Investigating Mechanical Properties of Reclaimed Asphalt Pavement Rejuvenated with Rubber Seed Oil

by

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Dissertation Submitted in Partial Fulfilment of
the Requirements for the
Bachelor of Civil Engineering with Honours

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF CIVIL ENGINEERING WITH HONOURS

Approved by,

____

(Ir. Dr Muslich Hartadi Sutanto)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

SEPTEMBER 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NUR IZZATI ALYA BINTI MOHD ARIFFIN

ABSTRACT

These days, transportation is seen as a basic need since so much labour can only be performed with the presence and assistance of some kind of transportation. The development of new roadways is crucial to the whole community of a city because of the widening usage of highways nowadays. Investing in new roadway pavement may be very beneficial for a nation, but the price in terms of environmental and energy sustainability is just too high. Reclaimed asphalt pavement (RAP) has been used as a cheaper alternative to fresh asphalt pavement in civil engineering projects. RAP's performance degrades with time owing to the fact that it is made from recycled, hardened asphalt pavement. This is a result of asphalt pavement losing volatile compounds as it ages and is subjected to harsh weather conditions. Studies on the usage of bio-based rejuvenators are becoming widely popular across the globe to mitigate the disadvantage of utilising RAP. Because bio-based rejuvenators include tiny molecules capable of filling in the void left by volatile particles, they improve the qualities of asphalt that has been exposed to the elements for a long period of time. Rubber seed oil (RSO) is recommended as a rejuvenator for RAP in anticipation of demand competition from edible bio-based rejuvenators. Using mechanical properties, this study investigates the qualities of RAP regenerated by RSO. Marshall and durability tests were used to examine the mechanical properties of 100% RAP rejuvenated with varying quantities of RSO. In terms of stability, cracking and moisture damage resistance, as well as durability, the rejuvenated mixtures containing 3.25% RSO outperformed the virgin mixtures. With this conclusion in mind, it can be said that RAP may be repurposed in the construction of new pavement by mixing with a suitable prescription of RSO. The planned incorporation of RSO with RAP would benefit the asphalt mixes industry's long-term viability and lower operating costs.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background of Study

Around the globe, there have been many constructions of asphalt concrete pavement roads, all of which have seen a decline in quality as a result of the natural ageing process. As one of the components that go into the production of refined fossil fuels, asphalt has been a major contributor to the ever-increasing need for oil and other forms of fossil fuel. The fact that there is such a high demand for resources that are running out poses a grave danger to future generations since these resources are neither renewable nor sustainable. As a matter of fact, road pavements have a propensity to deteriorate over time and undergo damage in the form of rutting, fatigue, cracking, and a great deal more as a consequence of long-term severe loads. According to the findings of a research conducted by Bieliatynskyi et al. (2022), the costs associated with repairing roads using more conventional ways are also quite expensive these days. Because of this, the use of reclaimed asphalt pavement, also known as RAP, is an alternative that comes highly recommended to enhance the condition of asphalt pavement over time.

RAP is increasingly being used as a binder in place of freshly refined asphalt in several nations across the world (Holtz & Eighmy, n.d.). The recycling process, environmental implications, and the quality of the reclaimed asphalt all have negatives when using reclaimed asphalt pavement. In the recycling process, there is a great quantity of waste material from the destruction of old pavement, which takes up a large amount of area and ultimately poses a danger to the environment. To recycle asphalt pavement, the most common approach is to use a hot recycled mix asphalt, which uses a significant amount of energy to heat the mixture, again having an adverse effect on the environment. The disadvantages of the hot-recycled asphalt (HRA) mixing process have led to the introduction of the cold-recycled asphalt (CRA) technology, which will be used in this research.

When compared to hot-recycled asphalt (HRA), cold-recycled asphalt (CRA) is a more environmentally friendly method of reclaiming asphalt pavement. Additionally, CRA is capable of repairing potholes, cracks, rutting and other pavement defects while doing so with little impact on the environment (Saeed et al., 2021). Reclaimed Asphalt Pavement (CRA) is a viable alternative for recycling asphalt pavement that does not affect the environment. Extraction, milling, screening, and gradation control, as well as the addition of a rejuvenating agent and mixing at ambient temperature are all part of the CRA process. Reclaimed asphalt, on the other hand, frequently has a worse quality since it is made from a greater volume of recovered pavement. RAP's durability is reduced, which leads the material to become stiffer and more brittle, increasing the pavement's potential to break and other distresses (Saeed et al., 2021). As a result, several researchers and pavement companies are working to improve RAP by the use of rejuvenating compounds.

Chemical and bio-based rejuvenators are able to offer an enhancement mechanism for RAP by restoring its mechanical properties, which in turn lengthens RAP's service life (Saeed et al., 2021). Numerous researchers have investigated the characteristics of RAP that has been rejuvenated by a variety of organic oils such as mustard oil, corn oil, soybean oil, palm oil, and many more (Behnood, 2019). Each distinct category of bio-based rejuvenators brings a different set of qualities and effects to RAP. Because the most of the stated rejuvenators are edible, there is a very high probability of demand rivalry to utilise the same resource for RAP rejuvenating agent. This competition may result in lower prices. In point of fact, diesel oil may likewise be used as a revitalising agent; nevertheless, the utilisation of diesel oil is associated with a number of adverse effects on both the environment and the resource sustainability. This study recommended using RSO to rejuvenate RAP due to the quantity of inedible rubber trees in Malaysia.

Malaysia is the fourth-largest rubber exporter in the world, behind Thailand, Indonesia, and Vietnam, according to the Department of Statistics Malaysia. Because of this, RSO is a great revitalising agent for RAP. A research of RAP rejuvenated by RSO is necessary to assess the efficiency of RSO as a rejuvenating agent for RAP. The rejuvenated RAP will be tested for mechanical properties.

1.2 Problem statement

A never-ending amount of development projects are relying on non-renewable energy supplies. Despite the fact that non-renewable resources are being exhausted, the demand for resources continues to rise. Sustainable development objectives need the utilisation of recycled resources for new projects. Many nations employ recycled asphalt pavement in the building of roads and highways from a civil engineering standpoint. Reusing resources for new projects is, in fact, a better alternative for the environment. Recycled asphalt pavements sometimes have downsides, too, including limited bitumen penetration, a considerable drop in maltenes concentration, and becoming more brittle, which raises the possibility of collapsing (Mansa & Zou, 2021).

In spite of this, CRA (cold recycled asphalt) technology has been developed to recycle old pavement at room temperature using chemical additives, which are more often known as "rejuvenors.". Improved asphalt pavement defects including potholes, reflecting cracks, rutting, and irregular cracks may be greatly improved with the cold in-place recycling process (CIR). Many researchers have studied the effects of using various bio-based rejuvenators, such as Jatropha crucas, crude palm oil, and soybean oil, on the qualities of reclaimed asphalt pavements in order to choose the best material for rejuvenation.

Since palm oil can be consumed by humans, there is sure to be a lot of competitors in the market for this source of palm oil despite the fact that it is abundantly available in Malaysia. For example, certain rejuvenators may have a positive influence on the recycled pavement quality while others can adversely affect the cost and availability of rejuvenators. There's still a lot to learn about the best rejuvenating materials to use when making recycled asphalt pavement, therefore more research is needed in this area. A bio-based rejuvenator derived from rubber seed oil (RSO) is to be used in this project to recycle asphalt pavements using the CRA technique. In Malaysia, where rubber is abundant, RSO should be one of the most important issues. The impacts of using RSO as an RAP rejuvenator will be evaluated through the mechanical properties of the RAP.

1.3 Objectives

The main objective of this project is to utilize RSO as a rejuvenator in cold recycled asphalt mixtures which is expected to promote more sustainable technology in pavement construction and rehabilitation. The specific objectives of this study are:

1) To assess the Marshall and volumetric properties of CRA mixtures incorporating RSO as rejuvenating agent.
2) To optimize mixing of RSO rejuvenated RAP

1.4 Scope of study

As part of this research, a number of tests are necessary, including those aimed at determining the mechanical properties of Reclaimed Asphalt Pavement Rejuvenated With Rubber Seed Oil. RSO rejuvenation or other bio-based rejuvenators may alter the mechanical properties of CRA mixes. Marshall mix design among the methods that uses to determine the mechanical properties of RAP rejuvenated with rubber seed oil.

It is possible to measure the qualities of both strength and flexibility using Marshall's method. Compressive strength is assessed in terms of Marshall Stability, or the greatest load a compacted specimen can bear at a standard temperature of 60 degrees Celsius. The purpose of this test is to determine the optimal binder content for the aggregate mix type and traffic intensity.

When it comes to determining the product's lifespan, durability testing is key. Quality tests are done over time, which is an easy way to think about it, but it's not quite that straightforward. The ability to last for an extended period of time without considerable degradation is what we mean when we talk about durability. By lowering the need for frequent maintenance and replacement, long-lasting materials reduce their negative influence on the environment. It's a key consideration when assessing a material's long-term viability. A long-lasting product is a better investment since it uses less resources, produces less waste, and spreads the environmental impact of production over a longer period of time if it is made with durable materials

In conclusion, the mechanical properties of Reclaimed Asphalt Pavement Rejuvenated With Rubber Seed Oil can be explored through the study of and participation in Marshall mix design and durability tests. The working principle and calculating methods will be presented in further depth in Chapter 3.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction

This is projected that a total of 25 million kilometres of new paved roads and highways will be built to improve transportation services by the year 2050 (Laurance et al., 2014). The demand for the raw materials such as aggregates and binders is expected to increase in a linear fashion as new roads and highways are continually built. Asphalt is a sort of non-renewable material that, although being one of the most often used binders for road pavements, will, at some point in the future, run out completely. In point of fact, the volume of fossil fuel supply is now reducing (Zhang et al., 2017), which will unquestionably lead to increasing costs associated with the deployment of raw materials. As a result of this, the use of reclaimed asphalt pavement, also known as RAP, is being strongly promoted and suggested these days in order to combat the issues that are now on the rise within the sector. This chapter discusses the research that was conducted as well as reviews on relevant topics in order to gain a deeper understanding of the significance of recycling asphalt pavement, the components that were utilised as bio-based rejuvenators, and the techniques that were applied in order to investigate the mechanical properties of reclaimed asphalt pavement rejuvenated with rubber seed oil.

