BE CIVIL ENGINEERING

PROJECT REPORT

Design and Optimization of Pumice Stone Ash based Cementitious Grouts for Grouted Macadam

Project submitted in partial fulfilment of the requirements for the degree of

BE Civil Engineering

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This is to certify that the Final Year Design Project

Design and Optimization of Pumice Stone Ash based Cementitious Grouts for Grouted Macadam

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DEDICATION

We, as a syndicate, have dedicated this Final Year Project to our parents, siblings, our instructors who have guided and helped us during this research and our great institution MCE where we have spent the four most memorable years of our life. We especially thank our Advisor who was very supportive and kind to direct us and provide us with useful materials. This would not have been possible without Dr Imran Khan.

بسم الله الرحمن الرحيم

DECLARATION

It is hereby declared that all the work carried out for this Final Year Design Project was performed by us and has not been submitted by any institution in whole or in part in any previous application for a degree. References to the work done by any individual, University or material used from other publications have been appropriately cited.

ACKNOWLEDGEMENTS

Foremost, we thank **Allah Almighty** who has enabled us to complete our degree leading to the culmination point in the form of this project. We would also like to give profound gratitude to our project advisor Assistant Professor Dr Imran Khan whose wealthy guidance and expert opinions have provided us with the correct direction in undertaking all the tasks connected to the fulfilment of the study. We would also like to thank all the Lab Instructors and Engineers who have provided us with valuable information and advice whilst completing the lab component of this project. We would also like to thank our Peers who gave us their ideas and fruitful advice which helped us during the project work. Lastly, we would like to thank all the researchers out there whose publications we have consulted for the completion of this project.

ABSTRACT

A new method known as "Grouted Macadam", or "Semi-Flexible Pavement" fills in open-graded asphalt concrete that has a high air void content by injecting or pouring specialized grouting materials. It is made without joints, contraction, or expansion and exhibits outstanding rut resistance. Additionally, these surfaces offer protection against fuel spillage. Flexible Pavements commonly experience rutting and fatigue distresses when subjected to extreme loading and weather conditions. In contrast, Rigid Pavements' building costs are high, the surface is rough, and it takes a while before it can be used for traffic. As a result, semi-flexible pavements can be used as an alternative to rigid and flexible pavements. Ordinary Portland Cement (OPC) has been partially replaced in the current investigation by Pumice Stone Ash (PSA) to create cementitious grouts. To prepare cement grouts, OPC is substituted with 5%, 10%, 15%, and 20% PSA, with a water-cement ratio of 0.30 to 0.40 and 1% superplasticizer. The grouts' flowability and compressive strength (7d and 28d) were also examined. Response Surface Methodology (RSM) was used for statistical analysis and optimization to identify the ideal composition of grouts. Semi-flexible specimens were created and put through performance tests (such as Marshal Stability and Resilient Modulus) based on the composition of the final chosen grouts. The specimen's resistance to fuel has also been examined. Environmental sustainability and a decrease in carbon footprint was achieved through recycling waste materials and cement replacement.

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LIST OF ABBREIVATIONS

Abbreviations	Description
PSA/PMA	Pumice Stone Ash
w/c	water/cement
ASTM	American Society for Testing and Materials
RSM	Response Surface Methodology
SP	Superplasticizer

CHAPTER 1: INTRODUCTION

1.1. Background

Construction of pavement strives to withstand environmental conditions as well as traffic loads. Rutting and fatigue resistance are regarded as crucial characteristics of high-quality pavements. Rigid and Flexible pavements are the two categories that have historically existed. Rigid Pavements are made of concrete, whilst Flexible Pavements are made of bituminous materials. Conventional Flexible Pavements are vulnerable to rutting, fatigue distresses, and bad weather when they are subjected to significant traffic loads. Flexible Pavement has a limited lifespan. On the other hand, stiff pavements are typically built for certain road types and have substantial maintenance expenses. Construction of rigid pavements and their introduction to traffic typically take longer. Over the last few decades, a new kind of pavement known as semi-flexible pavement has been utilized. A Semi-Flexible Pavement essentially combines the positive aspects of both Flexible and Rigid Pavements. It goes by the name Grouted Macadam and has a longer design life in addition to having excellent fatigue and rutting distress resistance. If built in locations where there are frequent oil and fuel spills, such as airports and bus terminals, a semi-flexible pavement also resists gasoline. (Khan et al., 2022)

1.1.1 History of Semi-Flexible Pavements:

Salviacim, the first semi-flexible pavement, was created as a fuel and abrasion resistant surface in France in the 1950s. Grouted Macadams were used extensively in Europe, the Far East, North America, and several African nations in the 1970s and 1980s. Research on heavy-duty road surface was conducted in 1979 at the University of Nottingham under the name Hardicrete. It was made of open-graded bituminous Macadam that was traditionally installed and completely grouted with high fluidity resin. Anderton (2000) asserts that previous investigations (conducted by BLIGHT, TARMAC, and AL-QADI) have demonstrated that Salviacim and RMP materials perform well regarding impact loads and spills of oil, chemicals, and fuel. These materials were shown to have low skid resistance when wet, but their skid resistance considerably increased when the standard of the pavement was raised. Ahlrich and Anderton (1991) investigated how military tanks and an accelerated loading facility (ALF) affected the durability of resin-modified pavement used by the US Army. The assessment revealed that the pavement had withstood oil and chemical spills and had not significantly deteriorated under traffic loads. The building of RMP can be separated into two 5-year periods up until the year 2000. The United States ran experimental programmes and small-scale projects from 1987 to 1991. The second timeframe, from 1991 to 1996, saw the execution of complete large-scale projects. The material's strong resistance to pavement deformation was one of the primary results. In Denmark, a new generation of special slurry grout was developed in the late 1980s, leading to advancements in semi-flexible pavements that showed strong potential for supporting extremely heavy loads. There were two improvements made to the grated macadams of this generation. First, a higher percentage of total voids was obtained by 16ptimizing the open-graded asphalt concrete. The second was a brand-new, high-performance slurry grout that was particularly good at penetrating the open-graded asphalt's void structure. More recently, Setyawan (2003) investigated numerous Grouted Macadam varieties with different types of binders. (Khan et al., 2022)

Table 1

History of Semi-Flexible Pavements

Country	Brand Name	Purpose of Construction
France	Salviacim	To provide resistance against waste oils, fuels, and abrasion
United States	Resin-Modified Pavement (RMP)	Airport taxiways, aprons, parking lots
Europe	Hardicrete Heavy Duty Surfacing. Worthycim Heavy Duty Paving. Confalt	Heavy-duty surface construction
Japan	RP-Pavement (Rut Proof Pavement)	Heavy-duty surface construction
France	combi-layer	Heavy-duty surface construction

1.2. Problem Statement

Typical Flexible Pavements are attacked by rutting and fatigue distresses also affect them when exposed to severe weather and loads. Rigid Pavements, on the other hand, are expensive to construct and have a rough surface. They also require a long time and maintenance before getting exposed to traffic. HMA pavements are highly susceptible to heat, oil, grease, and chemicals.

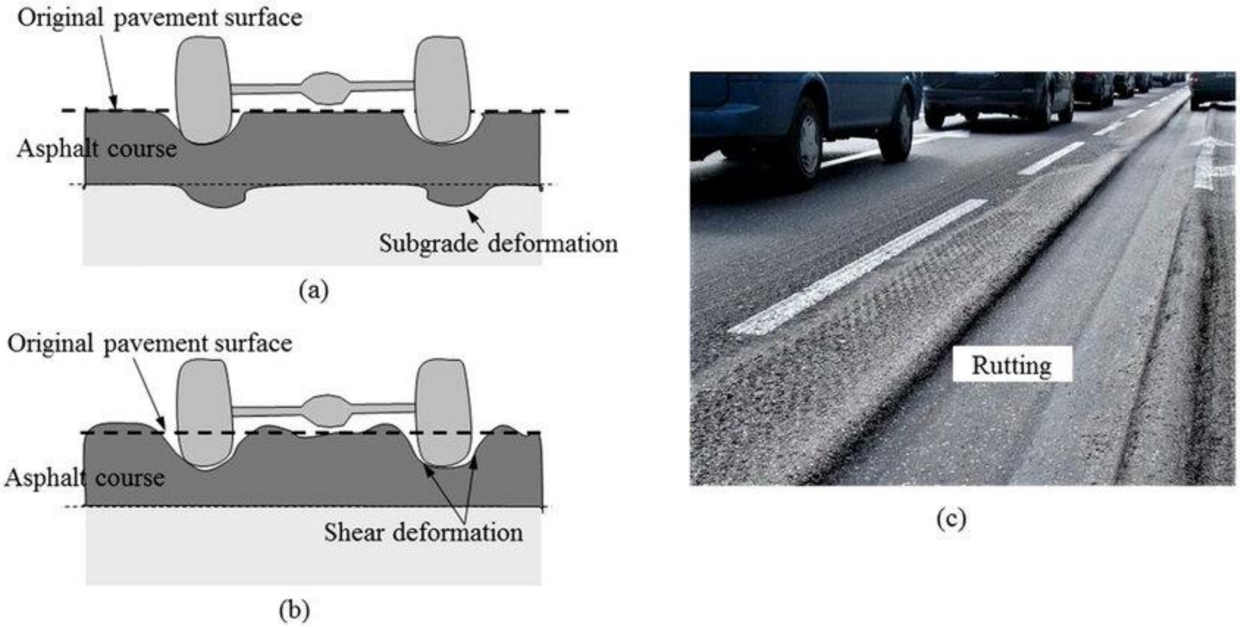


Figure 1.2 (a) Shows the traits of asphalt pavement rutting. The images below show structural rutting in the subgrade and bottom base, fluid rutting, and asphalt pavement rutting in a photograph.

Figure 1.2 (b) Cracks can be seen on a flexible pavement.

1.3 Objectives

The following goals must be met: -

1. To assess the mechanical and physical (flow) characteristics of cement grouts containing pumice stone ash.
2. To utilize Response Surface Methodology (RSM) to optimise the compositions of Pumice Stone Ash based Grouts.
3. To assess the performance of PSA-based grout-containing semi-flexible pavements.

1.4. Sustainable Development Goals (SDGS):

Goal 3: Good health and well-being.

Goal 7: Affordable and clean energy.

Goal 11: Sustainable cities and communities.

Goal 13: Climate action.

Goal 15: Life on land.

CHAPTER 2: LITERATURE REVIEW

Pavement Types:

The pavement is an area of the road where a variety of materials have been laid over the unimproved ground to support the weight of the vehicles. Road surfaces and pavement construction techniques can be divided into two categories: rigid pavement (usually of a single layer) and flexible pavement (generally made up of numerous layers). Pavements can be built from fake stone, flagstone, cobblestone, bricks, tiles, or even wood. Asphalt and concrete are the two materials that are most frequently used to make them. The components of the pavement dispersed the weight of the automobiles.

2.1. Flexible Pavement

Bituminous materials are used to make flexible pavements. Bituminous mixtures come in a wide variety of varieties that can be utilized in the layers. To keep the layers below from getting wet, the top layer or surface course needs to be impermeable. The base course typically distributes the traffic loads. Through the lateral distribution of the load, the stress/load is transferred to the lowest layer, which is the subgrade. Since sub-bases are already pricey, capping layer is employed to raise the thickness of the sub-grade.

The foundation, which is composed of the capping and sub-base and is made up of bituminous materials for the surface layers, bituminous or granular materials may be used for the base.

