BE CIVIL ENGINEERING

PROJECT REPORT

Design, Analysis and Optimization of Bentonite based Cementitious Grout for Semi-Flexible Pavement

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, Analysis and Optimization of Bentonite based Cementitious Grout for Semi-Flexible Pavement

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BE CIVIL ENGINEERING DEGREE

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DEDICATION

Dedicated to our parents, siblings, our instructors at MCE who have guided us during the course of this research and our great institution MCE where we have spent the four most memorable years of our life.

DECLARATION

It is hereby declared that all the work carried out for this final year design project was performed by us and it has not been submitted by any institution, in whole or in part in any previous application for a degree. Any references to the work done by any other person, University or material used from other publications have been appropriately cited.

ACKNOWLEDGEMENTS

First of all we thank ALLAH ALMIGHTY who enabled us to complete our degree leading to the culmination point in the form this project. We would also like to give our profound gratitude to our project advisor AP Dr Imran Khan whose 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 all have provided us with valuable information and advice during the course of completing the lab component of the project. We would like to thank our peers who gave us their opinions 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

Many leaders in the construction industry are considering newer environmentally friendly (green) and economically viable ways to produce concrete as a result of the growing threat of global warming and the high cost of raw materials for the production of cement, which is generally regarded as the second most used material in the world after water. Pavement construction makes an effort to endure environmental factors and traffic loads over the course of its design life. Semi-flexible pavement may be a better option to address the drawbacks of rigid and flexible pavements. Open-graded asphalt mixture with 20 to 35% voids makes up the semi-flexible pavement surface, which is then covered with highly flowable cementitious grouts for infiltration. In the current investigation, customized cementitious grouts were created by substituting bentonite (10 to 40%) for cement with a changing water to cement ratio (0.30 to 0.40). The grouts were subjected to flow test, 7-days and 28-days compressive strength and were analyzed using “Response Surface Methodology (RSM)”. The compositions were also optimized using RSM, which were concluded to be 22% Bentonite and 0.40 w/c ratio. The optimum composition of grouts was then utilized to prepare grouts and poured into the voids of open-graded asphalt mixture specimens. The semi-flexible specimens were tested for Marshal Stability and Fuel resistivity tests. HMA specimens were also prepared for comparing with semi-flexible. The results indicated that semi-flexible showed superior performance in terms of Marshall Stability and fuel resistance. Moreover, partially replacing Cement with Bentonite will also leads to sustainability in pavement construction.

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INTRODUCTION

1.1 Overview

After water, concrete is usually recognized as the material that is used most commonly on earth. Cement is a primary source that can be used as a bidding agent in typical OPC concrete. Ordinary Portland cement concrete is associated with a number of environmental risks (OPCC). Burning conventional hydrocarbons and calcining lime are required for OPC manufacture, which results in large carbon dioxide emissions (CO2). According to current estimations, one ton of fuel is needed to produce one ton of OPC. Only aluminum and steel require more energy to make than OPC.

Bentonite is clay that mostly consists of smectite minerals and is frequently created by the breakdown of volcanic ash or tuff, though it can also occasionally come from other igneous or sedimentary rocks. Bentonite is an extremely plastic clay that significantly shrinks (or swells) in reaction to the removal (or addition) of water.. Due to this, numerous research have been conducted on the idea of using bentonite instead of OPC as the primary binding agent in concrete to lessen the strain on the environment.

As a fuel and abrasion resistant surface, Salviacim was the first semi-flexible pavement built in France in the 1950s. Grouted Macadams were used extensively in the 1970s and 1980s throughout North America, numerous African nations, and much of Europe. The University of Nottingham conducted research on Hardicrete in 1979 to develop a heavy-duty road surface. It was made up of open-graded bituminous Macadam that was normally laid and completely grouted with high fluidity resin. Further investigations (conducted by BLIGHT, TARMAC, AL-QADI) have demonstrated that Salviacim and RMP materials perform well in respect to impact loads and oil/chemical/fuel spillage, according to Anderton (2000).