2.2 Reclaimed Asphalt Pavement

There have been several campaigns to raise people's awareness and educate them about the need of using materials that are less harmful to the environment (Ahmad et al., 2018). These days, there is a strong push toward the use of materials that are environmentally, socially, and economically sustainable. This is done to ensure that the resources will continue to be accessible to future generations. In the case of asphalt, which is one of the most essential raw materials for the building of roads, RAP is now being used by a number of researchers as up to one hundred percent of the brand new asphalt material (K. Holtz & T. T. Eighmy, 2000). This indicates that there is a high level of confidence in the use of RAP as a replacement for freshly manufactured asphalt in the building of roads and in research. The use of RAP in the construction of roads and highways, which may minimise the amount of new petroleum asphalt that is used, is one of the most effective methods to promote low-carbon campaigns (Wang et al., 2016).

RAP is created from a significant quantity of waste items that are generated during the demolition or reconstruction of older pavement(Saeed et al., 2021). The use of reclaimed pavement materials is, without a doubt, one of the most effective ways to save both the resources and the labour that goes into the construction itself. The production of RAP demands temperatures that are considerably lower than average, which leads to lessening of the effects of ageing and, in the long run, becomes the root cause of increased fatigue cracking and heat resistance (Ahmad et al., 2018). Oxidation and the loss of volatility are the two primary factors that contribute to the ageing of asphalt binders. As a result, asphalt binders ultimately become more rigid and have a greater degree of viscosity. When it comes to the construction of new pavements, the most common choice made by developers is to make use of RAP. This is due to the fact that rejuvenated RAP will benefit the asphalt pavements in a variety of ways. In addition to having a minimal impact on the surrounding ecosystem, the implementation of RAP should be considered for its potential to enhance the production of roads and highways intended for long-term usage.

FIGURE 2.1 Reclaimed asphalt pavement

2.3 Cold Reclaimed Asphalt (CRA)

Utilizing cold reclaimed asphalt technology, which is often utilized in the process of repairing pavement distresses is one environmentally friendly way to rehabilitate asphalt pavement and maximise the usage of RAP (Saeed et al., 2021). Cold reclaimed asphalt technology may be used to repair pavement problems including reflective cracking, rutting, and potholes, hence extending the lifetime of a specific pavement. An additional benefit of utilizing cold reclaimed asphalt technology is that it may use large amounts of RAP and so minimise production costs, safeguard our planet and preserve valuable land resources (Saeed et al., 2021) . Cold reclaimed asphalt's good influence on environmental sustainability can't be underestimated. Due to its lack of heating, the cold-recycling technique does not have an impact on the environment as a result of its usage. There are no dangerous gaseous emissions from the procedures involved in crushing used asphalt surface and adding in regenerative agents. Due of the high stiffness, limited workability, and difficulty in compacting RAP, it is difficult to maintain adequate pavement durability when incorporating large amounts of RAP into asphalt mixes. This might lead to possible pavement distresses such as cracking, ravelling, and much more (Carvajal Munoz et al., 2015). Because of this, bio-based rejuvenators are often used in the RAP production process to improve the product's quality.

2.4 The Use of Rejuvenators to Recycle Aged Asphalt

Mechanical properties of RAP may be repaired using oil or chemical rejuvenators in order to build asphalt pavement with extended service lives. In addition, bio-based rejuvenators such as vegetable oils, Jatropha curcas, maize oils, and soybean oils may significantly lower the stiffness of RAP binders when compared to chemical-based rejuvenators. That a bio-based rejuvenator may reduce stiffness and increase viscosity in regenerated old asphalt (Zhang et al., 2018). RAP binders must be tolerated, but the mix design must have the capacity to sustain long-term loading. Rutting, cracking, and collapse may all be symptoms of pavement stiffness that is too high. What's more, using bio-based rejuvenator may reduce the viscosity of binders at lower temperatures for better compaction, coating, and overall workability. The maltenes and flexibility of reclaimed asphalt pavement tend to be reduced, making it more brittle and more likely to collapse. Because bio-based rejuvenators employ waste biomass sources and waste building materials, they contribute significantly to the improvement of the environment.

2.5 Rubber Seed Oil as a Rejuvenator

Non-renewable fossil fuels are being replaced by bio-based chemicals such as biodiesel as the major source for many goods. The biodegradability, low-to-no toxicity, excellent lubricity, and eco-friendliness of biodiesel make it a viable alternative to fossil fuels (Onoji et al., 2016). Since the nations of Sub-Saharan Africa (SSA) mainly rely on fossil fuel, it is strongly suggested that rubber seed oil (RSO) be used instead (Onoji et al., 2016). RSO has a lot of potential to be put to good use in Malaysia, which is one of the top manufacturers of rubber products in the world. Malaysia has a lot of potential. It is anticipated that Malaysia, which has rubber tree plantations covering more than 1.2 million acres, would produce 30,000 metric tonnes of rubber seed year, in addition to 20 million litres of RSO annually (Fadzil et al., 2016). In comparison to the oil content of a variety of other vegetable oils, such as soybean, Jatropha curcas, and linseed oils, as well as crude palm oils, the oil content of rubber seed oil is almost as high as 40 to 50 percent.

FIGURE 2.2 Rubber seed

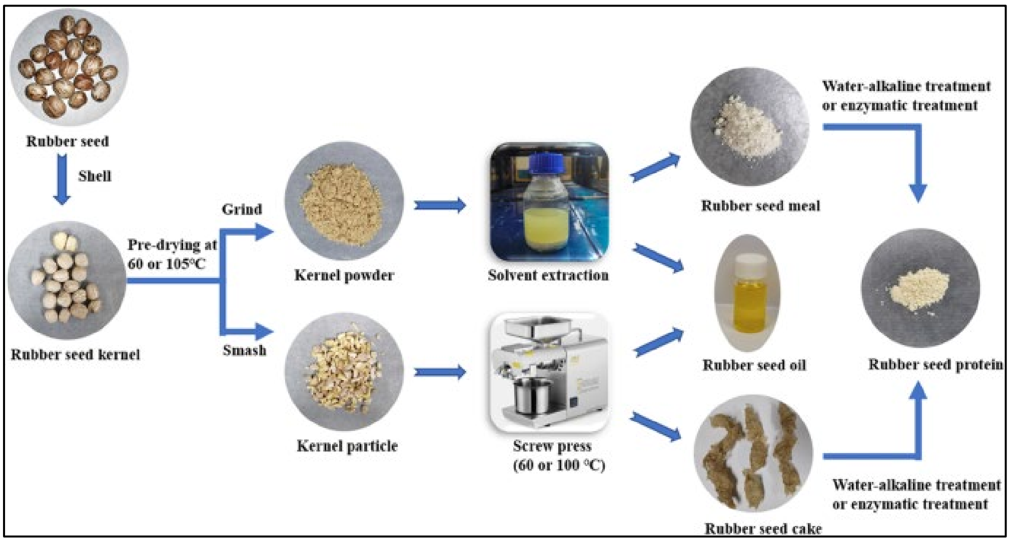


FIGURE 2.3 Preparation of rubber seed oil

2.6 Investigating Mechanical Properties of RAP Rejuvenated

A combination of asphalt and RAP, crumb rubber, and waste engine oil with high percentages of RAP was studied by Jahanbakhsh et al., (2020). The rejuvenated blends produced outcomes that were superior to or equivalent to those of virgin mixtures. In light of the foregoing, this study used RSO's rejuvenator capability, which is a biodiesel rejuvenator. Hot mix asphalt (HMA) containing 50% RAP and two kinds of additives was studied mechanically by Abreu et al. Used motor oil (UMO) and high-density polyethylene (HDPE) were shown to be effective in renewing the mechanical qualities of HMA with 50% RAP. However, in this research, this study uses the method of CRA which contains 100% RAP and at different temperature of the mixing which are 0 ºC and 45 ºC to evaluate the mechanical properties. RAP's mechanical properties are often assessed after an accelerated curing procedure is completed in order to standardize and standardise the evaluation of RAP performance. Recycling mixes may be ranked and/or quality controlled in a reasonably short period using this approach. As a consequence of this analysis, Marshall characteristics and durability were used to assess the mechanical properties of a 100 % RAP mixture with rejuvenators.

2.7 Volumetric Parameters and Marshall Properties

The Marshall stability and flow test estimates Marshall mix design performance. The Marshall stability test estimates an asphalt mixture's performance and maximum load. BUW calculates the volume of RAP, RSO and water in asphalt mixes, including solid aggregate particles and voids. Air spaces in bituminous materials are a quality control requirement for deposited and compacted bitumen. Too many air voids may let air and water in. In the early 1900s, mineral fillers were used to stiffen asphalt. Fillers in asphalt mixtures improve compatibility, workability, aggregate-bitumen adhesion, durability, and water resistance. This asphalt alteration increases stiffness at high temperatures while preserving flexibility at low temperatures.

In this project, both volumetric and Marshall properties have been taken into consideration. The conventional destructive method used to calculate the stability of asphalt concrete is known as the Marshall Stability method. The practise of destructive testing is widespread despite the fact that it is both expensive and time-consuming. On the other hand, the air void content (AV), apparent film thickness (AFT), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) are all common volumetric parameters whose requirements have been empirically established based on a large amount of laboratory and field data. Properties that can be measured of asphalt mixtures include the Marshall parameters as well as volumetric parameters. This project makes use of these characteristics, as well as RAP, RSO and water. It is essential and crucial to have a solid understanding of how these elements interact with one another and have an effect on the modification process.

2.8 Marshall Mix Design

For this research, prepare samples using Marshall mix design to measure air voids, bulk unit weight, Marshall stability, and flow. Following ASTM D6927, compacted samples were analysed using the Marshall mix design. Each volumetric parameter must be within the JKR, Malaysia, limits for asphalt mixture durability. Temperature and traffic loads were included in the Marshall mix design to analyse asphalt mixes empirically.