Most of the bituminous material is asphalt. Asphalt is divided into three categories: hot mix asphalt, warm mix asphalt, and cold mix asphalt depending on the temperature at which it is applied. The sub-base and capping that make up the foundation are constructed using pricey materials to distribute the stresses brought on by traffic loads and guard against the subgrade being harmed by those loads. Additionally, it can be utilized to keep the subgrade from freezing. There are two types of bituminous mixes: asphalt and macadams. The ratio of mortar to coarse aggregate in asphalt is high, and there are many spaces between the particles of coarse aggregate. Gap graded mixtures are this kind of mixture. Different aggregate sizes are used to create constantly graded macadams. (Martins De Oliveira, 2006)

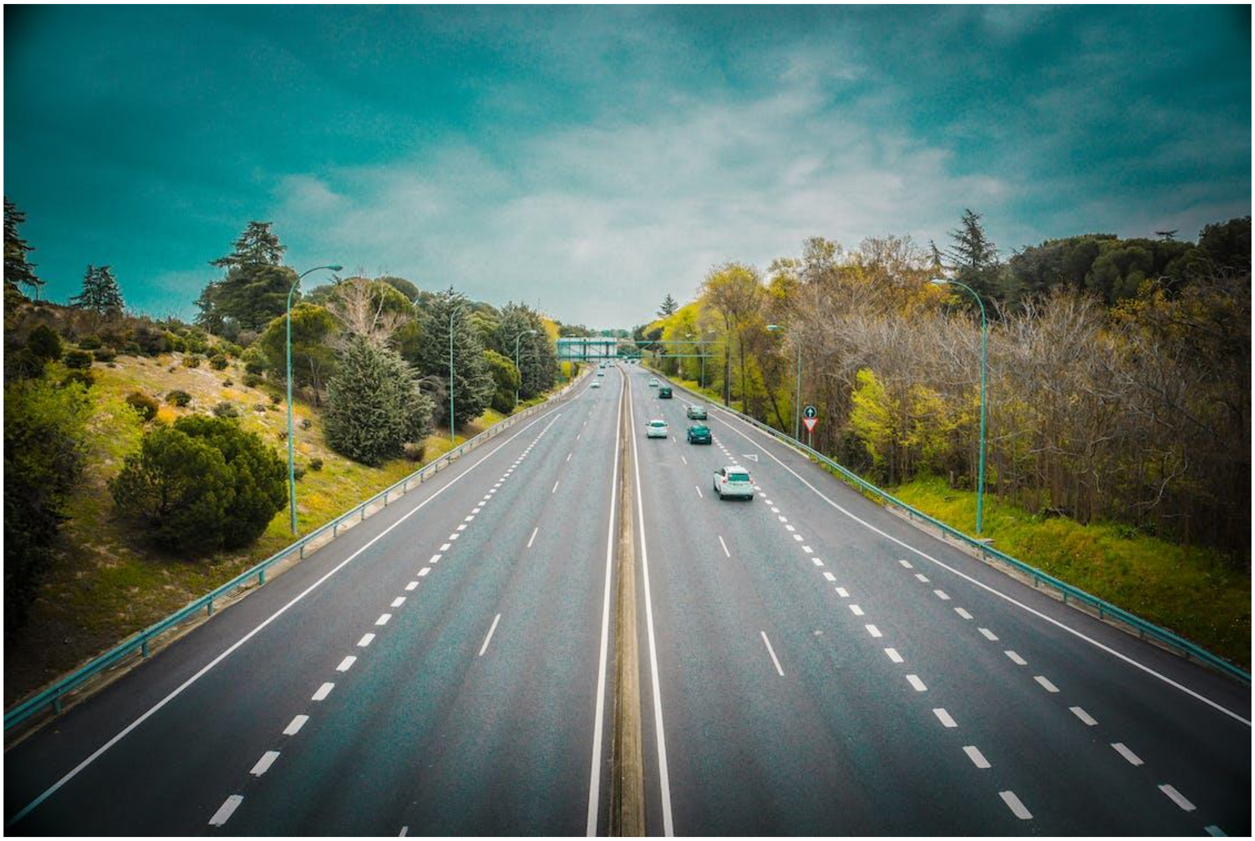


Figure 2.1 Figure showing Flexible Pavement

Types of Flexible Pavement:

There are three types of flexible pavements.

2.1.1. Conventional Layered Flexible Pavement

These are layered structures with high-quality materials at the top, where stresses are greatest, and low-quality, inexpensive materials at the bottom. Tack coat, prime coat, base course, sub-base course, seal coat, surface course, compacted subgrade, binder course, and natural subgrade are typical layers of a standard flexible pavement.

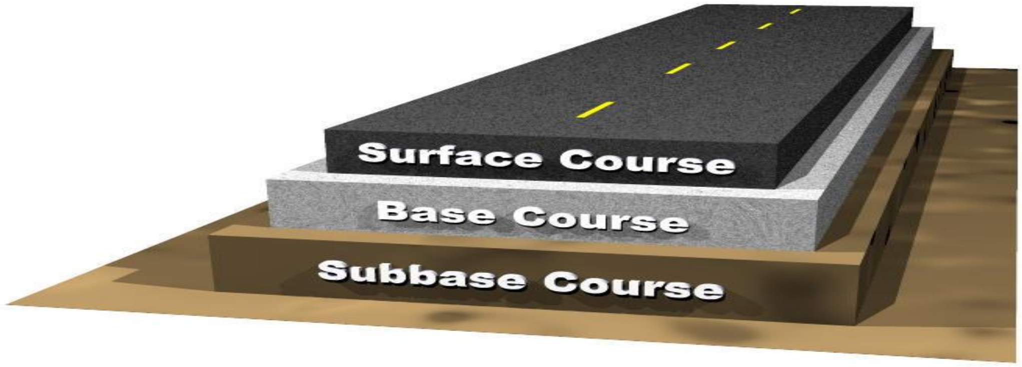


Figure 2.1.1 Conventional Layered Flexible Pavement

2.1.2. Full Depth Asphalt Pavement

Bituminous materials are immediately positioned on the soil sub-grade during construction. When there is a significant volume of traffic and no local materials are accessible, this is more appropriate. Full depth has many advantages, including lower costs and improved structural advantages. Full-depth pavement reclamation can prevent unnecessary landfill waste and preserve raw materials.

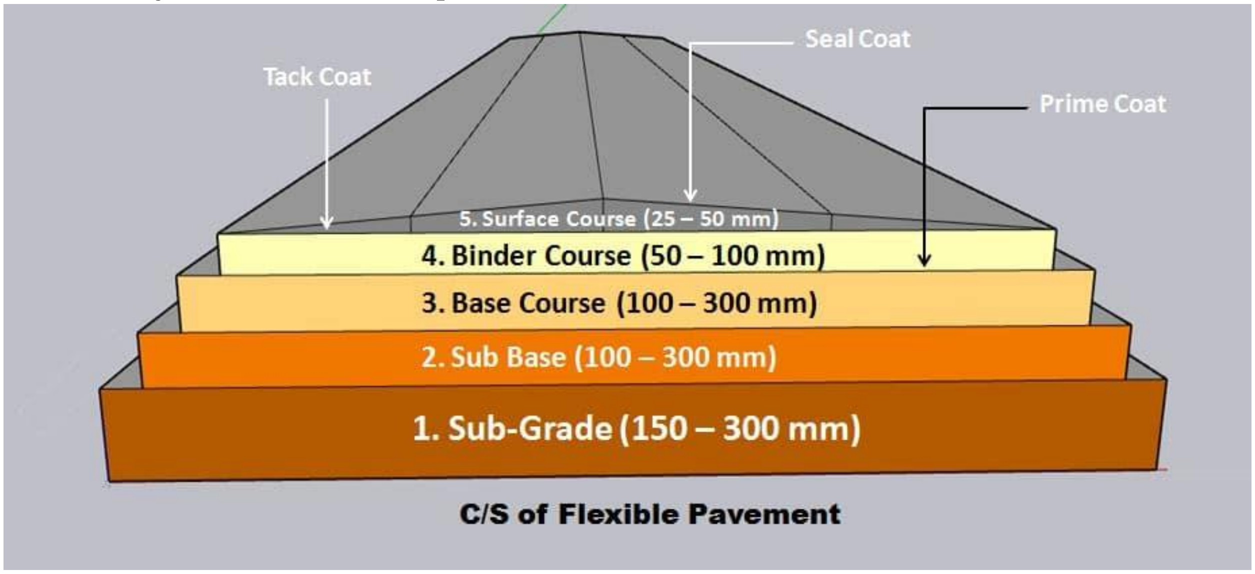


Figure 2.1.2 Layers of a Full Depth Asphalt Pavement

2.1.3. Contained Rock Asphalt Mat (CRAM)

CRAM is a pavement that is affordable and created for the contemporary world. It is regarded as being superior to conventional pavements while effectively distributing the wheel loads to subgrade soils. Because of CRAM's high strength, engineers have been able to offer clients a long-lasting road construction. It is made by sandwiching two asphalt layers with dense/open graded aggregate layers. To lessen stress on the soil subgrade, modified dense graded asphalt concrete is positioned above the sub-grade. (Suleman Khan, 2020)

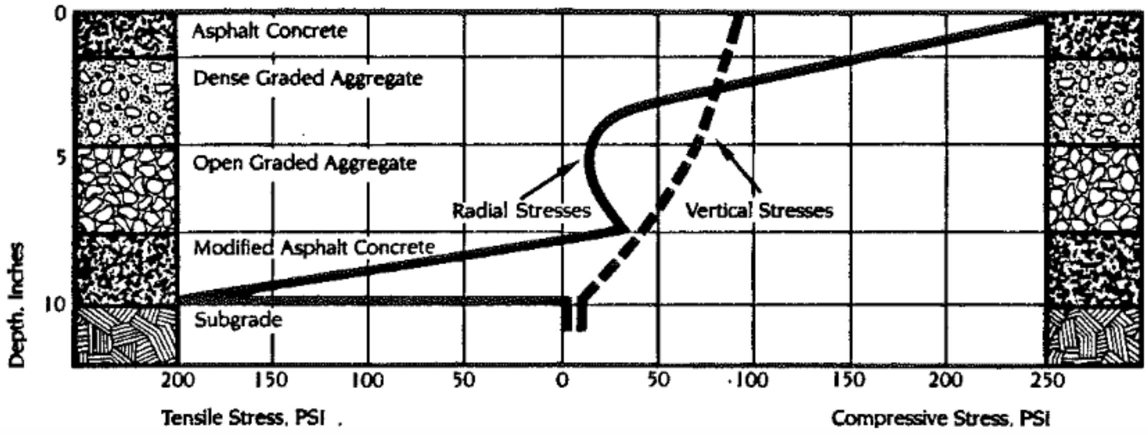


Figure 2.1.3 Comparison of CRAM with Conventional Concrete Pavements (Southgate et al., 1985)

2.1.4. Merits of Flexible Pavement

The initial cost of building flexible pavements is modest. Due to their capacity for unrestricted expansion and contraction, they are also free of thermal stresses. Flexible pavements do not need joints; joints are necessary to manage pavement movement and cracking. They can be put into use as soon as construction is finished. Reusing the surface will help with recuperation. With the increase in traffic, they can be strengthened and upgraded at any time. Flexible pavements may easily be repaired, and the thickness can be increased whenever it is necessary to meet the needs of the user. Additionally, flexible pavements don't reflect or glare from the sun. They have a lifespan of 10 to 15 years and don't need to be treated. On flexible pavements, underground work, such as pipe maintenance, can be completed without difficulty. Additionally, they may resist settlements to some amount and are convenient for transport. (Er. Madhu Krishna Poudel, 2022a)

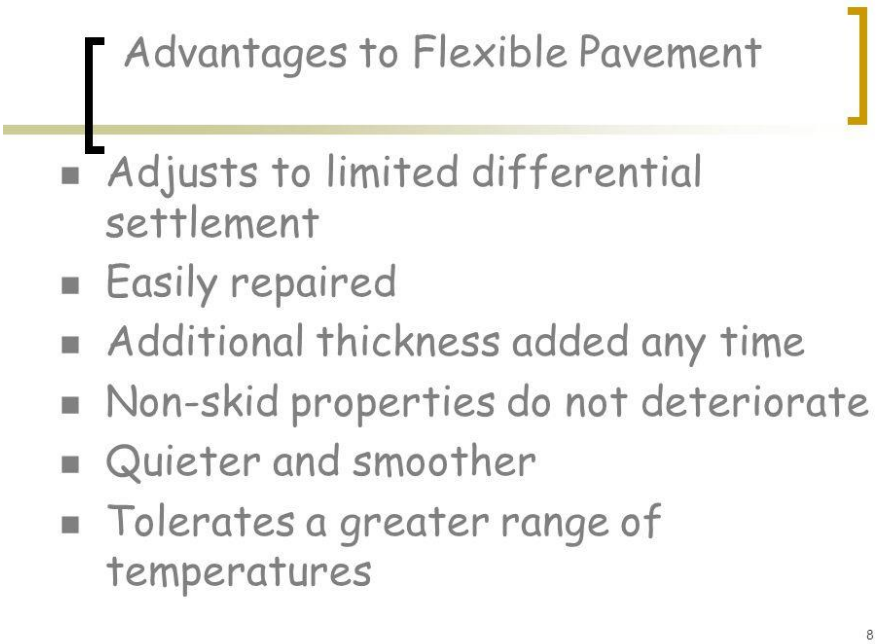


Figure 2.1.4 Figure showing advantages of Flexible Pavement

2.1.5. Demerits of Flexible Pavement

Where there are many merits, there are demerits of flexible pavements too which have been discussed in the following paragraph:

Pavements that are flexible are not very durable. Furthermore, because they don't distribute loads evenly, a solid subgrade and/or a capping layer are needed. Flexible pavements have substantial maintenance costs, and because asphalt is frequently utilized, nighttime visibility is significantly diminished. Flexible pavements have a poor flexural strength and are very vulnerable to heat, oil, grease, and chemicals. Additionally, flexible pavements require more regular maintenance, which raises the expense, and have a shorter lifespan than rigid pavements. Flexible pavement margins must have curbs placed since they are fragile. They degrade in stagnant water and have an excessive thickness. (ANASWARA, 2020)

