SPECIFIC GRAVITY MAX IN MIX	VOLUME IN THE SAMPLE	WEIGHT IN THE GRAMS IN THE AIR	DALAM WATER	SSD	Specific Gravity	VOID IN THE MIX %	Void IN AGG (%)	VOID IN Asphalt	STABILITY READ STRIP	IN (KG)	FLOW (MM)	MARSHALL QUETION
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	4.5	2.577	509.5	1165.0	667.2	1176.7	2.287				89	1004.3	2.60	
	4.5	2.577	515.9	1179.8	672.4	1188.3	2.287				87	981.7	2.32	
	4.5	2.577	493	1165.7	685.5	1178.5	2.365				85	959.1	1.97	
		2.577					**2.313**	**10.266**	**17.101**	**48.394**		**981.7**	**2.30**	**419.07**
2	5.0	2.559	495.6	1175.2	696.4	1192	2.371				95	1072.0	3.42	
	5.0	2.559	525.4	1177	664.3	1189.7	2.240				88	1032.7	2.62	
	5.0	2.559	497.8	1179.4	692.2	1190	2.369				95	1072.0	1.98	
		2.559					**2.327**	**9.059**	**17.027**	**54.298**		**1058.9**	**2.67**	**388.33**
3	5.5	2.540	468.7	1179.5	721.9	1190.6	2.517				89	1044.4	3.50	
	5.5	2.540	499.6	1175.3	692.2	1191.8	2.352				92	1079.7	2.87	
	5.5	2.540	516.0	1161.4	672.9	1188.9	2.251				86	970.4	2.73	
		2.540					**2.373**	**6.579**	**15.819**	**64.730**		**1031.5**	**3.03**	**333.39**
4	6.0	2.522	506.8	1161.4	675.9	1182.7	2.292				87	1021.0	3.64	
	6.0	2.522	494.2	1171.2	692.1	1186.3	2.370				84	985.8	2.78	
	6.0	2.522	486.4	1172.8	697.4	1183.8	2.411				82	962.3	3.68	
		2.522					**2.358**	**6.534**	**16.818**	**66.696**		**989.7**	**3.37**	**288.20**
5	6.5	2.505	483	1168.9	700.6	1183.6	2.420				71	833.2	3.34	
	6.5	2.505	496.7	1173.0	689.2	1185.9	2.362				82	962.3	3.85	
	6.5	2.505	504.4	1160.1	675.2	1179.6	2.300				78	915.4	3.75	
		2.505					**2.361**	**5.752**	**17.156**	**71.160**		**903.6**	**3.65**	**242.94**

KOMPOSISI AGREGAT		BULK	APP
AGGRGATE 3/4"	38	2.679	2.853
AGGREGATE 3/8"	29	2.659	2.853
FILLER	20	2.642	2.881
SAND	13	2.667	2.788

$$Gsb = \frac{100}{\frac{\%Agg3/4}{S.G} + \frac{\%Agg3/8}{S.G} + \frac{\%Filler}{S.G} + \frac{\%Sand}{S.G}}$$ **2.664**

$$Gse = \frac{Gsb + Gsa}{2}$$ **2.757**

$$Gsa = \frac{100}{\frac{\%Agg3/4}{S.G} + \frac{\%Agg3/8}{S.G} + \frac{\%Filler}{S.G} + \frac{\%Sand}{S.G}}$$ **2.850**

A: Asphalt (%). **B: Specific Gravity Max in Mix.** **C: Volume in The Sample.**

D: Weight in The Air. **E: Weight in The Water.** **F: Weight in SSD.**

G: Specific Gravity **H: Void in The Mix(%)** **I: Void in the Aggregate (%).**

J: Void in the Asphalt. **K: Stability Read Strip.** **L: Stability in KG.**

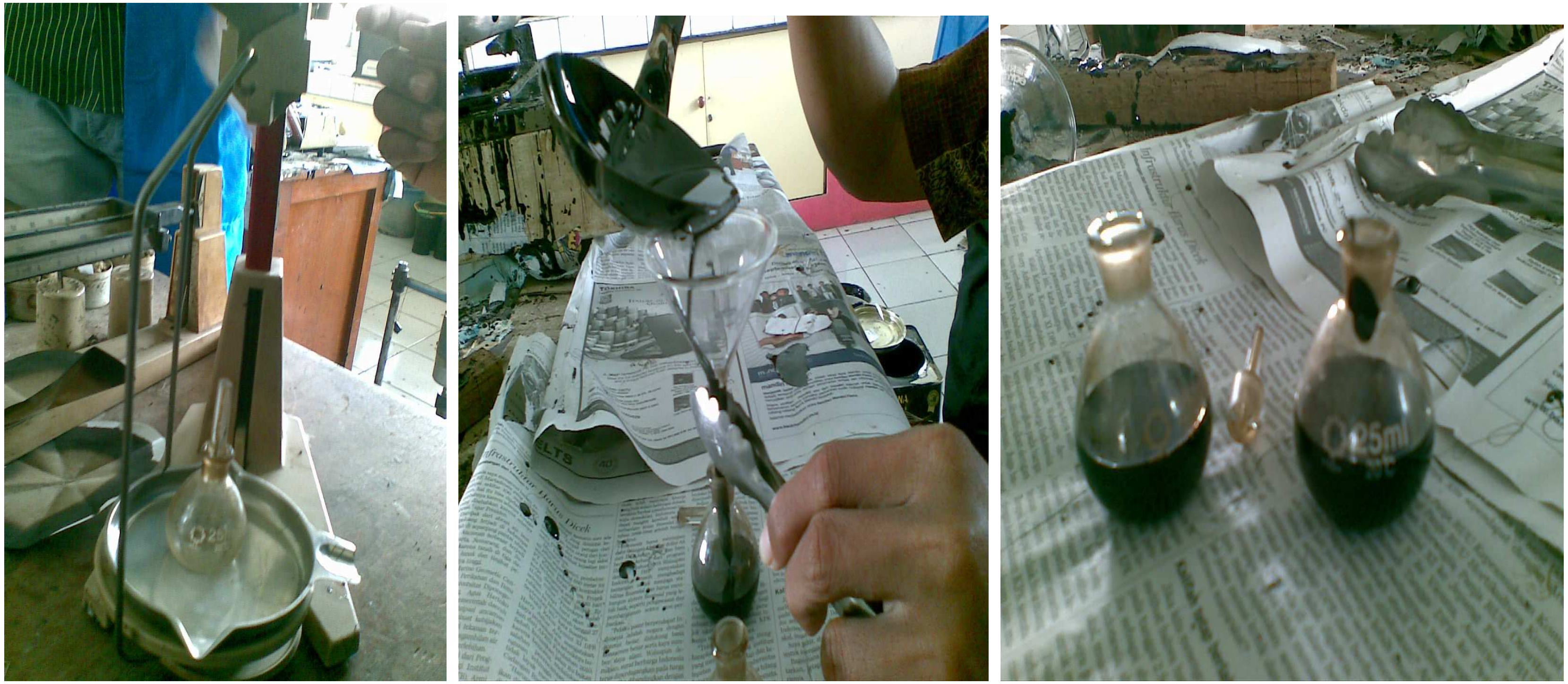
M: Flow (mm). **N: Marshall Question.**

APPENDIX B

1: Processed of Penetration Test

2: Process of Softening Point Test

3: Processed of Ductility Test



4: Process of Specific Gravity Test

5: Process of added Crumb Rubber into Hot Asphalt Mixture

6: Process of mixture materials and compressed of samples