The Marshall stability test is a procedure that is frequently used in the paving industry. The stability of bituminous mixes and the optimal bitumen concentration for pavements are both determined by its characteristics. The Marshall stability test is an example of an empirical test, and during this test, any deviations from the standard methodology are acceptable.

FIGURE 2.4 Marshall stability testing device

2.9 Response Surface Methodology

The response surface methodology, also known as RSM, is a type of effective method for optimising process conditions. Using RSM, one can determine the influence of various factors and their interactions on the indices that are being investigated (response value) while conducting an experimental study. It is also possible to use it to fit a complete quadratic polynomial model by means of a central composite experiment, and it can present a better experiment design and result expression. Both of these applications make use of the central composite experiment. According to Rafiq et al. (2021), the statistical tool RSM was utilised to effectively develop, evaluate, optimise, and finally validate experimentally based findings in order to gain access to the best performance parameter in this study. This was done in order to validate experimentally based findings and access the best performance parameter.

The impact that temperature and water content have on the Marshall and volumetric properties, specifically bulk specific density, air voids, Marshall stability, and Marshall flow, can be illustrated in both the two-dimensional and three-dimensional surface plots. Figure 2.5 and 2.6 provides an illustration of the results that were produced by the RSM software, which can serve as an example from the earlier study. This example demonstrates how the bulk specific gravity (BSG) is affected by the percentage of total water content as well as RSO. The diagnostic plots in two dimensions and three dimensions both show an oval-shaped contour, which indicates that there is sufficient connectivity between the independent variables. Because of this, it is possible to draw the conclusion that the percentage of RSO has a greater influence on BSG than the total water content. Therefore, the study of RSO rejuvenated RAP can be optimised and analysed using RSM software.

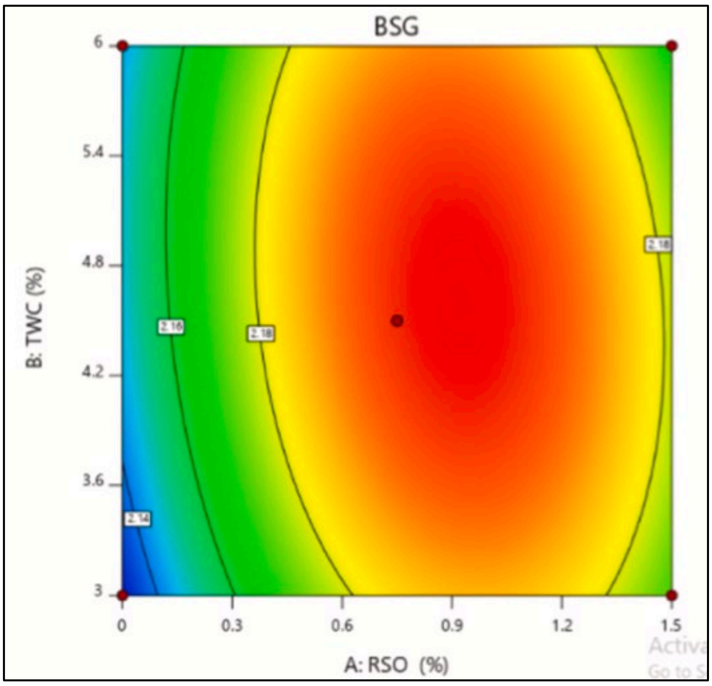


FIGURE 2.5 Example of 2D Model Generated by RSM Software

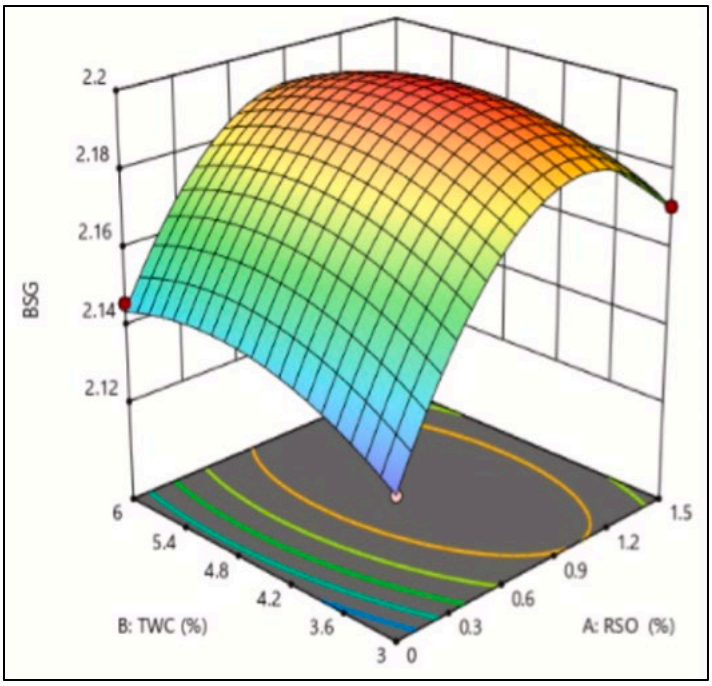


FIGURE 2.6 Example of 3D Model Generated by RSM Software

CHAPTER 3

3.0 METHODOLOGY

3.1 Overview

The main aim of the study is to investigate mechanical properties of reclaimed asphalt pavement rejuvenated with rubber seed oil. The tests that must be conducted to determine the stated properties are described in depth in this section. On the other hand, the method that will be undertaken to study the mechanical properties of RAP rejuvenated with RSO is Marshall mix design. The operating concept, relevant factors, computations, and projected result will be discussed in depth. The steps of the investigation are laid out in the chart below.

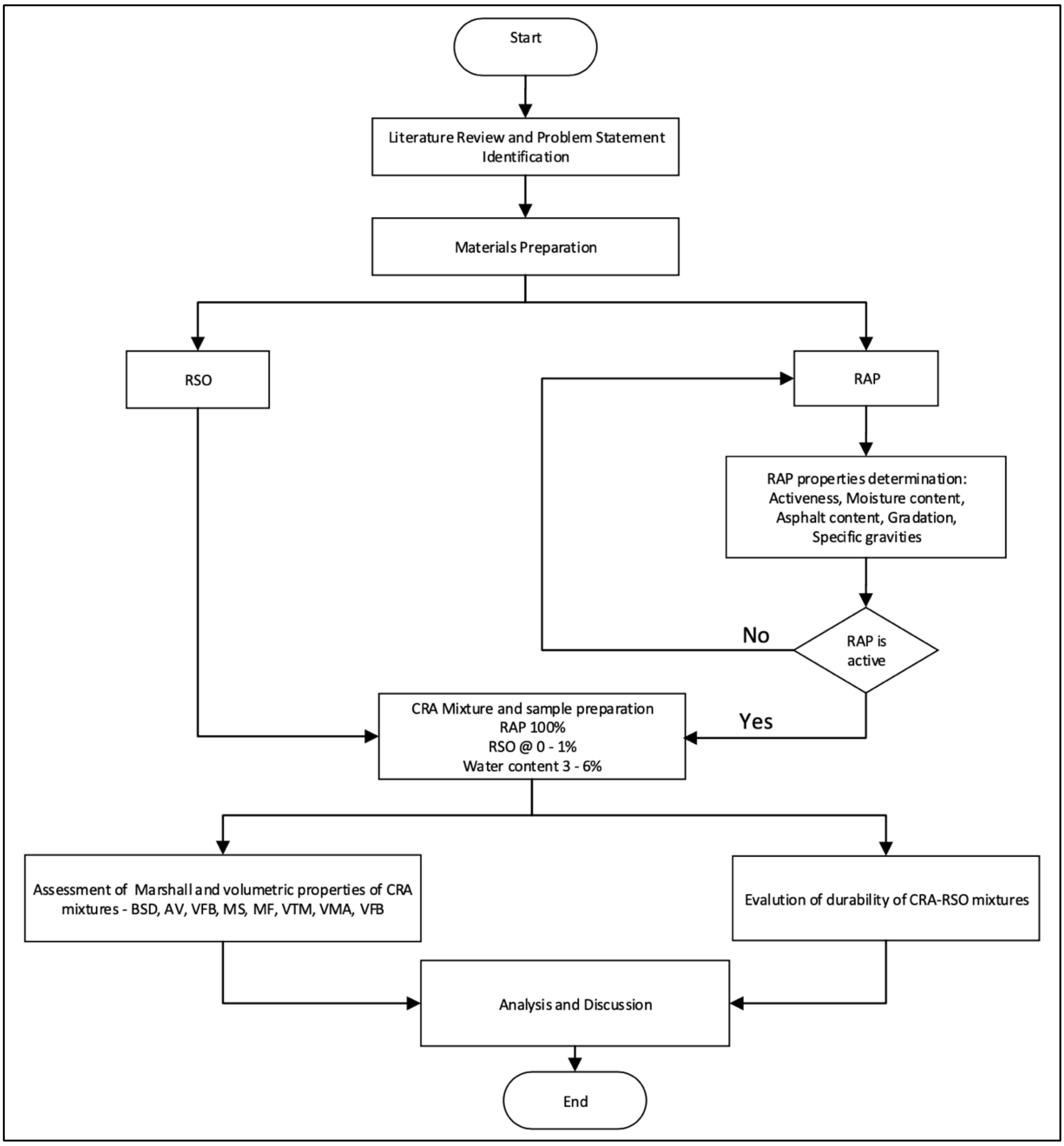


FIGURE 3.1 Flowchart of work

3.2 Material preparation

After obtaining the RAP material, it will be transported to the highway laboratory at Universiti Teknologi PETRONAS (UTP) in airtight containers or bags. This will ensure that no moisture is lost during transport. In order to determine whether or not the binder is active, RAP will be subjected to testing. If the binder is active, the RAP that is acquired will be used for sample preparation; if the binder is not active, however, RAP will have to be resourced. The RAP's asphalt composition will be evaluated with reference to the ASTM C566 (2013) protocols. The RAP aggregate gradation, specific gravities, and water absorption will be examined after the RAP binder has been removed with trichloroethylene in accordance with ASTM D2172.