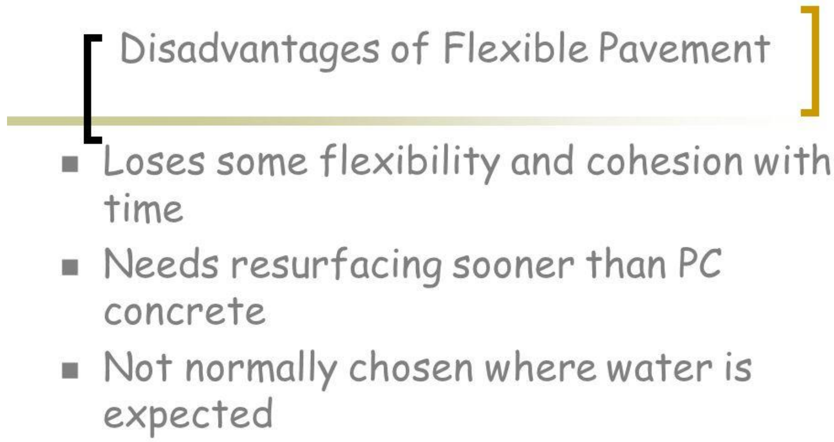


Figure 2.1.5 Figure showing disadvantages of Flexible Pavement

2.2. Rigid Pavement

The concrete slab and the sub-base are the two structural components that make up rigid pavements. The foundation of rigid pavement design is a structural cement concrete slab that is strong enough to withstand the loads of traffic. Rigid pavements behave like an elastic plate sitting on a viscous medium because the weight is dispersed through slab action. High elastic modulus rigid pavements can disperse loads across a large area of soil. The pavement slab made of cement and concrete can function as both a base course and a wearing course. The concrete slab needs to be sturdy enough to handle the weight of the traffic while also safeguarding the sub-base and subgrade. Although the pavement structure can differ, the basic makeup is constant.

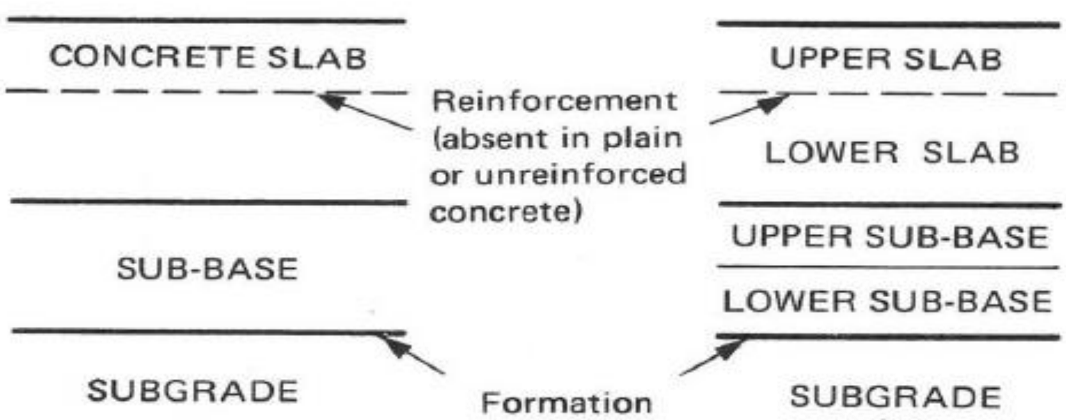


Figure 2.2 (a) Rigid Pavement's cross section

Unreinforced concrete pavements are often built with induced joints and lack reinforcement. It is built thick enough to withstand cracking brought on by vehicles. The concrete slabs can also be reinforced with steel to create rigid pavements. When put under stress, they hold their shape and only begin to shatter when the stress is too great. By means of slab action, the pavement distributes the wheel load to the subgrade. (Gopal Mishra, 2020)

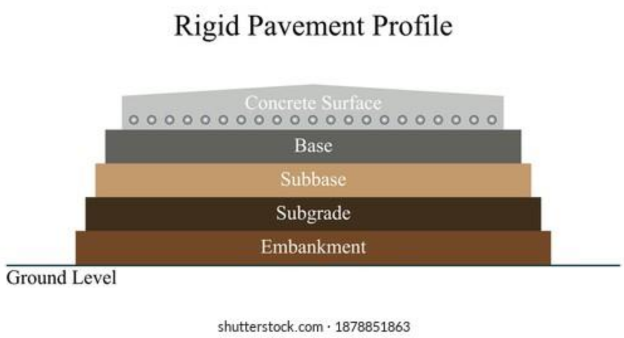


Figure 2.2 (b) Rigid Pavement's Profile

Types of Rigid Pavement:

There are two types of rigid pavement:

2.2.1. Unreinforced Concrete Pavement (URCP)

Unreinforced concrete pavement refers to rigid pavement that lacks reinforcement. Because it lacks strength, grooves are offered to prevent cracks. To prevent stones from entering the pavement in case of fractures, they are made to be too narrow for stones. In essence, grooves serve as crack-inducing mechanisms where prospective cracks resulting from shrinkage and heat contraction may develop. The pavement is just basic concrete. Additional two types include:

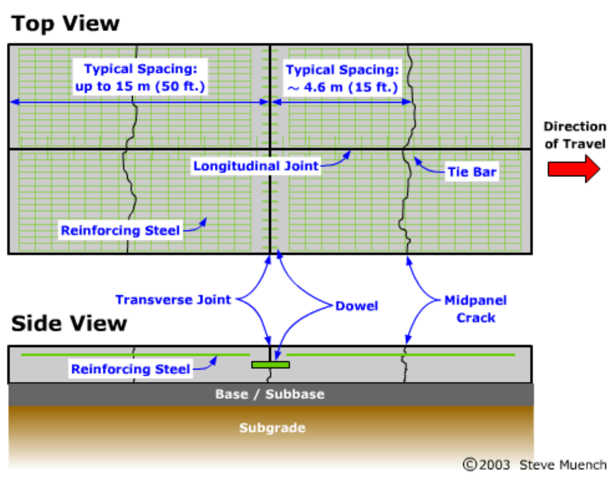


Figure 2.2.1 Unreinforced Concrete Pavement (URCP)

2.2.1.1. Jointed Dowelled Concrete Pavements (JDCP)

They can also be referred to as JPCP, or Jointed Plain Concrete Pavement. In this kind of pavement, the transverse joints have a joint spacing of 5–10 meters, and aggregate interlocks or dowel bars are used to provide the load transmission mechanism.

2.2.1.2. Jointed Un-Dowelled Concrete Pavements (JUDCP)

This type of pavement is constructed when the traffic load is very low and Dowel bars are not provided.

2.2.2. Reinforced Concrete Pavement (RCP)

The rigid pavement in which reinforcements are provided is called Reinforced Concrete Pavement. They are used when the traffic load is high. There are two types of RCP:

2.2.2.1. Jointed Reinforced Concrete Pavements (JRCP)

At the center of the slab is a JRCP steel mesh or mat. Reinforcement serves as a key barrier against cracking. It is suitable for light to medium traffic volumes.

2.2.2.2. Continuous Reinforced Concrete Pavements (CRCP)

On this pavement, there are ongoing reinforcements. They are primarily employed in the construction of busy roadways. Where the strength of the sub-grade soil is very low, the space between the slabs is also eliminated. (Er. Madhu Krishna Poudel, 2022b)

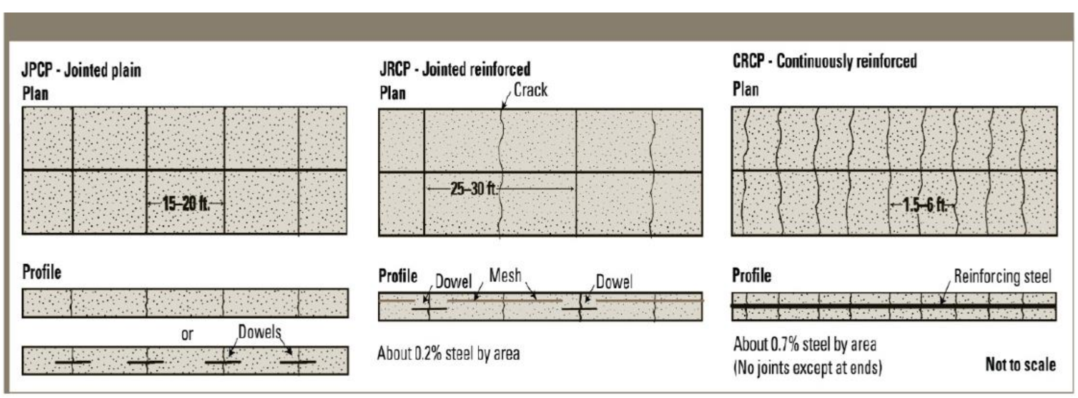


Figure 2.2.2 Types of Reinforced Concrete Pavement (RCP)

2.2.3. Merits of Rigid Pavement

The flexural strength of rigid pavements is sufficient to distribute the stresses caused by wheel loads to a larger area below. The subgrade does not cause the following layers to deform. Rigid pavements provide low maintenance costs, and surfacing can be put directly on the subgrade. The surfacing does not require rolling, and oils and chemicals do not harm it. Pavements that are rigid last longer than those that are flexible. They are also capable of being put on both high-quality and low-quality soil, and they enable future asphalt resurfacing. They have solid edges that don't need curbs or edging work, unlike flexible pavements. Additionally, they have excellent nighttime visibility and always offer comfortable transportation.

2.2.4. Demerits of Rigid Pavement

Pavements that are rigid might become slick over time. For their development and operation to be effective, high upfront costs are needed. Additionally, stiff pavements are sturdy and designed for high traffic volumes, but once a fracture develops, it spreads uncontrollably. In the event of worsening weather, they are also more susceptible to cracks. Additionally, rigid pavements reflect sunlight and become noisier over time. There is a need for highly skilled labor for construction and maintenance. They cannot be briefly opened for traffic after construction before being cured.

2.3. Semi-Flexible Pavement:

Grouted Macadam or semi-flexible pavements are surfaces that blend the qualities of two different classes of building materials into a single layer. The aggregate grading of the porous asphalt, the characteristics of bitumen, and the characteristics of cementitious grout all influence the mechanical qualities of a grouted macadam. The finished product combines the flexibility and lack of joints/rigidity of asphalt with the best attributes of concrete. Studies done in the lab showed that grouted madams have far more stability, durability, and strength than ordinary pavements. Pavement that is semi-flexible has a lot of air gaps that need to be filled with grout. It takes two steps to build grouted macadam because the asphalt layer must cool before grout can be poured into its pores. The voids can be filled with cementitious grout as soon as it has cooled. A light steel roller in vibration mode may be used to ensure that all the gaps have been filled with grout, depending on the type of powder that was used to form the grout. The surface can be treated to enhance its qualities, like durability, after the grout has been filled. The formulation of cementitious grouts to ensure they are fluid and have high strength is the main factor to consider in grated macadams. They must be fluid enough to fill the gaps. With a low w/c ratio, a poly carboxylate superplasticizer can improve fluidity and strength.

There is a need to create sustainable cement grouts since the usage of Ordinary Portland Cement (OPC) in grated macadams produces greenhouse gas emissions and harms the environment. Cement can be replaced with trash such as plastic waste and other byproducts as one method of reducing emissions. When it comes to pavement performance, grouts are crucial. The mechanical qualities of grouted macadams vary depending on the mix design of porous asphalt and grout. Semi-Flexible Pavements also have the benefit of early strength development and quicker final layer property development. Within two to three days, this kind of pavement can be made accessible to vehicles.

Figure 2.3 Semi-Flexible pavement

2.3.1. Open-Graded Asphalt:

A top layer is made up of an asphalt concrete mixture with a very open grading that is filled with a modified cementitious grout, creating a semi-flexible layer that can support heavy loads. The porous asphalt mixture that makes up the asphalt concrete has 25% air space. If the amount of air space is too low, it's possible that not all gaps can be filled with cementitious grout, and if it's too large, the pavement will behave like a concrete slab. To prevent cracks from forming, the asphalt layer is typically pored with an asphalt paver and then compacted with a steel roller.

Figure 2.3.1 Mixing of open-graded asphalt specimens

2.3.2 Cement Grouts:

The cementitious grout, which primarily contributes to rigidity and longevity as well as high compressive strength, is an important part of a semi-flexible pavement. To penetrate the asphalt skeleton, the grouts must be extremely flowable. The elements needed to create the desired flowability without sacrificing the strength attributes of grouts may be included in the grouts, along with cement, water, superplasticizer, and other ingredients. The effectiveness of the semi-flexible pavement was assessed using cementitious grouts made of pumice, stone, and ash. Grouts are crucial to the effectiveness of semi-flexible pavements.