The building of RMP can be separated into two 5-year periods up until the year 2000. The United States ran experimental initiatives and small-scale projects from 1987 through 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. Nonetheless, reflecting fissures were discovered in a number of places. In Denmark, a new generation of unique slurry grout was developed in the late 1980s, bringing Semi Flexible Pavements with tremendous potentials for very heavy loads. There were two improvements made to the grated macadam’s of this generation.

Secondly, a higher percentage of total voids was obtained by optimizing the open-graded asphalt concrete. Second, a brand-new high-performance slurry grout that was better able to penetrate the open-graded asphalt's void structure. More recently, Setyawan (2003) investigated numerous grouted macadam kinds with different types of binders.

1.2 Bentonite Based Concrete

A type of naturally occurring pozzolan known as bentonite is known to enhance the mechanical qualities of cementitious materials and lower the overall CO2 output of the cement manufacturing process. This project substitutes bentonite for traditional cement as a binding agent. Bentonite is employed, like OPCC, to bind non-reacting fine and coarse aggregates that are present in loose form, with or without admixtures.

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1.3 Problem Statement

- Concrete needs cement as a key component. The production of cement uses a lot of energy, and it has been determined that 0.9 pounds of CO2 are emitted into the atmosphere for every pound of cement produced.
- Due to a number of variables, including the price of fuel, the cost of power, and the availability of raw materials, cement prices fluctuate significantly on the market.
- Construction of rigid pavements and their introduction to traffic typically take longer. because of how slowly concrete sets. Due to its rough riding characteristics and lack of joints to relieve thermal strains, stiff pavement is also avoided.
- Leaders in the industry believe that alternative sources of concrete production are necessary to counteract the high costs associated with depending on a single material (cement).

1.4 Objectives of Project

The objectives envisioned for the projects were as follows:

- To examine the efficacy of **Cement Grout containing Bentonite** for use in **Semi-Flexible Pavements.**
- **To analyze and optimize the** composition of bentonite based grouts Bentonite-based grout utilizing **Response Surface Methodology (RSM).**
- **To evaluate the** performance of Semi-Flexible Pavement having bentonite based cement grouts.

1.5 Sustainable Development Goals

The following sustainable development goals adopted are:

- SDG-9 : Industry, Innovation and Economic Growth
- SDG-11 : Sustainable Cities and Communities
- SDG-13 : Climate Action

CHAPTER: 2

LITERATURE REVIEW

2.1 Types of Pavements

The two primary types of pavement building techniques are rigid pavement (one layer) and flexible pavement (usually numerous layers).But pavements can be classified into four categories which are as follows:

- Flexible Pavement
- Rigid Pavement
- Composite Pavement
- Semi-Flexible Pavement

2.1.1 Flexible Pavement

For the creation of flexible pavements, bituminous material is employed. The layers can be constructed using a wide range of bituminous combinations. 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. Via the lateral distribution of the load, the stress/load is transferred to the lowest layer, which is the subgrade. The foundation, which consists of Capping and Sub-base, is often built of granular materials. The surfacing layers are made of bituminous materials; the base may be bituminous or granular.

Asphalt comprises the bulk of the bituminous material. According to the temperature at which it is applied, asphalt is categorized into three categories: hot mix asphalt, warm mix asphalt, and cold mix asphalt. 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. Moreover, it can be utilized to keep the subgrade from freezing. There are two types of bituminous mixes: asphalts and macadam’s. The ratio of mortar to coarse aggregate in asphalt is high, and there are many spaces between the individual particles of coarse aggregate. Gap graded mixtures are this kind of mixture. Several aggregate sizes are used to create constantly graded macadam’s.