3.2.1. Preparation of Rubber Seed Oil

a) Break the shell of the rubber seed by using rubber hammer to get the kernel.

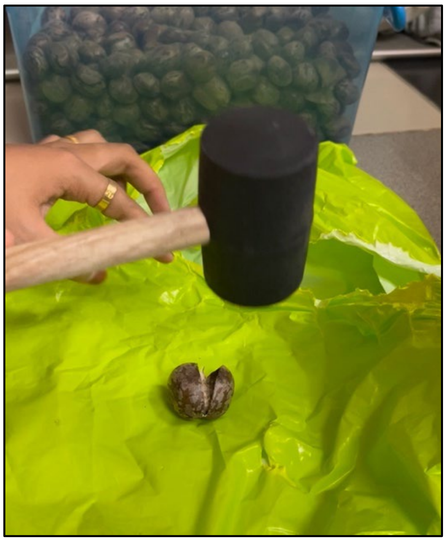


FIGURE 3.2 Break the shell of rubber seed

FIGURE 3.3 Kernel inside the rubber seed

b) Crush the kernel until it look like powder (maximum 2mm).

FIGURE 3.4 Kernel become powder

c) Extract the oil by using Soxhlet extractor.

FIGURE 3.5 Soxhlet Extractor apparatus

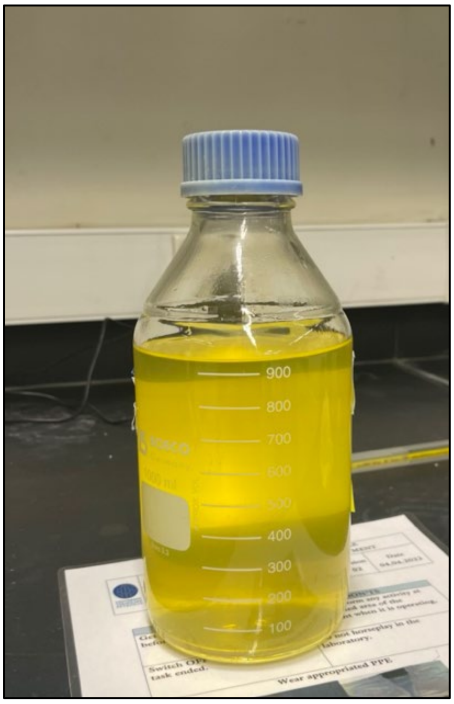


FIGURE 3.6 The oil that mix with the solvent

d) Separate the oil and solvent by using rotary evaporator.

FIGURE 3.7 Rotary Evaporator

3.2.2. Preparation of Reclaimed Asphalt Pavement (RAP)

a) Put a 1000g of RAP on the scale.
b) Separate fine and coarse aggregates by passing 1000 g of RAP through a 4.75 mm sieve.
c) Dry some RAP at 45 ° C in the oven while store some in the fridge at zero 0 ° C.

3.2.3. Preparation of Water Content

Water content is essential in cold recycled asphalt mixes because it reduces viscosity and improves workability and compatibility. Water helps distribute rejuvenator in cold recycled mixes. Depending on the targeted air void, the percentage of water added must be carefully determined because at the optimum water content it is assumed that all the void will be fully filled with water and any further addition above this critical amount, the water may tend to be squeezed out of the specimen during compaction to attain the air void target and there is a high tendency of washing away some fine particles and the rejuvenator during this process.

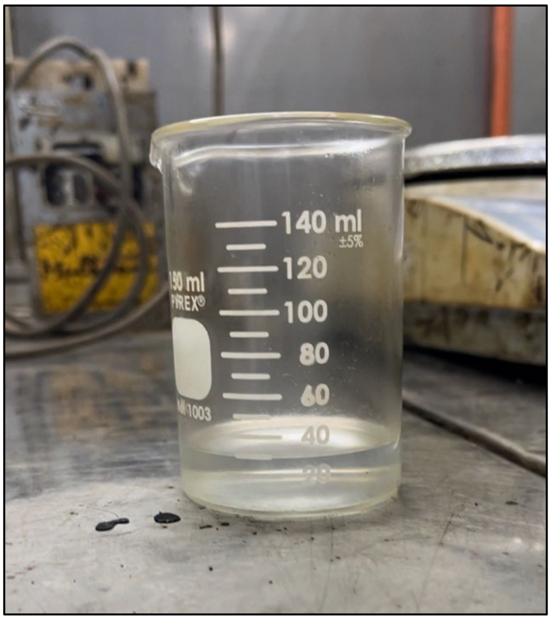


FIGURE 3.8 Water

3.3 Laboratory Experiment and Data Collection

This research relies on original data, collected in a laboratory setting, for its analysis. The laboratory uses Marshall testing equipment to determine properties including bulk unit weight, air voids, Marshall stability, and Marshall flow, all of which are essential to the Marshall method of work.

3.3.1. Properties of the RAP Material

Moisture content (ASTM C566), Asphalt content (ASTM D2172), original gradation, and specific gravity were all used to evaluate the RAP. Table 3.1 shows that RAP has an asphalt content of 4.04%; this optimal binder concentration appears to be low, probably as a consequence of the coarser quality of the grading. According to Malaysia's public works agency, the initial grade was ACWC20. However, it was observed that the coarse aggregates were below the necessary limit. This may be due to the fact that the road had previously undergone maintenance, such as patching, and that milling has an influence on the crushing of RAP aggregate particles, resulting in a finer gradation.

FIGURE 3.9 Coarse Aggregates after sieving the RAP

3.3.2. Sample Preparation

All of the samples were prepared by hand in the lab based on the recipe where is presented in Table 3.1. Coarse aggregate and rubber seed oil were put into the mixer which was previously weighed at 1000g and mixed for 2 minutes. After that, fine aggregate is added to the mixture and mixed for another 2 minutes. Following the addition of water, the mixture was agitated for a further minute.

The mixture was immediately placed in the mould and compacted with 75 gyrations using the Marshall compactor mould of 100 mm diameter, the number of gyrations was chosen in order to achieve an air void of 15-17% since there is no established specification for number of gyrations for cold recycled asphalt mixtures. After the compaction, the specimens were cured. The original RAP gradation was used without any modification or correction.

TABLE 3.1 Sample preparation recipe

Material	**Quantity**
RAP	1000 g
RSO	3.25 %
Water Content	3 – 5 %
Temperature	0 and 45 ^{o}C

3.3.3. Compaction Procedure

The materials were compacted using a Marshall Compactor. There is a leaking area for the water as the specimen is crushed since the bottom of the mould is free and the cover plate is angled. The specimens were compressed with 75 gyrations to create an air vacuum of 15-17%, which is typically preferable for specimens that contain a larger quantity of water and, owing to oversaturation, the water must be squeezed out to obtain the appropriate compaction.

FIGURE 3.10 Marshall Compactor

3.3.4. Curing Procedure

The strength of cold recycled asphalt mixes could only be achieved after they had been cured. It takes time for the water in the compacted sample to evaporate and for the rejuvenator to permeate into the aged bitumen, much as it does with emulsified asphalt cold recycled mixes. In this experiment, both a short-term and a long-term curative technique were used. After initial compaction during curing, specimens were allowed to rest for 1 hour at room temperature before being taken from the mould to prevent any damage. Specimens were cured for 24 hours at a curing temperature of 40ºC in a draft oven before being tested.

3.3.5. Marshall Stability and Flow

The samples were immersed in a water bath at 60 C for 30–40 minutes before to the Marshall test, as specified by ASTM D1559. At a continuous strain rate of 2 in. per minute, the Marshall stability is defined as the stress at which the specimen fails. Using a typical accuracy of 0.25 mm, the flow value (vertical deformation) of the specimen at the point of failure may be measured with a dial gauge that is typically connected to the machine.

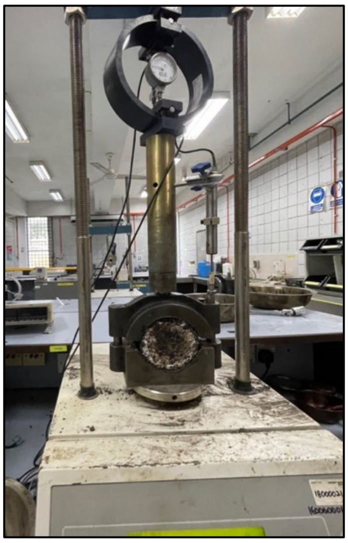


FIGURE 3.11 Marshall stability testing device

3.3.6. Volumetric and strength properties

The Marshall Mix design standard approach was used to figure out the volumetric properties and the strength characteristics of the revitalised cold recycled asphalt mixes. In this investigation, the bulk unit weight (BUW), air voids (AV), Marshall stability (MS), and Marshall flow (MF) were used as responses for strength and volumetric parameters.