Figure 2.3.2 Cement grout cube undergoing Compressive Strength Test

Following are the factors that influence the properties of grouts and semi-flexible mixtures:

2.3.3. Porous Asphalt mixture gradation

The qualities of the finished mixture are significantly influenced by the choice of aggregate gradation. For the cement grout to fully penetrate, the chosen gradation should offer air gaps of 25 to 35 percent. Bitumen is mostly used because open-graded asphalt has a higher proportion of course materials and a lower proportion of particles.

2.3.4. Porosity / Voids of Asphalt mixture

The final characteristics of Semi-Flexible Pavement are significantly influenced by the void's ratio of the asphalt mixture. When the porosity is too low, the voids may not be filled with cement grout; when the porosity is too high, sufficient grouts are needed, and the pavement may act rigidly. Additionally, a higher void content raises the asphalt skeleton's flow rate.

2.3.5. Degree of grout saturation

Determine the grout mixture to determine a Semi-Flexible Pavement's grouting capacity. It shows the number of asphalt mixture gaps that cementitious grouts have filled. When it comes to huge traffic loads and bad weather, it is one of the most crucial qualities.

2.3.6. Type of Asphalt binder

The characteristics of a Semi-Flexible layer are significantly influenced by the type of asphalt binder employed in a porous asphalt mixture. The compressive strength of grout macadam increases even at high temperatures because of the use of a stiffer and harder asphalt binder. However, repeated traffic loads over stronger binder might also result in cracks.

2.3.7. Water/Cement ratio of grout

To thoroughly permeate the porous asphalt structure of Semi-Flexible Pavements, the grouts must be very fluid. To increase the strength and fluidity of the cementitious grout, the w/c ratio is crucial. The fluidity of cementitious grouts is the most significant aspect that can influence the mechanical properties of grouts.

2.3.8. Industrial wastes and other additives

The pavement is rigid and long-lasting thanks to the cementitious grouts. However, using OPC might harm the environment. Furthermore, building Semi-Flexible Pavements demands a significant financial investment due to the high cost of cement. To reduce the use of OPC, other cement materials or industrial waste are being examined. (Khan et al., 2022)

2.4. Pumice Stone

Stone of Pumice stone is ground to create ash. Pumice Stone is an igneous rock that forms in volcanoes and has a foamy or spongy surface. It is utilized as an abrasive in numerous industrial items and as an aggregate in lightweight concrete. The lava cools as it descends, finally forming a rough-surfaced rock. Crystals might or might not be present. Foam is created in the solid rocks when a volcano erupts because ash rises into the sky and falls all over the place. The term "Products of Volcanoes" might be used to describe these rocks. Gas bubbles that were entrapped during the cooling process are found in the pore spaces. Since cooling happens so quickly, atoms cannot organize themselves into crystalline structures.

Figure 2.4 Pumice Rock – Foam like surface

2.4.1. Mining of Pumice Stone

Because igneous rocks are deposited on the Earth's surface, where they can be easily mined, it is a simple and user-friendly process compared to other methods. To obtain pure pumice stone, machinery removes soils. Because different sizes are utilized for different reasons and because crushers can ground material, blasting is not required.

Figure 2.4.1 Collecting of Pumice Stone from a mountain.

2.4.2. Properties of Pumice Stone

It often has a light hue, ranging from white to black or green, or brown. It frequently forms zones in the upper portions of silicic lavas and is a common byproduct of volcanic eruptions. It can float on water for years due to its high porosity before eventually becoming waterlogged and sinking. Volcanic glass is what it is because it lacks a crystal structure. Depending on the thickness of the solid material in between the bubbles, pumice stone has a range of densities. Its specific gravity is low. Its size may increase to the point that it may be detected by satellites and pose a risk to ships passing by. It is primarily rhyolitic in composition and contains a lot of silica.

Figure 2.4.2 Low Density of Pumice Stone – Floating on a $20 note.

2.4.3. Uses of Pumice Stone

Pumice stone is mostly used to make concrete blocks out of lightweight concrete. The gas bubbles in the concrete still contain some air when it is mixed, which lowers the block's weight. It is also employed in horticulture and landscaping. In addition to being used as a drainage rock in plantings, pumice stone is also employed as a decorative ground cover in planters. Pumice stone has a few minor applications, like:

1. As a traction enhancer in tire rubbers.
2. As an abrasive for polishing.
3. As an abrasive in pencil erasers.

Figure 2.4.3 Pumice Stone – Also used to remove dead skin cells.

2.4.4. Area of Pumice Stone Ash

Pumice Stone can be found all around the globe where volcanoes are present. There are large reserves of Pumice Stone in Asian countries including Afghanistan, Japan, and Syria. (Hobart M. King, n.d.)

2.4.5. Pumice Stone as a cementitious material

Pumice stone has an acceptable compressive strength, decent thermal insulation, and low density. It is suitable for lightweight aggregate because it is non-combustible, low permeability, and both. The 90-day compressive strength increased when pumice stone was replaced with cement up to 5-15%, however the 28-day compressive strength fell. When portions of pumice stone were substituted with cement, compressive strength decreased less when the samples were heated to high temperatures. It was discovered that mortars using pumice stone as a replacement had higher abrasion resistance. Like this, mortars that used pumice stone as a replacement showed higher electrical resistance after 90 days. Alaa M. Rashid highlighted the following advantages using cement in place of pumice stone:

- Increasing thermal insulation
- Increasing fire resistance
- Increasing abrasion resistance
- Decreasing unit weight
- Decreasing hydration heat
- Reduction in quantity of cement which led to lower CO_2 emissions.
- Has a lower modulus of elasticity than normal concrete. (Rashad, 2020)

Figure 2.4.5 Pumice Stone being used as a cementitious material.

CHAPTER 3: METHODOLOGY

3.1. Collection of materials

The following materials have been procured from different dealers / locations for our project.

3.1.1. Pumice Stone Ash

Well Graded Pumice Stone Ash that qualifies No. 200 sieve was brought from Peshawar. The total amount to be used for this project is 10 kgs of Pumice Stone Ash. It is greyish white in color.

Figure 3.1.1 Pumice Stone Ash – Powdered Form.

3.1.2. Super Plasticizer

Super Plasticizer was collected for Sika Industries, Islamabad. 5 kgs sample of Super Plasticizer was obtained for free. The primary reason behind adding Super Plasticizer is to make the grout more fluid.

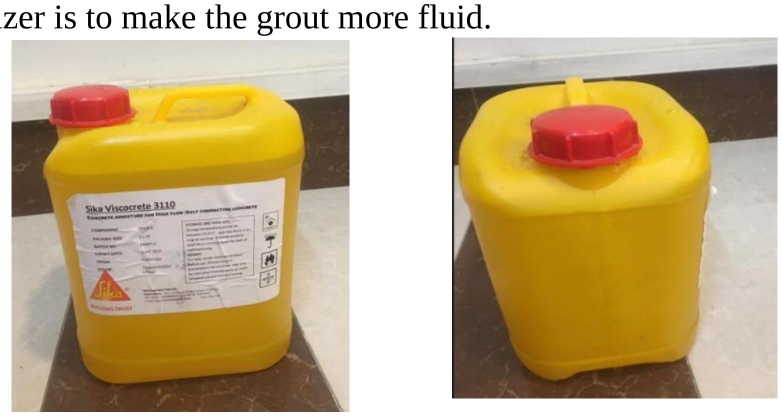


Figure 3.1.2 Super Plasticizer – Liquid Form.

3.1.3. Flow cone

Flow Cones are used for the flowability test. It was procured from a local mechanic. The volume of our flow cone is 1725 +/- 5ml as per ASTM C939 standards.

Figure 3.1.3 Welded Flow Cones – Max V = 1725ml.

3.1.4. Cement

Askari Cement which is an Ordinary Portland Cement (OPC) has been used in this design project.

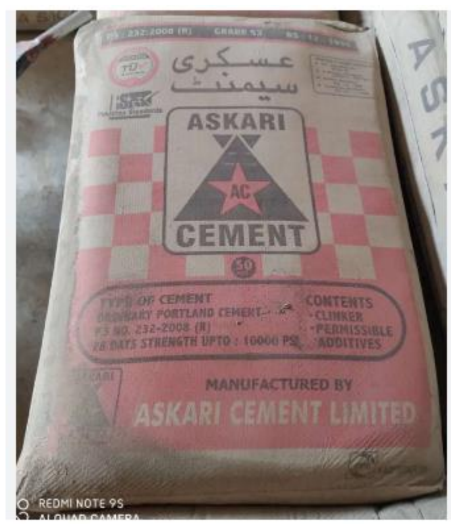


Figure 3.1.4 Askari Cement – Ordinary Portland Cement.

3.1.5 Bitumen

Bitumen is basically a binder that is mostly used in Pavements, it is called Asphalt when combined with aggregates. Bitumen was taken from Transportation Lab and was added in liquid form.

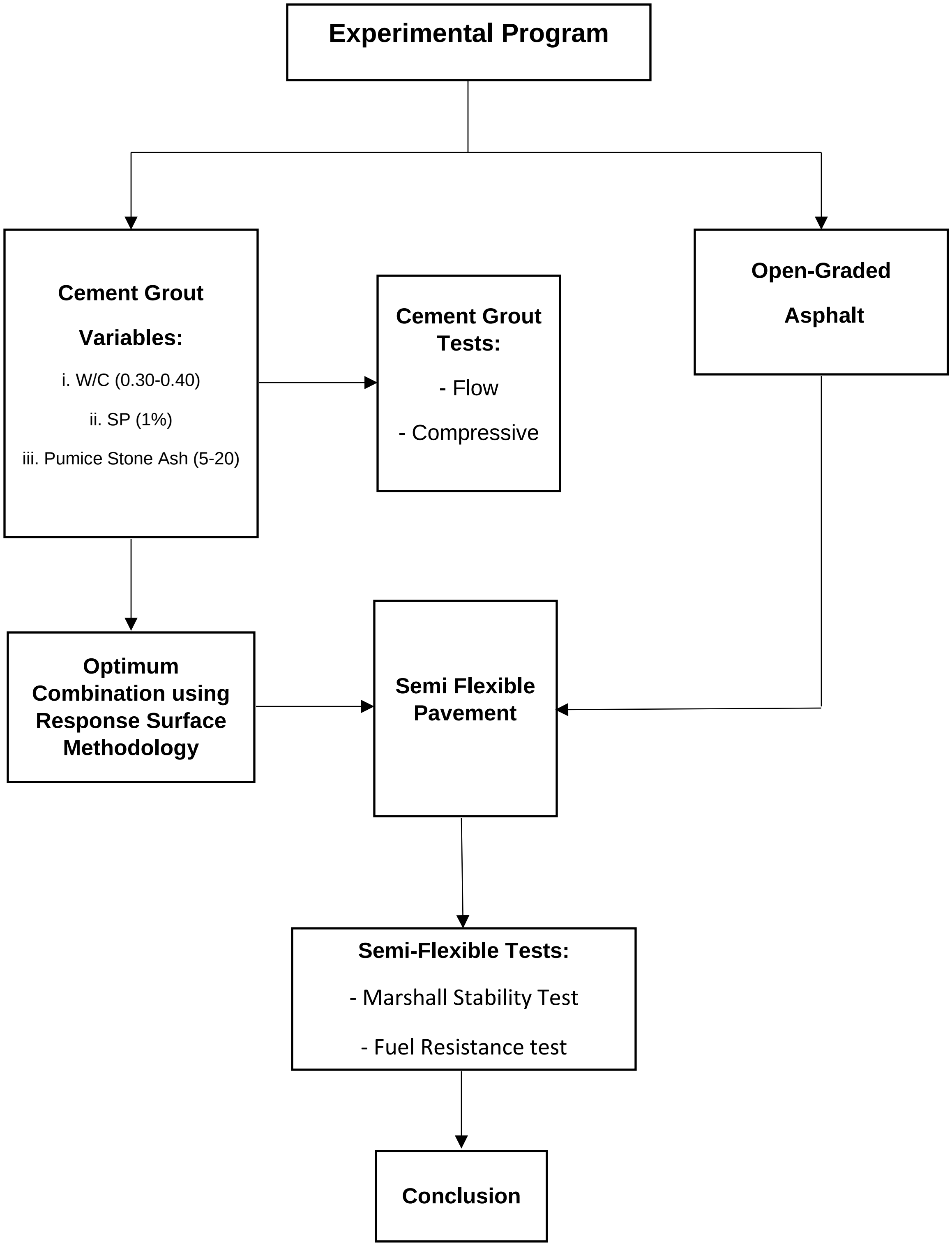
Figure 3.1.5 Bitumen – Liquid form

3.1.6 Aggregates

Aggregates were taken from Transportation lab and combined with Bitumen to form the open-graded asphalt mixture.