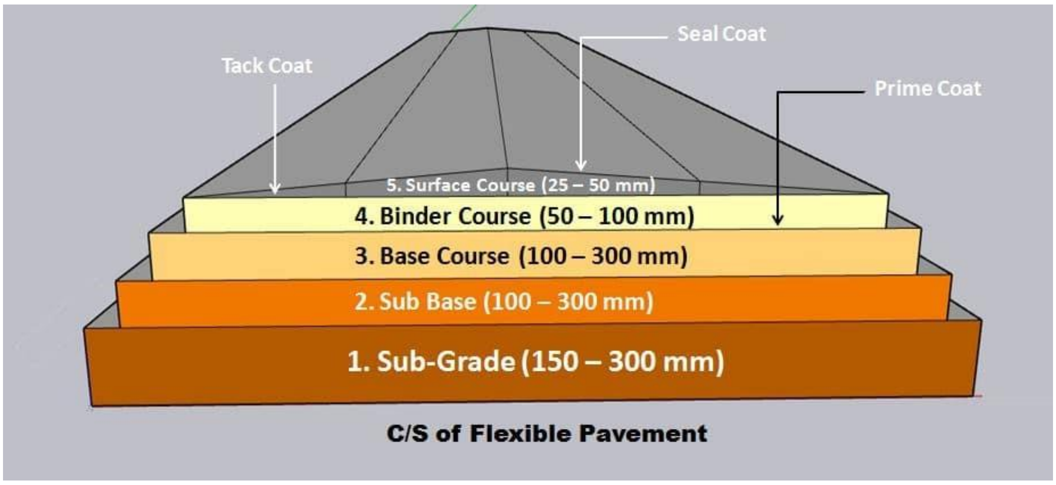


Figure 1 : Flexible Pavement Layers

Figure 2 : Flexible Pavement

2.1.2 Rigid Pavement

The concrete slab and the sub-base are the two structural components that make up rigid pavements. An adequately strong structural cement concrete slab serves as the basis for rigid pavement designs. Because of the way that slab movement distributes the weight, rigid pavements behave like an elastic plate resting on a viscous medium. 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. You can have reinforced or unreinforced concrete slabs.

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. Wheel weight is transferred to the subgrade by slab action from the pavement.

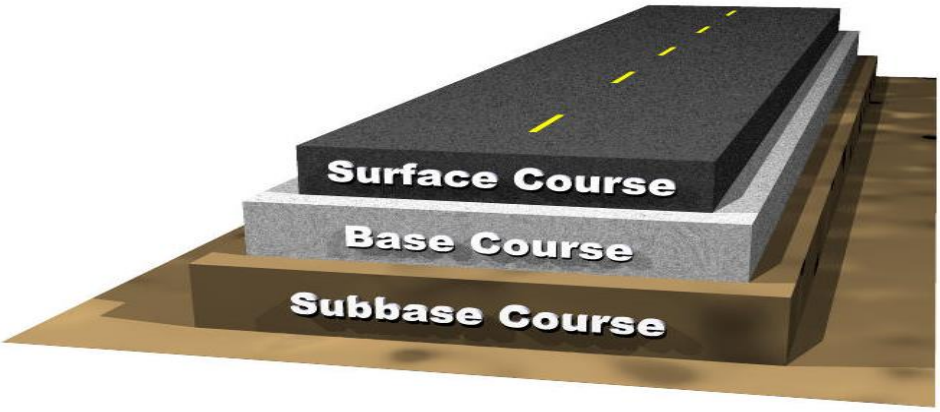


Figure 3 : Rigid Pavement Layers

Figure 4 : Flexible Pavement Layers

2.1.3 Composite Pavement

Composite structures are also referred to as semi-rigid or flexible composite structures in various countries. These pavements have commonly been employed on roads with high traffic volumes, heavily loaded vehicles (resulting in high ESALs), and where the designer aimed for the pavements to possess a long lifespan and require minimal maintenance (such as replacing worn-out surfaces). There is a strong desire to have durable pavements with excellent serviceability and quick, cost-effective maintenance operations, particularly for high-volume, high-priority corridors. Composite pavement constructions can provide these advantages. For instance, hot-mix asphalt (HMA) fatigue cracking, subgrade rutting, Portland cement concrete (PCC) erosion, and PCC loss of friction are all structural and functional challenges that are frequently encountered in flexible or rigid pavements. Composite pavements address these issues and many others. The reflective cracking and rutting of the HMA layer are two problems that composite systems may be more susceptible to. Premium HMA surfaces or techniques to mitigate reflective cracking may be necessary to tackle these potential issues.