CHAPTER 4

4.0 RESULT AND DISCUSSION

4.1 Determination of asphalt composition

TABLE 4.1 Asphalt Composition

Total RAP (g)	Total bitumen (g)	Total bitumen (g)
1000	40.4	4.04%

4.2 Laboratory result

TABLE 4.2 Marshall Mix Design result for 0° C

Water Content (%)	Bitumen Content (%)	Samples	W_A (g)	W_W (g)	SG_{bulk}	Avg. SG_{bulk}	SG_{MAX}	Air Voids (%)	Avg. Air Voids (%)	Stability (kN)	Avg. Stability (kN)	Flow (mm)	Average Flow (mm)
3	**4.04**	1	1001.50	528.70	2.12	2.12	2.55	16.80	16.92	12.43	12.80	2.78	3.05
		2	993.40	521.30	2.10		2.55	17.35		13.11		3.55	
		3	995.30	526.40	2.12		2.55	16.62		12.87		2.82	
4	**4.04**	1	998.30	531.40	2.14	2.14	2.55	16.01	16.01	12.76	13.02	2.97	2.91
		2	999.40	532.40	2.14		2.55	15.94		13.42		2.56	
		3	997.40	530.60	2.14		2.55	16.07		12.89		3.21	
5	**4.04**	1	990.30	525.10	2.13	2.13	2.55	16.38	16.24	12.43	12.71	2.87	3.52
		2	997.80	528.20	2.12		2.55	16.54		12.72		3.91	
		3	994.60	530.60	2.14		2.55	15.80		12.97		3.78	

TABLE 4.3 Marshall Mix Design result for 45° C

Water Content (%)	Bitumen Content (%)	Samples	W_A (g)	W_W (g)	SG_{bulk}	Avg. SG_{bulk}	SG_{MAX}	Air Voids (%)	Avg. Air Voids (%)	Stability (kN)	Avg. Stability (kN)	Flow (mm)	Average Flow (mm)
3	**4.04**	1	994.80	516.20	2.08	2.09	2.55	18.35	18.00	12.42	12.67	2.40	3.01
		2	996.50	523.70	2.11		2.55	17.21		12.10		3.50	
		3	1002.40	519.60	2.08		2.55	18.45		13.50		3.14	
4	**4.04**	1	998.50	531.50	2.14	2.14	2.55	16.02	15.89	12.43	12.93	2.78	2.97
		2	989.40	527.40	2.14		2.55	15.88		13.41		3.51	
		3	994.60	530.80	2.14		2.55	15.77		12.94		2.62	
5	**4.04**	1	997.30	531.30	2.14	2.14	2.55	15.94	16.05	12.45	12.58	2.94	4.05
		2	992.40	520.30	2.10		2.55	17.43		12.37		4.60	
		3	995.30	536.60	2.17		2.55	14.77		12.92		4.60	

TABLE 4.4 Summary of Marshall Mix Design result for 0° C

Summary (Avg Results)				
Water Content (%)	Average SG_{bulk}	Average Air Voids (%)	Average Stability (kN)	Average Flow (mm)
3	2.12	16.92	12.80	3.05
4	2.14	16.01	13.02	2.91
5	2.13	16.24	12.71	3.52

TABLE 4.5 Summary of Marshall Mix Design result for 45° C

Summary (Avg Results)				
Water Content (%)	Average SG_{bulk}	Average Air Voids (%)	Average Stability (kN)	Average Flow (mm)
3	2.09	18.00	12.67	3.01
4	2.14	15.89	12.93	2.97
5	2.14	16.05	12.58	4.05

4.3 ANOVA and model development

TABLE 4.6 ANOVA for the analysis of the response

Response	SS	DOF	MS	F-value	P-value	Observation	Model performance
BUW							
Model	0.0129	5	0.0026	33.28	< 0.0001	significant	Quadratic
Residual	0.0005	7	0.0001	-	-	-	
Lack of Fit	0.0004	3	0.0001	3.75	0.1170	not significant	
Pure Error	0.0001	4	0.0000	-	-	-	
Cor Total	0.0135	12	-	-	-	-	
Air Voids							
Model	30.32	5	6.05	109.47	< 0.0001	significant	Quadratic
Residual	0.3878	7	0.0554	-	-	-	
Lack of Fit	0.3829	3	0.1276	103.76	0.0003	significant	
Pure Error	0.0049	4	0.0012	-	-	-	
Cor Total	30.71	12	-	-	-	-	
Marshall Stability							
Model	39.83	5	7.97	73.81	< 0.0001	significant	Quadratic
Residual	0.7554	7	0.1079	-	-	-	
Lack of Fit	0.1738	3	0.0582	0.4009	0.7607	not significant	
Pure Error	0.5756	4	0.1452	-	-	-	
Cor Total	40.49	12	-	-	-	-	
Marshall Flow							
Model	4.07	2	2.03	73.02	< 0.0001	significant	Linear
Residual	0.2877	10	0.0278	-	-	-	
Lack of Fit	0.2676	6	0.0461	184.48	< 0.0001	significant	
Pure Error	0.0010	4	0.0003	-	-	-	
Cor Total	4.32	12	-	-	-	-	

Table 4.6 shows the ANOVA models. All of the dependent variables have quadratic models presented for regression, and these models are well matched with the investigated parameters. The highest-order polynomials with meaningful extra terms and non-aliased models were recommended by the programme. Equations (1)-(4) provide the projected models' numerical variables in coded form (A, B), where A and B stand for temperature and water content, respectively.

$$BUW = 2.14 - 0.0033\,A + 0.015\,B - 0.01\,AB - 0.02\,B2 \quad (1)$$

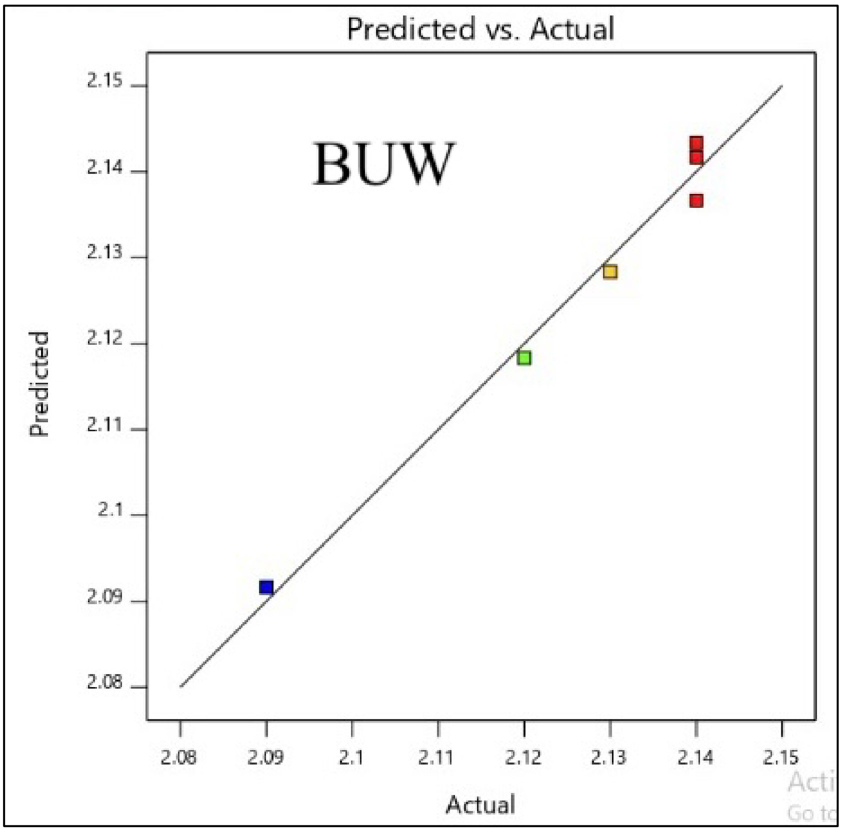
$$AV = 15.95 + 0.128\,A - 0.658\,B - 0.318\,AB + 0.853\,B2 \quad (2)$$

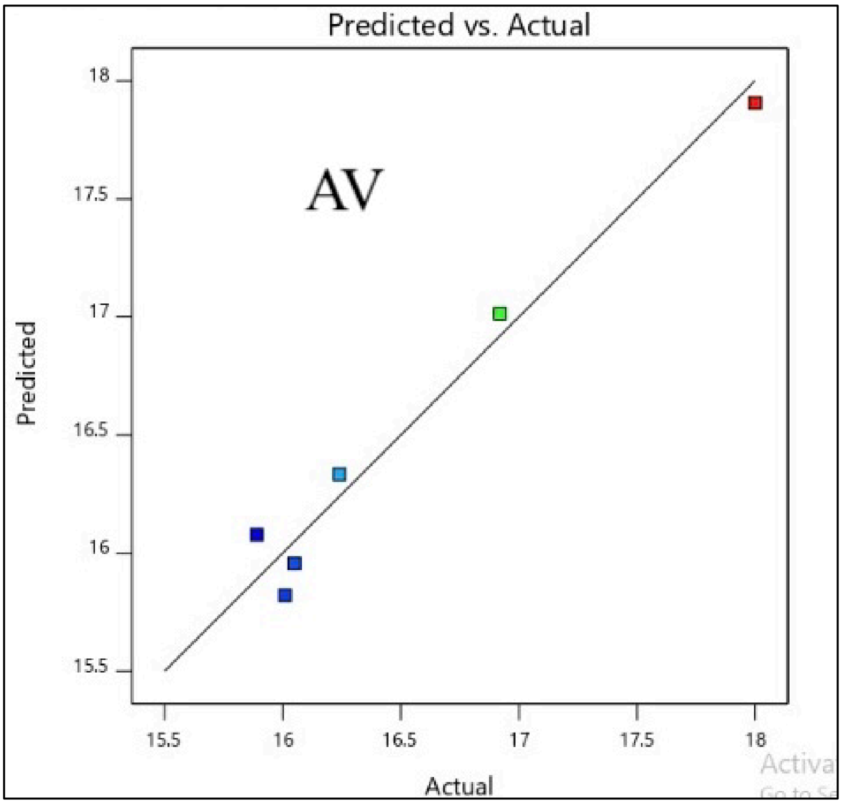
$$MS = 5.91 - 0.056\,A - 0.118\,AB - 0.628\,B2 \quad (3)$$

$$MF = 2.94 + 0.092\,A + 0.378\,AB + 0.468\,B2 \quad (4)$$

4.4 Diagnostics Plots and Synergetic Influence of Parameters

Diagnostic plots to fit statistics, such as the one shown in Figure 4.1, allow for an evaluation of the data's acceptability and normal distribution. To further assess the accuracy of the models, comparison plots between the predicted and laboratory values were examined. Additionally, in all diagnostic plots for the response, practically all points were distributed equally close to the equality line, suggesting that the models created had enough fitting accuracy. Also, because all of the points inside the straight line were shown, the plots show a positive relationship between what was expected and what was found in the lab.