Figure 3.1.6 Aggregates

3.2. Flow Chart



3.3. Sample Preparation:

Following types of samples were prepared:

3.3.1. Preparation of control samples

Cement, water, and superplasticizer alone—without any Pumice Stone Ash percentages—were used to create control samples. The control samples were made using a Hobart mortar mixer in accordance with ASTM C305 guidelines. Using this technique, the mixture was dry mixed at a slow pace for 1 minute. After adding the second-third of the water, the dry mixture was stirred slowly for two minutes. Superplasticizer (SP) and the remainder were then added, and the mixture was mixed for five minutes at low speed. The grout was then vigorously mixed for a further three minutes. The material that had accumulated on the sidewalls was cleaned up and mixed once more. The material was then vigorously stirred for an additional minute.

Table 2

Different combinations of control samples

w/c ratio	Cement (g)	Water (ml)	SP (%)
0.30	3000	900	1%
0.35	3000	1050	1%
0.40	3000	1200	1%

3.3.2. Preparation of cementitious grouts

To create semi-flexible combinations, pre-designed cement grouts with established compositions were used. To create semi-flexible mixtures, three different types of cement grouts with variable PSA percentages and w/c ratios were used. One of the compositions employing the RSM technique was chosen and is discussed in chapter 4. The open-graded asphalt mixture's voids are filled with cementitious grouts. Cement, water, and the substance being used to partially replace the cement are the three major ingredients of cementitious grouts. To improve flowability and allow the grouts to penetrate the open-graded asphalt mixture more easily, superplasticizer is also added.

Table 3

Different combinations of cementitious grouts

w/c ratio	Cement (g)	PSA (%)	Water (ml)	SP (%)
0.30	3000	5	945	1%
	3000	10	1102.5	1%
	3000	15	1260	1%
	3000	20	990	1%
0.35	3000	5	1155	1%
	3000	10	1320	1%
	3000	15	1035	1%
	3000	20	1207.5	1%
0.40	3000	5	1380	1%
	3000	10	1080	1%
	3000	15	1260	1%
	3000	20	1440	1%

The cementitious grouts were prepared in a Hobart mortar mixer as per ASTM C305 specifications. In this method, the mixture was dry mixed for 1 minute at a slow speed. 2/3rd of the water was added to the dry mix and mixed for two minutes at low speed. The remaining and superplasticizer (SP) were added thereafter and mixed for five minutes at low speed. Additionally, the grout was mixed for a further three minutes at high speed. Material that was collected on the sides was cleared and re-mixed. Finally, the grout was mixed for an additional one minute at high speed.

Figure 3.3.2 (a) Mixture being mixed in Hobart's mixer and (b) Molds being placed to settle.

3.3.3. Preparation of asphalt mixture and optimum bitumen content

The bitumen and aggregates were heated beforehand to the proper mixing temperature. The bitumen was blended with the needed number of aggregates while maintaining the temperature in accordance with ASTM D6925 (ASTMD6925, 2015) regulations. The samples were crushed with 25 blows on one side only to achieve air voids in the range of 25-35%. These open-graded asphalt mixtures were then to be employed in generating Grouted Macadam specimens. The HMA (Flexible) specimens, on the other hand, were compressed using 75 strikes on each side. They were just made to be compared to semi-flexible ones. The specimens (open-graded) were finished, left to cool for 24 hours, and then taken out of the molds. The vacuum of material in open-graded specimens was estimated to be between 25 and 35 percent. Three HMA samples and six open-graded samples altogether were created. Two of the six open-graded ones were utilized for the Marshall Stability Test, while three were used for fuel resistivity. A total of 4200g of aggregates were removed, while 3.3% of bitumen was added to open-graded mixtures and 4.1% to HMA.

Table 4

Gradation for open-graded asphalt mixtures

Gradation for Open-Graded Asphalt Mixtures (Densiphalt-12)				
Sieve size (mm)	% Passing	% Retained	Weight for one Marshal Sample (700 g)	For 6 samples
3/4" (19 mm)	100	0	0	0
1/2" (12.5 mm)	97.5	2.5	17.5	105
3/8" (9.5 mm)	18	79.5	556.5	3339
#4 (4.75 mm)	10	8	56	336
#8 (2.36 mm)	8	2	14	84
# 200 (0.075 mm)	4.5	3.5	24.5	147
Filler (Passing # 200 sieve)		4.5	31.5	189
Total		100	700	4200
*Bitumen Content = 3% by weight of Agg				
*Compaction with 25 blown on one side only				
**Total of 6 Specimens shall be made				

Table 5

Gradation for HMA samples

Gradation for HMA (NHA Class A Specification)				
Sieve Size	% Passing	% Retained	Weight for one Marshal Sample (1150 g)	for 3 samples
1 " (25 mm)	100	0	0	0
3/4" (19 mm)	95	5	57.5	172.5
3/8" (9.5 mm)	68	27	310.5	931.5
#4 (4.75)	50	18	207	621
#8 (2.36 mm)	36	14	161	483
#50 (0.3 mm)	12	24	276	828
#200 (0.075 mm)	5	7	80.5	241.5
#200 (0.075 mm)	--	5	57.5	172.5
*Bitumen Content = 4.1% by weight of Agg				
*Compaction with 75 blown on both side				
**Total of 3 Specimens shall be made				

\

Figure 3.3.3 (a) Group member Faisal giving blows to the sample and (b) Aggregates being heated along with the bitumen.

3.3.4. Grouting and fabrication of semi-flexible mixtures

To prevent the cementitious grout from leaking, talic sheets were used to seal all the specimens' sides. The necessary amount of grout was put on top, and then there were some vibrations. Vibrations were used to make sure that grout penetrated all the way to the bottom of the specimens. The grout mixtures were made with the 0.40 w/c ratio and 18% PSA, which provided the highest compressive strength and shortest flow time, as well as control samples made solely of cement. After 24 hours, the semi-flexible specimens were taken from the moulds, and the amount of cementitious grout was calculated using equation (1).

$$S = \frac{(M2 - M1)}{\rho * Vol * Vair} * 100 \qquad (1)$$

Where S is the degree of saturation (%), M_1 is the initial mass of the specimen and M_2 is the mass after grouting. ρ is the density of the cement grout, Vol is the volume of the specimen and V_{air} is the air voids in porous asphalt skeleton.

Figure 3.3.4 (a) Grouts being poured into the open-graded specimen and (b) open-graded specimens wrapped in a talic sheet.

3.4. Testing on grouts

Following tests were performed on grouts:

3.4.1. Measurement of flow

The ASTM C939 standard cone of 1725ml is used during the flow test to gauge how quickly the grout flows out. The funnel was filled with one liter of grout, and the flow-out period was timed. This test was done to make sure that the grouts would pour into the open-graded asphalt samples with enough fluidity. As per ASTM guidelines, the flow-out time should be between 11 and 16 seconds. Because the cementitious mixture has a lower viscosity, the flow-out time directly correlates with the workability of cementitious grouts; the shorter the flow time, the more workable the grout is. The current study has confirmed that the flow-out time is decreased when water and superplasticizer are added because the relationship between the two variables is inverse. In the Results section, it has been demonstrated. Less flow-out time, or higher fluidity, is what we need in order for the cementitious grout to thoroughly permeate the open-graded asphalt mixture.

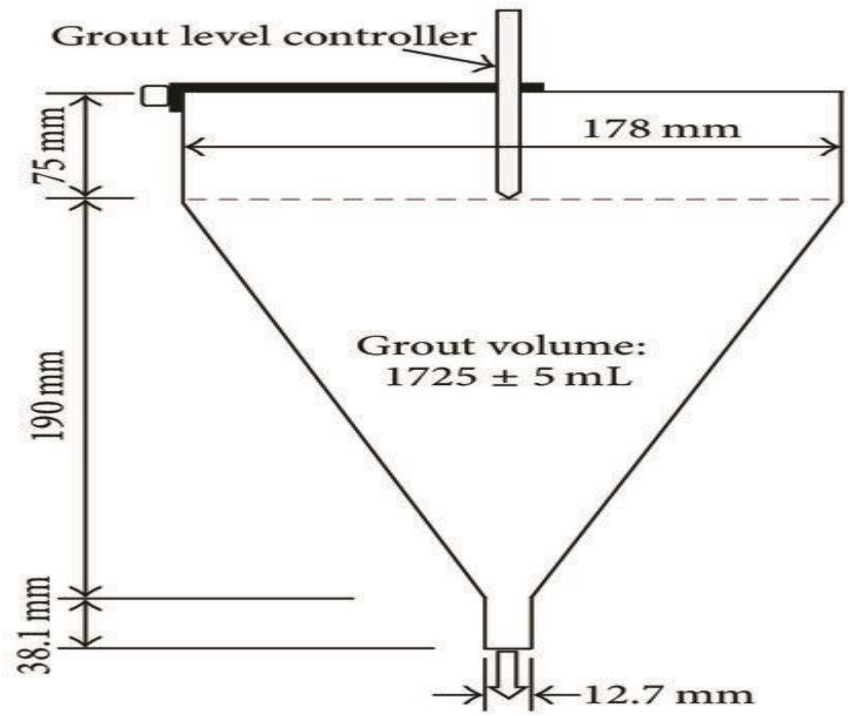


Figure 3.4.1 (a) Flow cone showing how the flow grout test is performed and (b) Group leader Mohammad performing the flow cone test.

3.4.2. Compressive Strength Test

Each type of grout combination was formed into cubes that were roughly 50 mm x 50 mm x 50 mm in size, and the compressive strength after 7 and 28 days was calculated. According to the ASTM C109 standard, the compressive strength was tested using a Universal Testing Machine (UTM) with a 3000kN capacity at a speed of 9.0kN/s. The ASTM process is explained below:

Create cement mortars first. Return the mortars from the flow table to the mixing bowl as soon as the flow test is over. Scrape the bowl's sides quickly, add them to the batch, and then mix everything together for 15 seconds at medium speed. Complete mortar consolidation in molds using either hand tamping or a different technique. Prepare 6 or 9 cube batches with one of the cements on a single day, and then cast a minimum of 36 cubes. All cubes should be tested after seven days. Before 24 hours, the specimens are taken out of the molds. For 24-hour specimens, test the samples as soon as you remove them from the humid closet. Each specimen should be dried on the surface, and any loose sand particles should be removed from the faces that will meet the testing machine's bearing blocks. Place the specimen in the testing device so that it is below the upper bearing block's center. Apply the load rate necessary to load the specimen at a rate between 200 and 400 lbs/s. Record the total maximum load and calculate the compressive strength. The compressive strength of all acceptable test specimens made from the same sample shall be averaged.

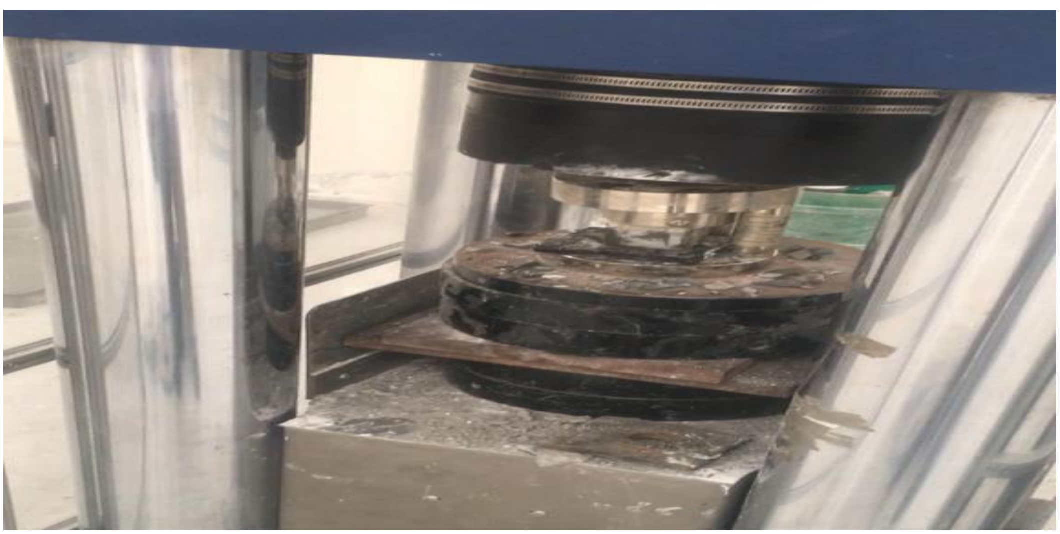


Figure 3.4.2 (a) Settings of the Universal Testing Machine (UTM) and (b) A block undergoing compressive strength test at the Structural Lab.