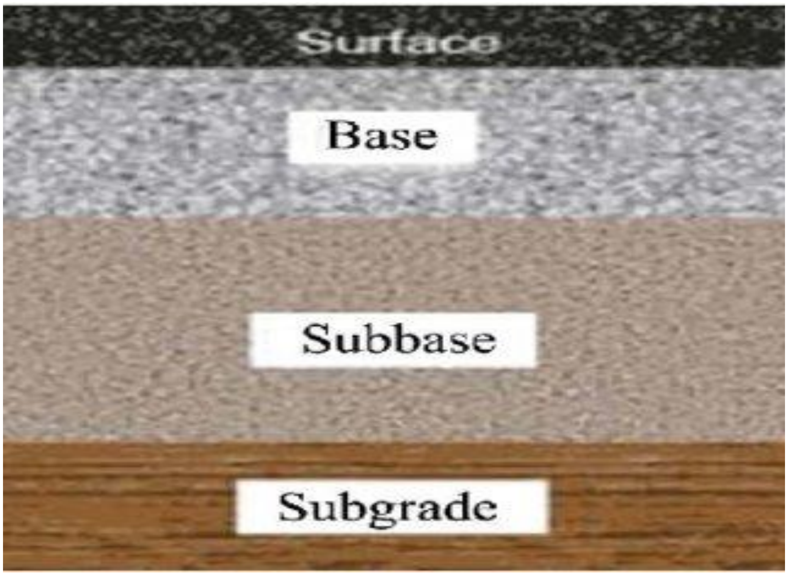


Figure 5 : Composite Pavement Layers

2.1.4 Semi-Flexible Pavement

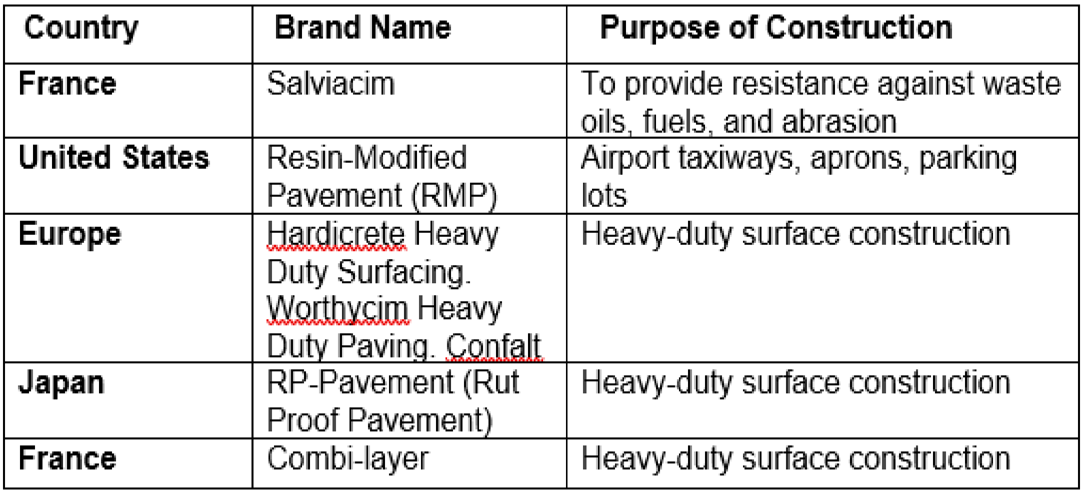
Pavements called grouted macadam or semi-flexible pavements combine the advantages of two different kinds of building materials into a single layer. In order to create a semi-flexible layer capable of supporting heavy loads, a top layer is made of a very open graded asphalt concrete mixture filled with a modified cementitious grout. The aggregate grading of the porous asphalt, bitumen characteristics, and cementitious grout properties all have an impact on the mechanical capabilities of a grouted macadam. The porous asphalt mixture used to create the asphalt concrete has 25% air gaps in it. If the air void content is too high, the pavement will function as a concrete slab; if it is too low, some voids may not be filled with cementitious grout. Flexibility and joint/rigidity freedom are two of the best qualities of concrete and asphalt combined in the final product. Grouted madams exhibited much superior stability, durability, and strength than regular pavements, according to laboratory research. A significant amount of the air voids in semi-flexible pavement must be filled with grout. Because it is required to cool the asphalt layer before pouring grout into its pores, the building of grouted macadam is a two-stage process. To avoid crack development, the asphalt layer is generally pored with an asphalt paver and then compacted with a steel roller. The spaces can be filled with cementitious grout as soon as it cools. Depending on the powder type used to form the grout, a light steel roller in vibration mode may be employed to ensure that all voids have been filled with the grout. When the grout has been filled, the surface can be treated to increase its attributes such as durability. The formulation of cement grouts to provide fluidity and strength is the key factor in grouted macadam's. They must be fluid enough to fill the spaces. With a low w/c ratio, the inclusion of a poly carboxylate superplasticizer can improve fluidity and strength. Because the usage of Ordinary Portland Cement (OPC) in grouted macadam's emits greenhouse gases and harms the environment, there is a need to produce sustainable cement grout. One method for lowering emissions is to substitute cement with wastes such as plastic and other byproducts. Grouts have a vital part in pavement performance. The mechanical qualities of grouted macadams vary depending on the mix design of porous asphalt and grout. Another benefit of semi-flexible pavements is that they build strength quickly and take less time to attain final layer qualities. This sort of road may be opened to traffic in two to three days.