Predicted vs. Actual
BUW
Predicted
Actual
2.08
2.09
2.1
2.11
2.12
2.13
2.14
2.15


Predicted vs. Actual
AV
Predicted
Actual
15.5
16
16.5
17
17.5
18

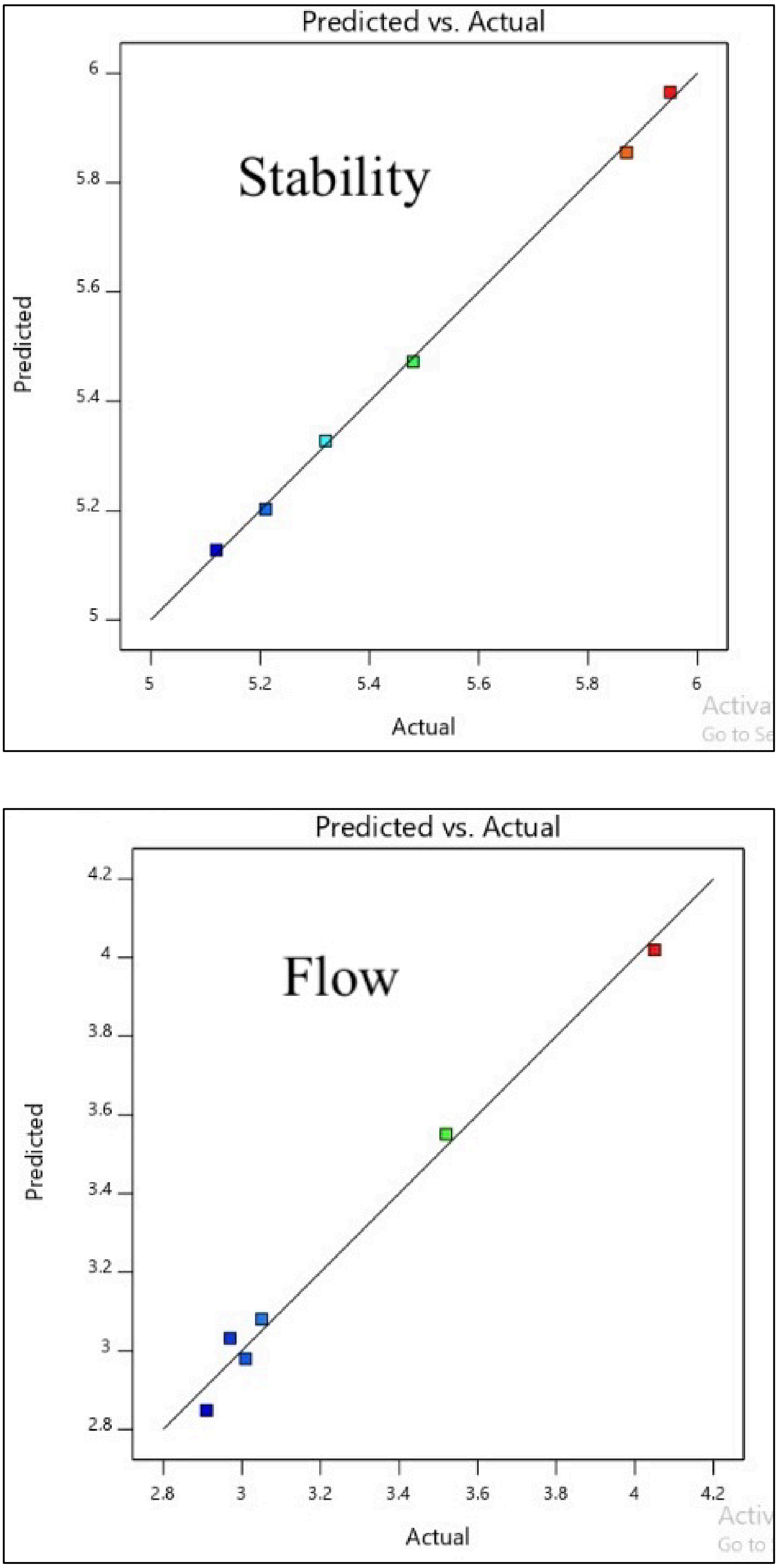


FIGURE 4.1 RSM graph showing predicted versus actual values

4.5 RSM Plot Analysis

For the purpose of investigating possible relationships between variables, surface plots are typically quite helpful. Figures 4.2 – 4.6 illustrate 2D and 3D contour charts depicting the impact of temperature and water content on BUW, air voids, Marshall stability, and flow, respectively. The use of colour in such graphs represents the impact of the mutual effect of the inputs and the outcomes. For all graphs, a higher response value is shown by a deeper blue to red tint. These charts demonstrate the potential significance of a synergistic interaction among the elements that make up the mixing parameters.

4.3.1. Bulk Unit Weight (BUW)

Figures 4.2 and 4.3 demonstrate the influence of the interaction between the two independent factors (temperature and water content) on the output variables (responses) on the bulk unit weight (BUW) of the rejuvenated mixes. These plots are in the form of two-dimensional and three-dimensional contour plots. As the BUW rises fast with an increase in water content up to a value of approximately 4.5% and then begins to decrease gradually with further addition of the water content, it is clear that solely the water content showed an important influence on the BUW of the mixes. At a temperature of around 0, the amount of water present was found to be at its maximum. The rejuvenator may have loosened the binder and caused more binder to be absorbed by the aggregate, increasing the density of the mixture, or the higher content of the water content in the mixture may absorb some of the compaction energy, resulting in a lower density due to the presence of more air voids.

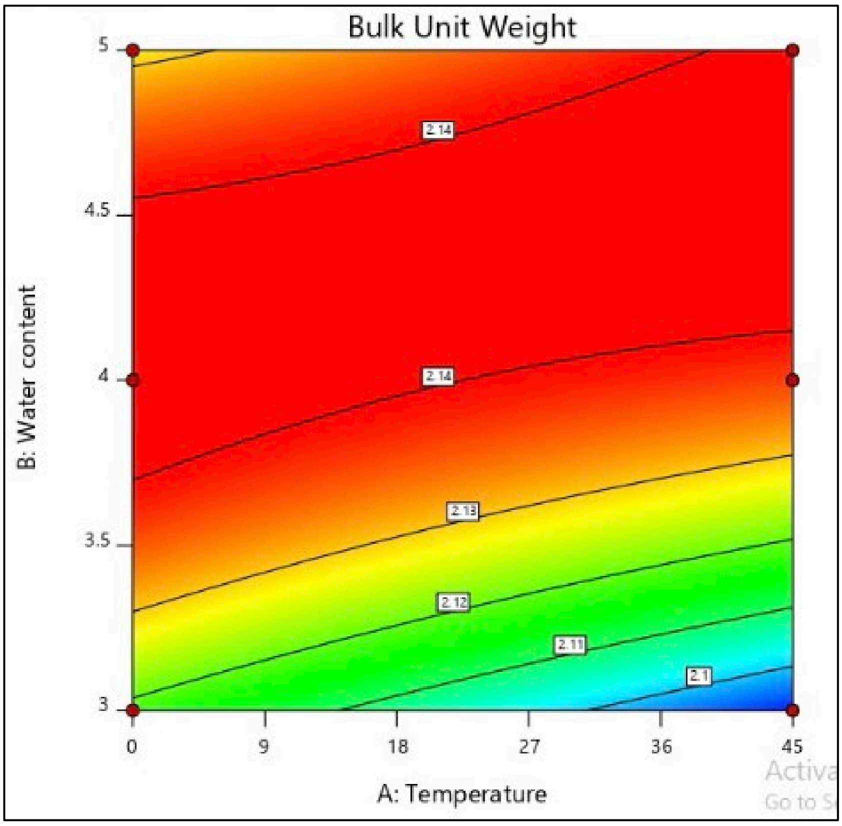


FIGURE 4.2 Effect of temperature and water content on BUW 2D

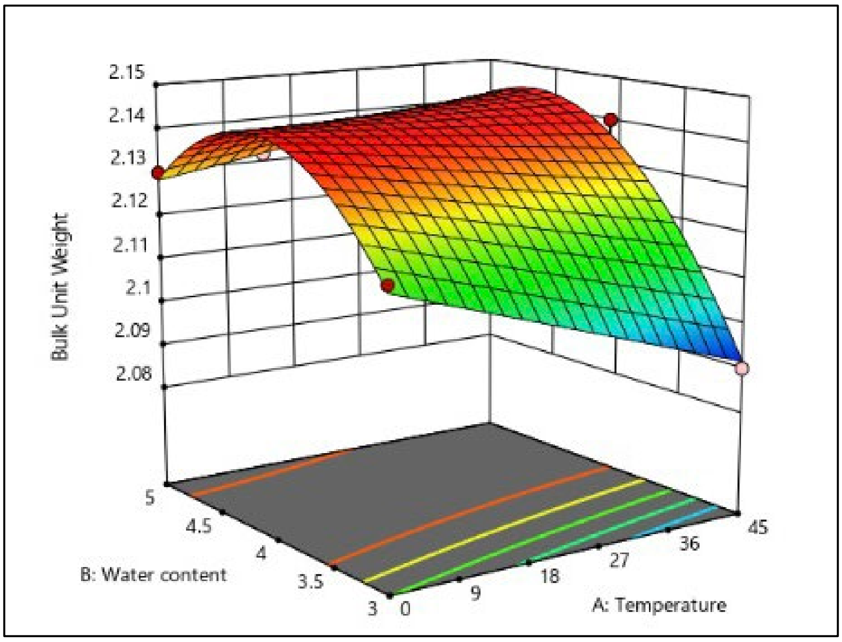


FIGURE 4.3 Effect of temperature and water content on BUW 3D

4.3.2. Air Voids

The ability of asphalt mixes to entrap air is important. Empirical evidence suggests that the ideal range for the air void volume in cold recycled mixes is between 15% and 18%. The 2D contour plot shown in Figure 4.4 reveals that the interaction impact of the water content and temperature on the percentage air void is negligible, since the contour line is virtually linear or intermediate between linear and oval in form. The 3D contour plot in Figure 4.5 shows that the rejuvenated, cold recycled mixture significantly affected the air gap due to the water content rather than the temperature, as expected. As the water content increased from 0% to 4%, the AV decreased; however, as the water content increased further, the AV increased. It's possible that this tendency arises from the rejuvenation effect, or the interplay of the high water content and high temperature will absorb certain portion of the applied compaction energy, affecting the mixture's compatibility and resulting in a high air void.