3.5. Experimental design and analysis using RSM.

To attain the desired results with fewer experimental runs, the RSM's main goal is to identify the best combination of independent variables. RSM is particularly useful for experiment design and establishing the causality between independent and dependent variables. The software Design Expert 11 performs RSM. The flow, 7-day compressive strength, and 28-day compressive strength are the dependent variables (responses), whereas the w/c ratio and percentages of PSA are the independent variables (factors). The results were evaluated using the ANOVA analytic technique in terms of R2, p-value, acceptable precision, and lack-of-fit. After that, a combination of flow, compressive strength for 7 days, and compressive strength for 28 days was chosen since it would produce the best results.

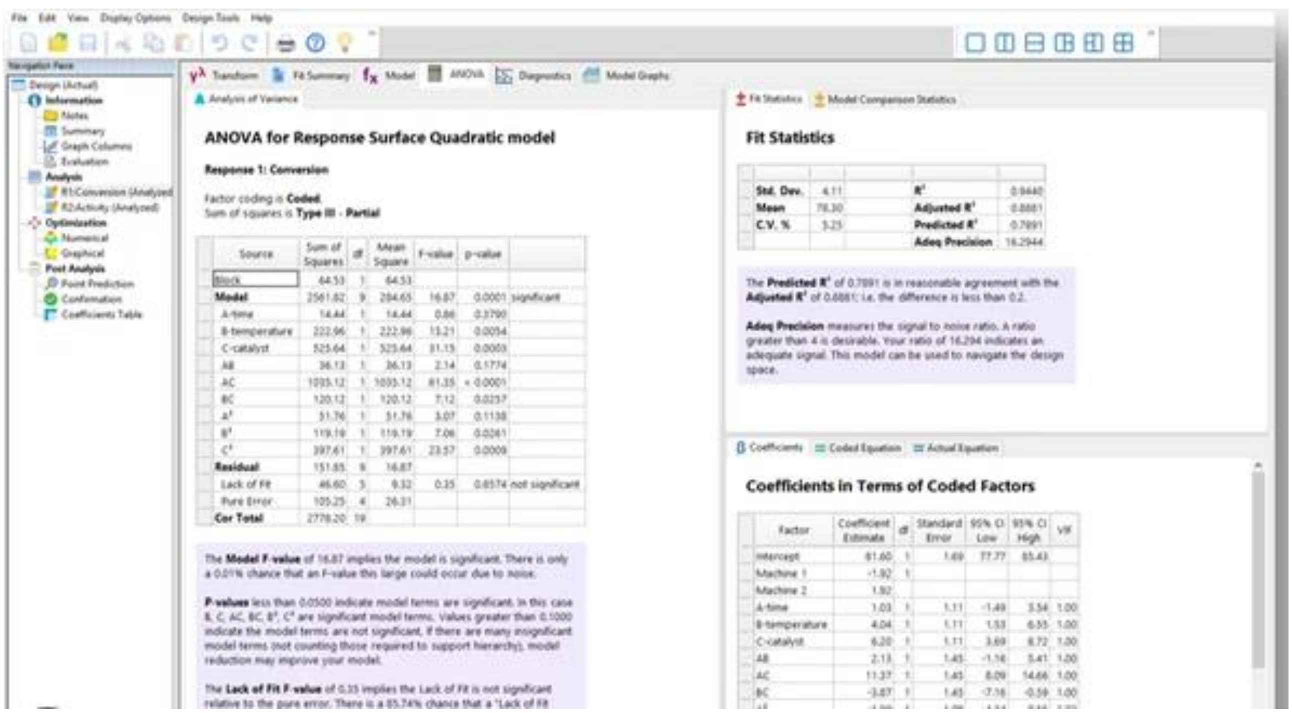


Figure 3.5 (a) Design Expert 11's USER-INTERFACE.

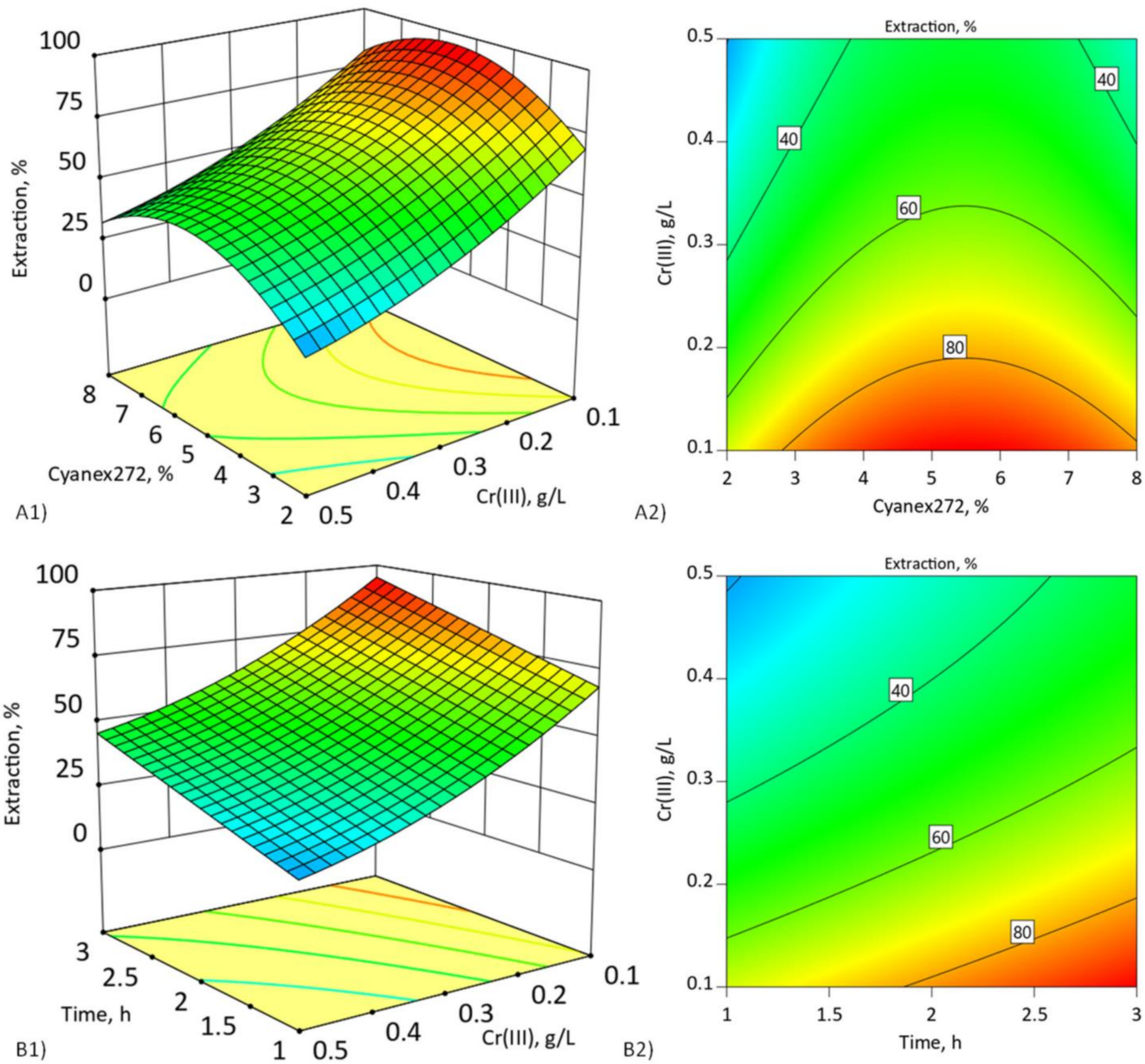


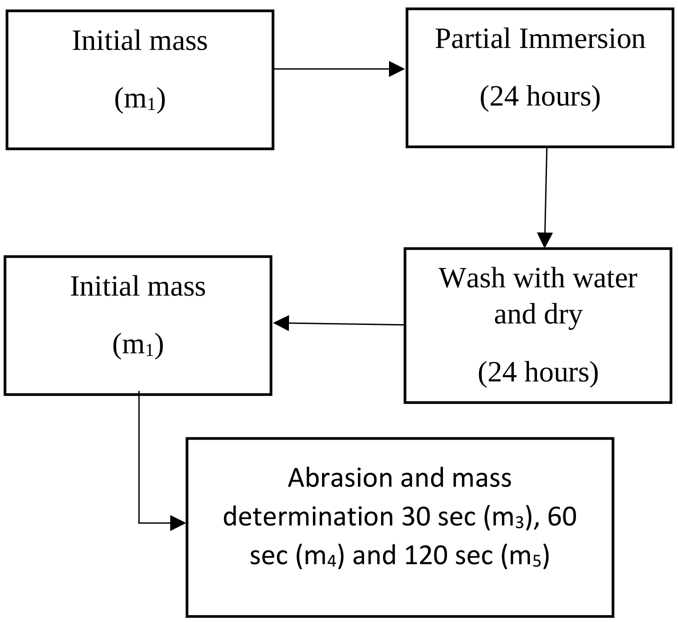
Figure 3.5 (b) Figure showing difference RSM graphs.

3.6. Testing on grouted macadam specimens

Following tests were conducted on grouted macadam specimens:

3.6.1. Fuel Resistance Test (Partial Immersion test)

Fuel can spill onto paved areas such as those found in parking lots, airports, and bus stops. The bitumen softens and causes distress when typical HMA pavements are subjected to diesel, kerosene, and other oils. Aggregate separation results from this. The literature claims that a key benefit of semi-flexible pavement is its resistance to fuel spills. When conventional HMA specimens and semi-flexible specimens were submerged in diesel oil with the top left untouched, the amount of mass lost was calculated.



In this experiment, samples were partially submerged in diesel for 24 hours; their initial weight was determined to be m1. They were then washed and dried for an additional 24 hours, after which their weight was once more estimated as m2. After being rubbed with a steel brush for 30 seconds, 60 seconds, and 120 seconds, the specimens' masses were recorded as m3, m4, and m5. Parameters A and B are used to assess fuel resistance, per standard (BS EN 12697-24). A is the mass loss brought on by gasoline immersion, and B is the mass loss brought on by abrasion. The formula is as follows:

$$A = \frac{m1 - m2}{m1} * 100 \qquad (3.5.1)$$

$$B = \frac{m2 - m5}{m2} * 100 \qquad (3.5.2)$$

By determining “A” and “B”, BS EN – 12697-24 sets the following criteria to characterize resistance to fuel. (Imran Khan et al., 2021)

A ≤ 5% and B < 1% ⟶ Good resistance

A ≤ 5% and 1% B ≤ 5% ⟶ Moderate resistance

A > 5% or B > 5% ⟶ Poor resistance

In another detailed studies, Ronald Blab introduced a new parameter “C” which combines the effect of both parameters’ “A” and “B”. The parameter “C” is given by the following equation:

$$C = \frac{m1 - m5}{m1} * 100 \qquad (3.5.3)$$

C < 6% ⟶ Good resistance

6% ≤ C ≤ 10% ⟶ Moderate resistance

C > 10% ⟶ Poor resistance

Figure 3.6.1 (a) Samples submerged in diesel and (b) Sample being subjected to abrasion by steel brush by group member Abubakr.

3.6.2 Marshall Stability Test

To ascertain the stability and flow characteristics of semi-flexible mixes, the Marshall stability test was carried out in accordance with ASTM D6926. The stability of the cylinder samples was examined. The specimens were subjected to testing after spending 30 minutes in a water bath heated to 60 °C, in accordance with the norm. The load was applied at a 50.8 mm/min rate, and the apparatus's display was used to record the stability and flow readings. The highest load that a cylindrical specimen can withstand before failing is known as the Marshall stability, and the flow is the measured deformation at that load.

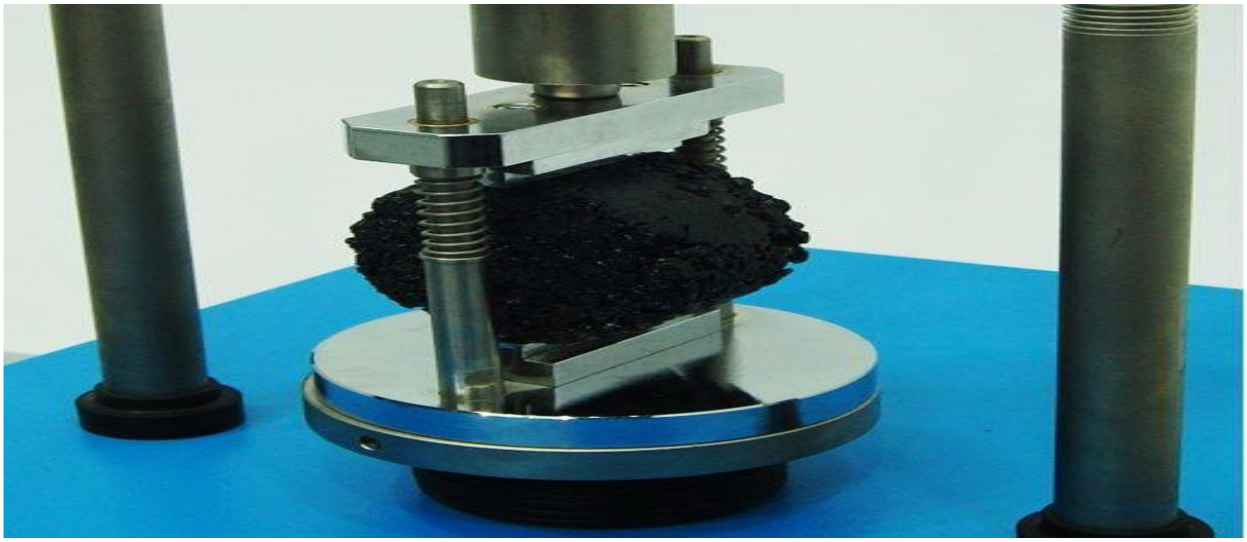


Figure 3.6.2 (a) Marshall Stability Test being performed.

Figure 3.6.2 (b) Block placed in Marshall test machine.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

Based on the flow and compressive strength results of 12 grouts with varied w/c ratios (0.30-0.40) and Pumice Stone Ash percentages (5-20%), a single combination of w/c ratio and Pumice Stone Ash percentage was chosen. The Response Surface Methodology approach chose one set of w/c ratio of 0.40 and 18% Pumice Stone Ash based on the goal to achieve a flow range of 11–16 seconds and maximize the compressive strength. The RSM approach was carried out by the program "Design Expert 11."

4.2. Results of compressive and flow test

According to Table 3, the flow-out time significantly decreases as the w/c ratio rises. Additionally, it can be shown that a large percentage of pumice stone ash reduces compressive strength; as a result, we performed RSM to determine the ideal concentration. The combination of 0.35 w/c ratio and 20% PSA produced the lowest 7-days and 28-days strength, whereas 0.40 w/c ratio and 10% PSA produced the greatest.

Table 6

Flow and compressive strength of grouts

w/c ratio	Pumice Stone Ash (%)	Flow (sec)	Compressive strength (MPa)	
			7-days	28-days
0.30	5	25	20.469	31.020
	10	26	33.137	51.520
	15	24	34.251	55.469
	20	26	34.271	49.084
0.35	5	21	28.866	43.258
	10	20	33.537	49.034
	15	19	25.657	38.293
	20	17	16.262	24.778
0.40	5	12	41.536	61.995
	10	11	58.499	92.923
	15	13	48.423	72.274
	20	11	39.216	56.165

Table 7

Flow and compressive strength of control samples

w/c ratio	Flow (sec)	Compressive strength (MPa)	
		7-days	28-days
0.30	25	61.628	99.891
0.35	21	50.204	74.932
0.40	12	21	60.913

The compressive strength is highest at a w/c ratio of 0.30 and lowest at a w/c ratio of 0.40. It clearly means that higher w/c ratio reduces the strength of control samples, however, having a high w/c ratio means that its fluidity is more and hence, we got less flow-out times at higher w/c ratios.

Figure 4.2 Block undergoing compressive strength test.

4.3. Statistical Modelling and optimization of grouts

When two or more quantitative elements are considered, Response Surface Methodology, also known as Response Surface Modelling, essentially optimizes the response(s). The independent variables are known as the predictor variables, whilst the dependent variables are known as the responses.

The current study's design, optimization, and statistical modelling were all carried out using the commercially available Design Expert® 11 program. While flow value (Y1) and compressive strength (Y2) indicate the responses, two parameters—water-cement ratio (X1) and pumice stone ash percentage (X2)—were recognized as independent variables that denote the factors. At 7 and 28 days of curing, the responses (flow and compressive strength) were estimated using linear and quadratic models, respectively. Based on a review of the literature, the range of the w/c ratio (0.30 to 0.40) and the percentage of pumice stone ash (5 to 20) were chosen to optimize the w/c ratio and Pumice Stone Ash content to meet the minimal flow requirements and maximum compressive strength. The statistical analysis of components' effects on responses and the validity of proposed models were both done using the ANOVA technique.

Table 7 includes the results of the ANOVA analysis for model and fit statistics to evaluate the importance of well-established models. The significance of the models is denoted by higher F-values and a lower p value (0.05). Furthermore, the adjusted and anticipated R2 differences are both less than 0.2 and the higher R2 value (> 0.80) is also present. As a result, it supports the models' significance and readiness to forecast precise reactions. R2 describes the caliber of the models that have been created. R2 is larger than 0.80, indicating that the models are sound.

Additionally, a lack-of-fit study can be done to determine a model's suitability. A decent model has a smaller lack-of-fit F-value and p-value (> 0.05). From the ANOVA analysis shown in Table 2, it is evident that the models are significant because the F-values are reduced.

The empirical equations (1) through (3) were created based on the real factors (W/C and PSA) to forecast the reactions (flow, compressive strength). The model reduction technique was used to eliminate unnecessary terms.

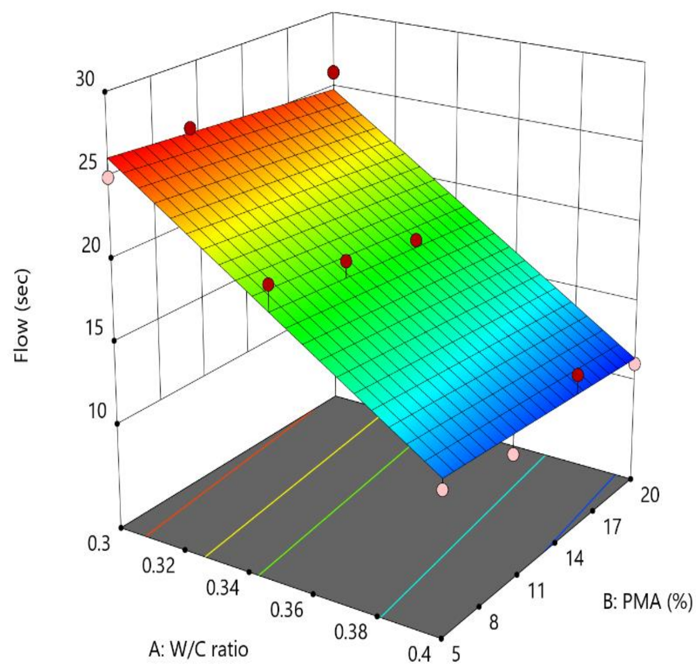
$$Flow = -135.0000(W/C\ ratio) - 0.086667(PSA) + 67.08333 \qquad (1)$$

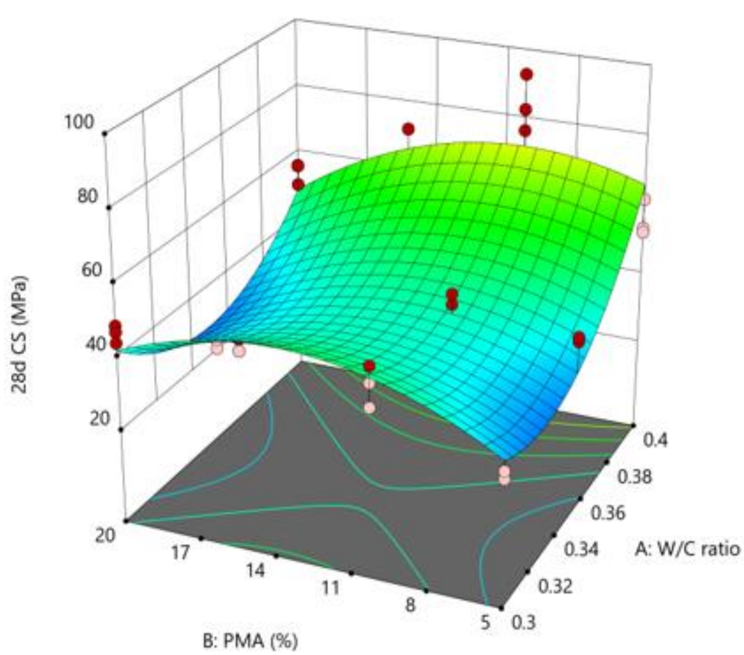
$$CompressiveStrength(7_{days}) = -2867.04274(W/C\ ratio) + 7.83995(PSA) + 4486.22321(W/C\ ratio)^2 - 0.162058(PSA)^2 - 11.31214(W/C\ ratio * PSA) + 460.51963 \qquad (2)$$

$$CompressiveStrength(28_{days}) = -4308.85400(W/C\ ratio) + 11.66330(PSA) + 6743.01630(W/C\ ratio)^2 - 0.236527(PSA)^2 - 17.28267(W/C\ ratio * PSA) + 693.03893 \qquad (3)$$

Table 8
ANOVA analysis and model validation for cementitious grouts

Responses	Flow (sec)	7-days compressive strength (MPa)	28-days compressive strength (MPa)
Standard Deviation	1.08	5.71	8.59
Mean	18.75	32.22	48.03
R^2	0.9660	0.7488	0.7453
Predicted R^2	0.9595	0.6350	0.6347
Adjusted R^2	0.9639	0.7069	0.7029
Adequate Precision	47.2817	12.4583	12.4299
F- value (model)	468.61	17.88	17.56
p- value (model)	<0.0001	<0.0001	<0.0001
Model	Significant	Significant	Significant
Lack of fit (F and p-values)	N/A	Significant (F- value = 14.75, p-value < 0.0001)	Significant (F-value = 10.64, p-value < 0.0001)
Final Model Type	**Linear**	**Quadratic**	**Quadratic**


Flow (sec)
30
25
20
15
10
0.3
0.32
0.34
0.36
0.38
0.4
A: W/C ratio
5
8
11
14
17
20
B: PMA (%)


28d CS (MPa)
100
80
60
40
20
20
17
14
11
8
5
B: PMA (%)
0.3
0.32
0.34
0.36
0.38
0.4
A: W/C ratio

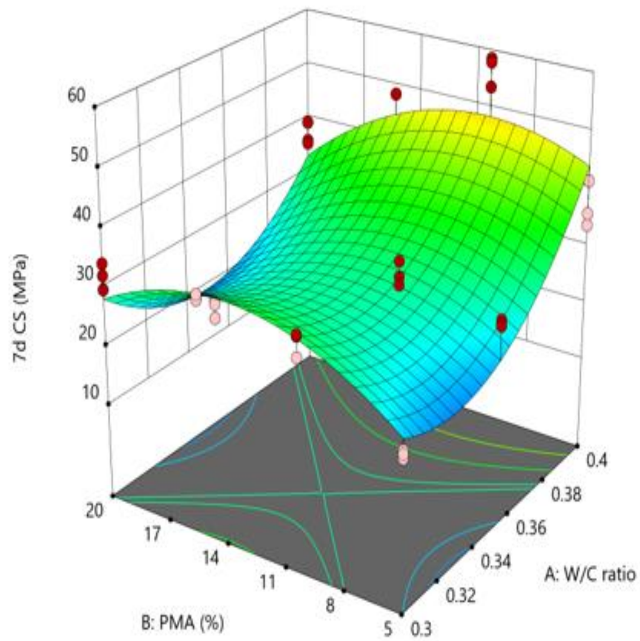
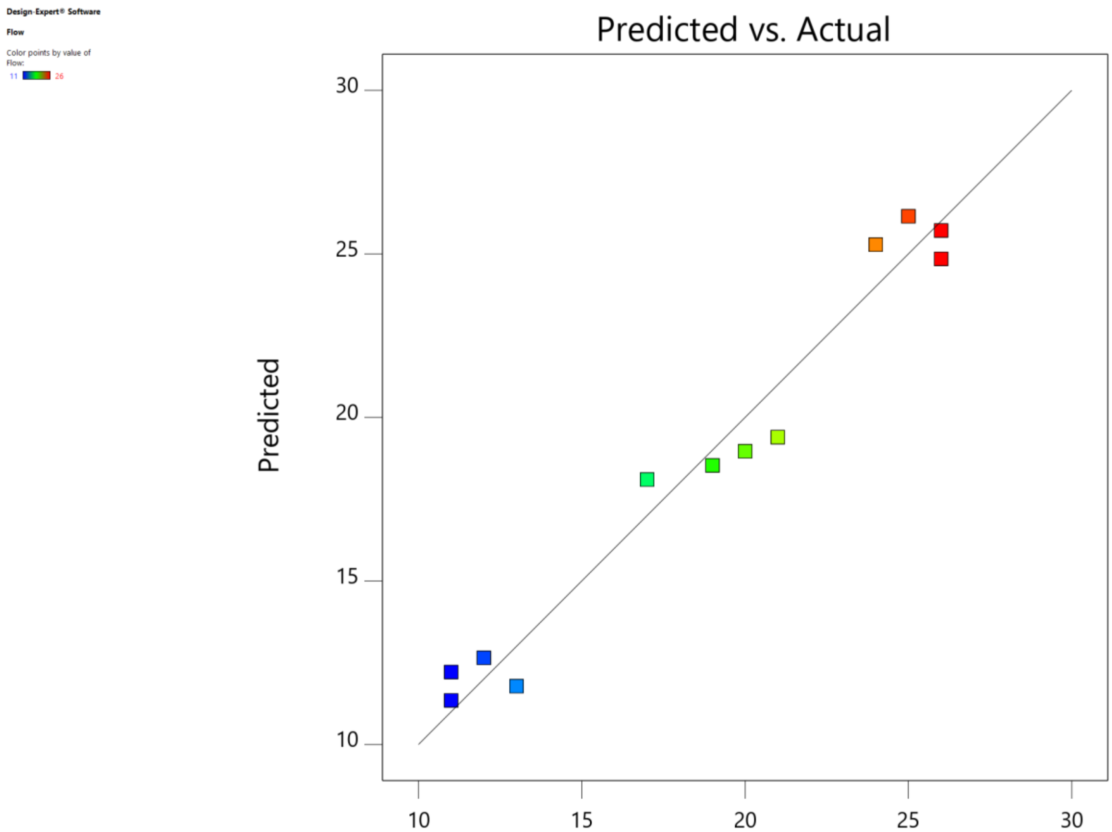