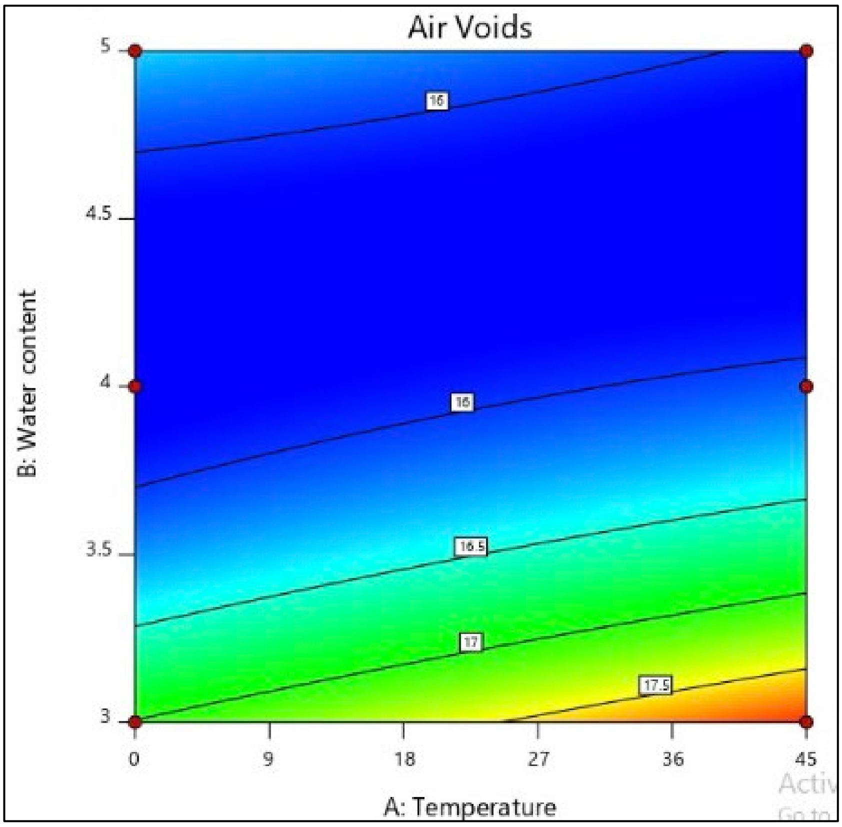


FIGURE 4.4 Effect of temperature and water content on Air Voids 2D

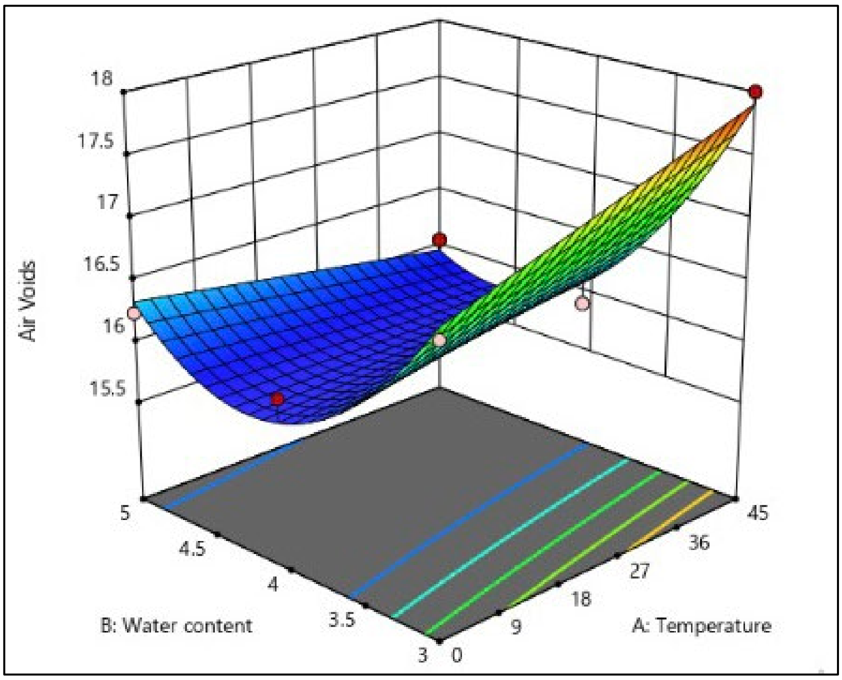


FIGURE 4.5 Effect of temperature and water content on Air Voids 3D

4.3.3. Marshall Stability

The ability of an asphalt surface to withstand traffic loading conditions without being deformed, displaced, rutted, or shoved may be referred to as its Marshall stability. When the road surface does not meet the standards for stability and flow, there will be a strong propensity for flow and unravelling on the road surface. This is because the road surface will not be stable enough. Figures 4.6 and 4.7 illustrate the relationship that exists between the dependent variable known as Marshall stability and the two independent factors known as water content and temperature. The 2D plots in Figure 4.6 have an oval form and a reddish colour, both of which point to the fact that the variables are interacting perfectly with one another. Figures 4.6 and 4.7 show that the two separate elements have a considerable influence on the stability of Marshall. When the amount of water present in the mixes is increased from 0 to 4% and the temperature is decreased from 0 to 45 degrees Celsius, the Marshall stability values increase at a quick rate. The Marshall stability values, on the other hand, start to drop when the water content becomes higher than 4%. In addition, the 2D and 3D graphs that are shown in Figures 4.6 and 4.7 demonstrate that there is a performance range that is ideal.

The sample has a high water content, which makes it a desirable material for strengthening asphalt mixes. This is the reason that may possibly be related with the growth in Marshall stability. The stability of the Marshall Islands is significantly influenced by two independent variables: the amount of water present as well as the temperature. It has been shown that the amount of water present has a significant influence on the Marshall stability.

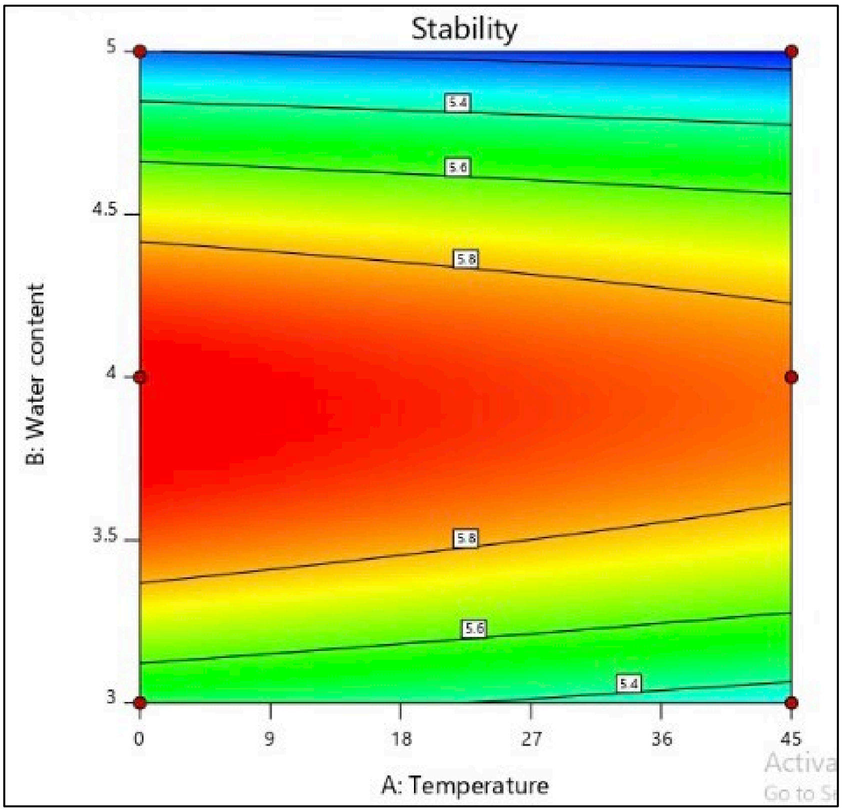


FIGURE 4.6 Effect of temperature and water content on Stability 2D

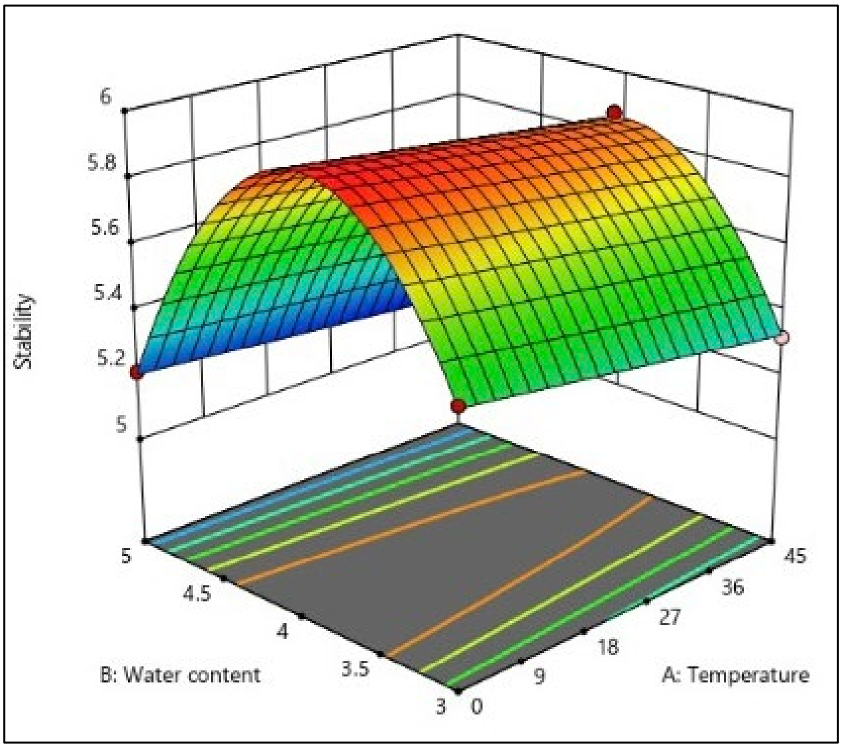


FIGURE 4.7 Effect of temperature and water content on Stability 3D

4.3.4. Marshall Flow

The capacity of an asphalt mixture to respond to slow settlement and movement without breaking is measured using a technique called Marshall Flow (MF). The flow value is also used in the process of determining whether or not the pavement wearing course is reversible when subjected to loads of traffic. Figures 4.8 and 4.9 show the contour plots of two-dimensional and three-dimensional surfaces, respectively. It is clear from looking at the numbers that the interaction of temperature had the most visible impact on the flow, although the amount of water present had no detectable impact. This implies that RSO has the effect of reviving the old binder in the RAP, which results in the RAP's strength increasing and the old RAP binder losing some of its stiffer characteristics.

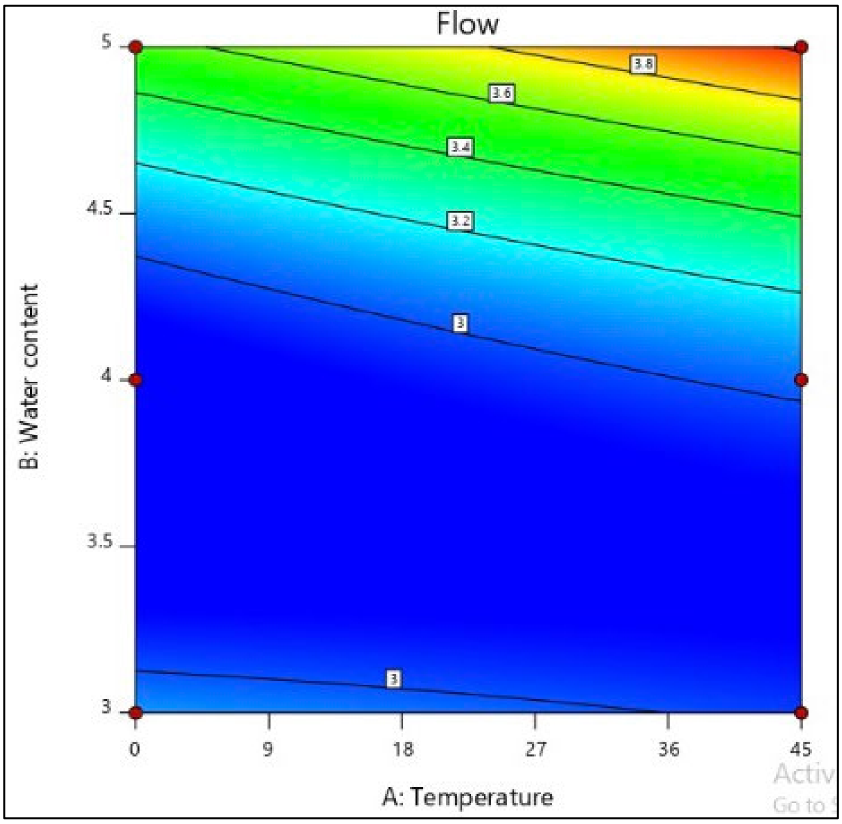


FIGURE 4.8 Effect of temperature and water content on Marshall Flow 2D

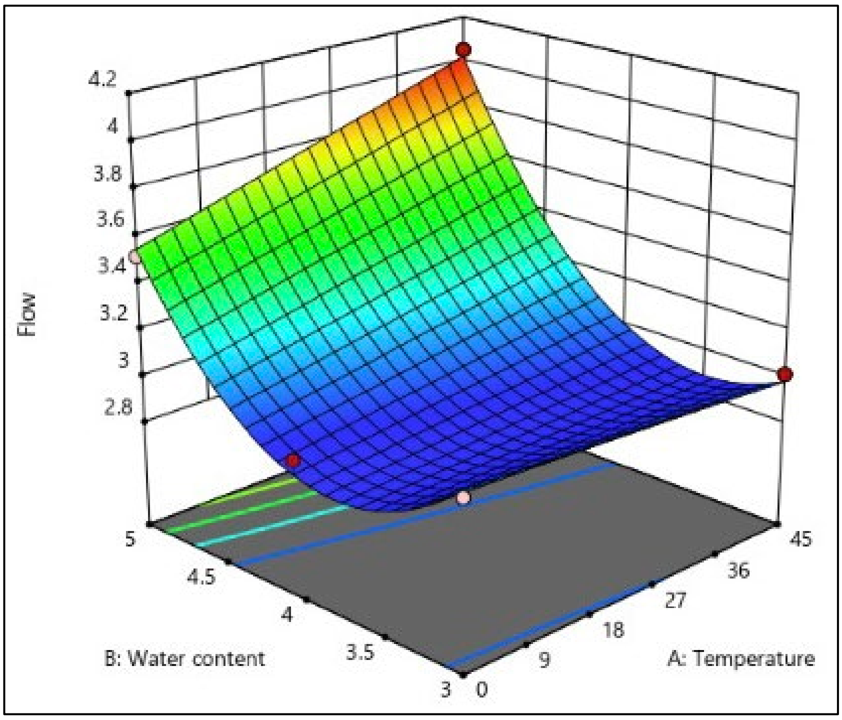


FIGURE 4.9 Effect of temperature and water content on Marshall Flow 3D

4.6 Numerical Multi-Objective Optimization and Validation of Modelled Results

In this study, the optimal values for the independent variables and the precision of the proposed models were determined by numerical optimization. The target outcomes and optimization bands are displayed in Table 4.7, while optimal values for the independent variables and the maximum projected responses are shown in Figure 4.10. In order to achieve a desirability of 0.839, the ideal concentrations of temperature and water content were found to be 0° C and 4.55%, respectively. Using the globally optimum independent parameters produced from numerical optimization analysis, the experiment had been run for three times with replicate samples to verify the accuracy of the predicted model and to compare the expected and actual responses.

TABLE 4.7 Selected numerical conditions for optimization for Marshall mix design requirements

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Temperature	is in range	0	45	1	1	3
B: Water content	is in range	3	5	1	1	3
Bulk Unit Weight	maximize	2.09	2.14	1	1	3
Air Voids	is in range	15.89	18	1	1	3
Stability	maximize	5.12	5.95	1	1	3
Flow	is in range	2.91	4.05	1	1	3

The results of the validation tests are shown in Table 4.7, and the predictability is evaluated using Equation (5), which calculates the absolute relative percentage error (RPE) between the lab and the ideally anticipated values. According to Table 4.8, the air voids has the lowest RPE (2.09%), followed by Marshall stability (3.55%), BUW (7.36%), and Marshall flow (7.96%). The percentage error between RSM predictions and laboratory data was below 10% for all answers, indicating that the models were quite accurate.

TABLE 4.8 Model validation for laboratory and predicted outputs

Responses	Unit	Predicted	Actual	Percentage Error	Remark	Desirability
BUW	-	2.14	2.31	7.36	Pass	83.9
Air Voids	%	15.89	16.23	2.09	Pass	
Stability	kN	5.70	5.91	3.55	Pass	
Flow	mm	3.12	3.39	7.96	Pass	

$$RPE = \left|1 - \frac{Predicted\ values}{Actual\ value}\right| x\ 100 \qquad (5)$$

Figure 4.10 shows the optimization ramps for temperature, water content and value of desirability. Wherever there is a dot on the ramp, that's the value for an input variable or response. The desirability of dependent variables ranging from 0 to 1 is revealed on the optimization ramps.

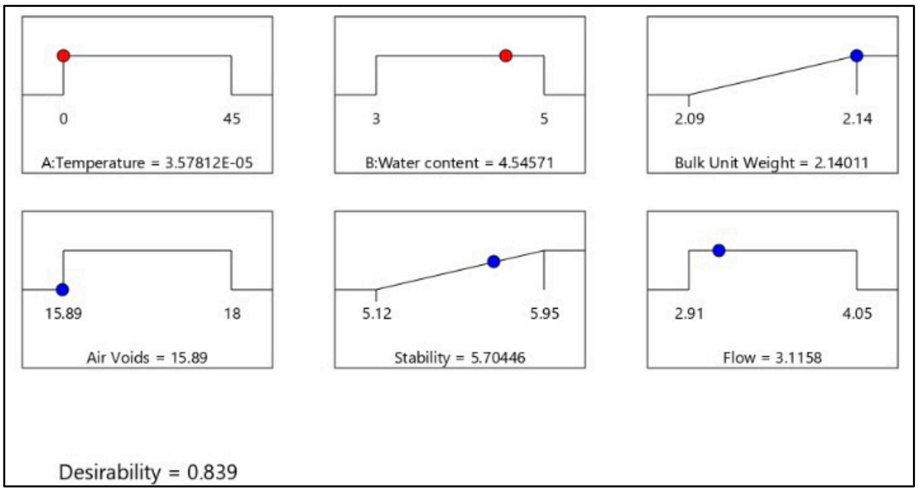


FIGURE 4.10 Numerical optimization ramp for input parameters and output responses

CHAPTER 5
CONCLUSION

The Marshall tests are going to be used to try to accomplish one of the primary goals of this research, which is to figure out the mechanical properties of RAP after it has been rejuvenated using RSO. In addition, there is an abundant annual supply of rubber seed, which helps to ensure that adequate resources will be available for subsequent generations to make use of RSO as a rejuvenator. Because RSO is not a resource that can be eaten, there is very little to no cause for worry over RSO's potential to compete with the food and beverage industry for the edible resources that can be used as RAP rejuvenator. In the end of this project, the objectives which are to assess the Marshall and volumetric properties of CRA mixtures incorporating RSO as rejuvenating agent and to optimize mixing of RSO rejuvenated RAP has been achieved. Thus, it would be useful to carry out this project since an innovative study on the components derived from industrial waste that are utilised in asphalt mixes, as this would enhance the performance of the pavement.

RECOMMENDATION

1. Long-term curing - put in a draft oven at a curing temperature of 40 ◦C for a period of 8 days and 15 days before testing. As the curing duration increases, the interaction between the water content and RSO on the stability becomes more significant
2. During mixing, use electrical stove to make sure the temperature is constant.

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