Figure 4.3 Effect of PSA and W/C ratio on (a) flow, (b) 7-days compressive strength and (c) 28-days compressive strength


Design-Expert® Software
Flow
Color points by value of Flow:
11
26
Predicted vs. Actual
Predicted
30
25
20
15
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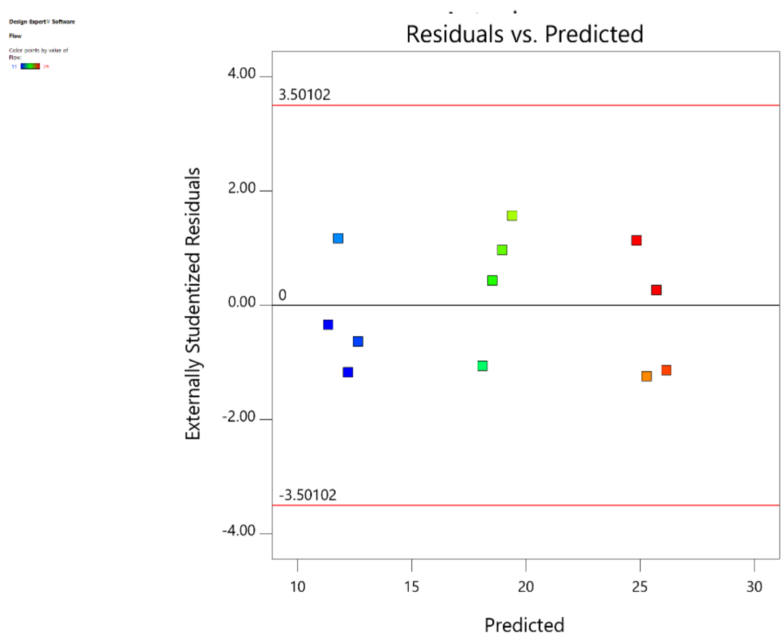
30


Residuals vs. Predicted
Externally Studentized Residuals
4.00
2.00
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-4.00
3.50102
0
-3.50102
10
15
20
25
30
Predicted

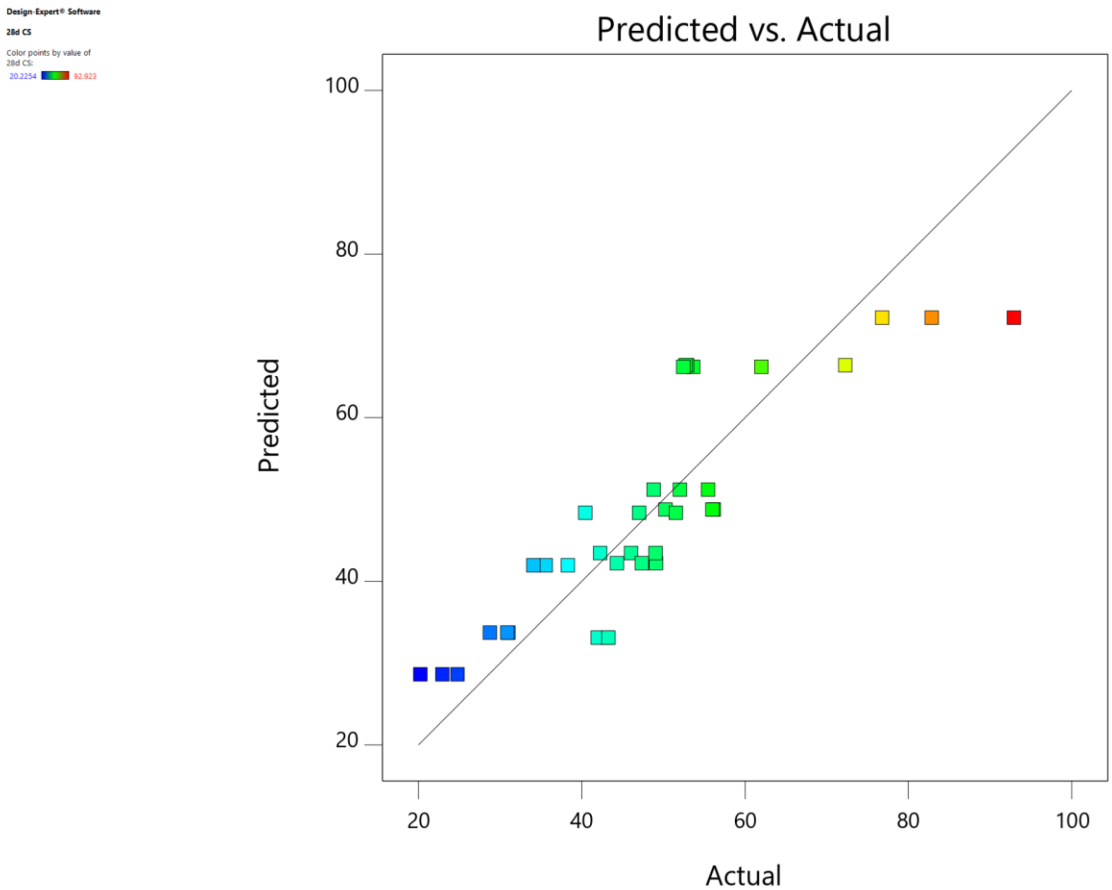

Figure 4.3 (d) Predicted vs Actual values of different factors

4.4. Results of Fuel Resistance Test

Parameters "A" and "B" were used to compute the mass loss of specimens of open-graded asphalt and HMA. Mass loss from fuel and abrasion are represented by parameters A and B, respectively. The semi-flexible combinations demonstrated significant resistance to diesel while having a low mass loss, in contrast to the HMA mixtures, which had significant mass loss. Like semi-flexible mixtures, the mass loss from abrasion of HMA mixtures, which is represented by Parameter B, is likewise substantially greater.

Figure 4.4 (a) Marking of specimens (HMA) before submerging them into diesel.

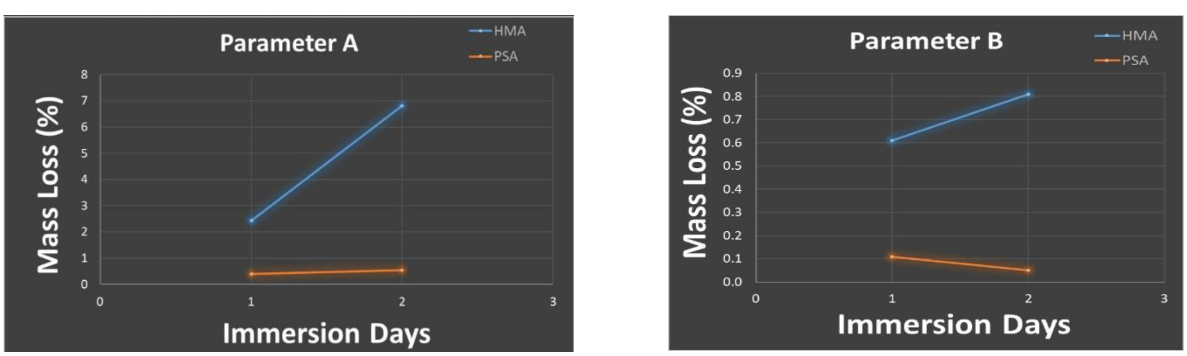

Figure 4.4 (b) Graphs showing results of parameters A and B

4.5. Results of Marshall Stability Test

Semi-flexible mixes' stability was assessed and contrasted with HMA's. It makes sense that semi-flexible mixtures, when compared to HMA, have a substantially greater Marshall stability value. The stability of the dense graded HMA was 16.72 kN, while for semi-flexible mixes, this value improved by 146–156%. When compared to HMA combinations, cement grout's contribution to semi-flexible mixtures contributes to an increase in stability. Although this analysis was done for comparison purposes, there are currently no known design stability criteria for semi-flexible pavement surfacing materials. According to additional research, semi-flexible mixtures have stability values that are more than twice as high as those produced from HMA mixtures.

Figure 4.5 (a) Machine showing Marshall Stability Test machine.

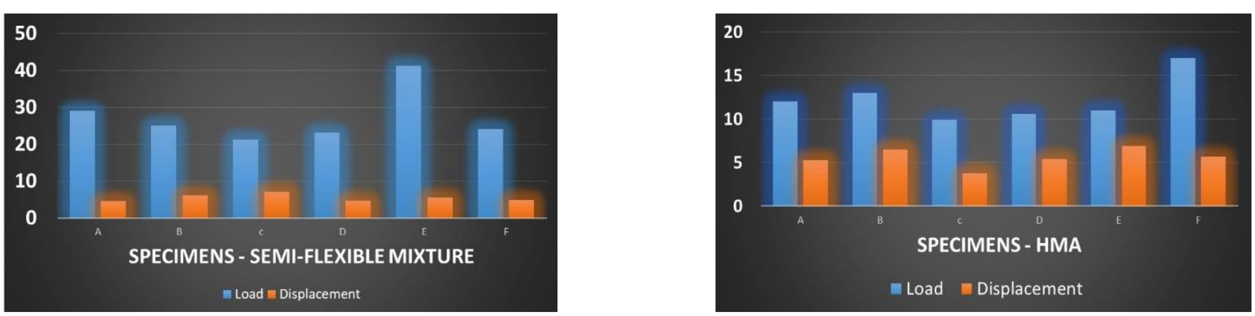

Figure 4.5 (b) Graphs showing results of Marshall Tests

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In this study, the performance and resistance to fuel of semi-flexible pavements built with the best cementitious grout were assessed, and comparisons were established as a result. Additionally, their performance was completed using the traditional HMA combinations. It can be inferred from papers on semi-flexible pavements that this kind of pavement can result in a high-performance pavement surface. The study's key conclusions are listed below.

- The open-graded asphalt mixture's measured voids fell within the design range, or 28%, and met the standards for semi-flexible pavements.

- The resistance of semi-flexible pavements to fuel leakage is one of their most distinctive uses. Semi-flexible pavements performed better in the current investigation while partially submerged in diesel. HMA specimens, however, displayed weak fuel resistance. Diesel oil has hardly any impact on semi-flexible combinations.

- It can be concluded that the durability and performance properties of Semi-Flexible Pavements largely depend on the mix design of the porous asphalt skeleton and composition of cementitious grouts. The selection of aggregate gradation and type of Bitumen play a vital role.

- The grouts created are required to be highly flowable to penetrate the porous asphalt skeleton. A flow-out time of 11 to 16 seconds is recommended while using a flow cone as per ASTM C939 standard. Superplasticizer (1%) is used to achieve high fluidity at a relatively low w/c ratio (0.30 to 0.35). Pumice Stone ash is used to achieve medium-to-high-strength grouts and hence, medium-to-high-strength Semi-Flexible Pavements alongside the sustainability goals. Pumice Stone Ash up to 20 percent can be used to replace cement, while achieving the desired strength properties.

- The performance of cementitious grout is closely related to the performance of Semi-Flexible Specimen. Therefore, the grouts are carefully designed to produce high performance Semi-Flexible Pavement surfaces.

5.2. Recommendations

The following points are being recommended from this FYP project.

- Numerical analysis can be performed to simulate the wider spectrum of material combinations in relation to the mechanical performance of semi flexible pavement surfaces using advance software (for e.g changing the superplasticizer percentages as well).

- Field verification can be conducted to study the life cycle cost as well as to investigate the performance against traffic and environmental stresses.

- Furthermore, the serviceability and distresses can be evaluated during this field verification period and proper maintenance procedures can be outlined accordingly.

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