Figure 6 : Semi-Flexible Pavement

2.2 History of Semi-Flexible Pavement

During the early stages of creating semi-flexible paving surfaces, researchers and organizations assigned different names to the same construction and operational concepts. To develop a surface that was resistant to fuel and abrasion, Salviacim, the first semi-flexible pavement, was constructed in France in the 1950s. In the 1970s and 1980s, the construction of semi-flexible pavements expanded to North America, the South Pacific, the Far East, various African countries, and Europe. Table 1 illustrates the history of semi-flexible pavement development and its utilization. The open-graded asphalt mixture (or porous asphalt mixture) employed for surfacing semi-flexible pavements incorporates cementitious grout infused into the voids. As a result, the construction process is carried out in two phases. The porous asphalt layer is lightly compacted during construction and allowed to cool. Then, the pre-designed cementitious grout is applied and allowed to infiltrate the surface. To ensure thorough penetration of the grout, a light vibration application with a steel roller may be employed. The primary considerations include the formulation of cement grout compositions, the selection of appropriate aggregate gradation, the mix design of porous mixtures, and so forth.

Table 1: Development and Purpose 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

2.3 Design Philosophy of Stress/ Strain Distribution in Flexible and Rigid Pavements

Pavement design philosophy differs significantly from those of other civil engineering constructions (reinforced concrete structural parts, steel structures, etc.). It is expected that there will be some distresses in the form of cracks," roughness, or permanent deration throughout the pavement structure's service life. A multi-layered elastic system is typically utilized in the design of flexible pavements, with the materials in separate layers characterized by qualities like as elastic modulus, resilient modulus, and the Poisons ratio. The strata above sub-grade is presumed to be finite in the vertical direction and unlimited in the horizontal direction during the design phase. Figure 7 depicts the stress distribution in the flexible pavement when a wheel load is applied. Vertical stresses are compressive in nature, are greatest right under the wheel load, and tend to diminish as the depth of the pavement structure increases. As indicated in Figure 7, the vertical strain caused by these loads at the top of the subgrade is responsible for persistent deformation (rutting). As a result, the vertical strain at the subgrade surface is taken into account in the design of flexible pavement based on running requirements.

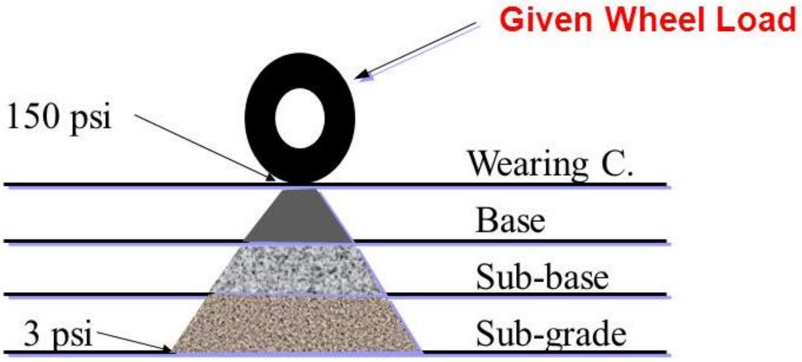


Figure 7 : Stress Distribution in Semi-Flexible Pavement

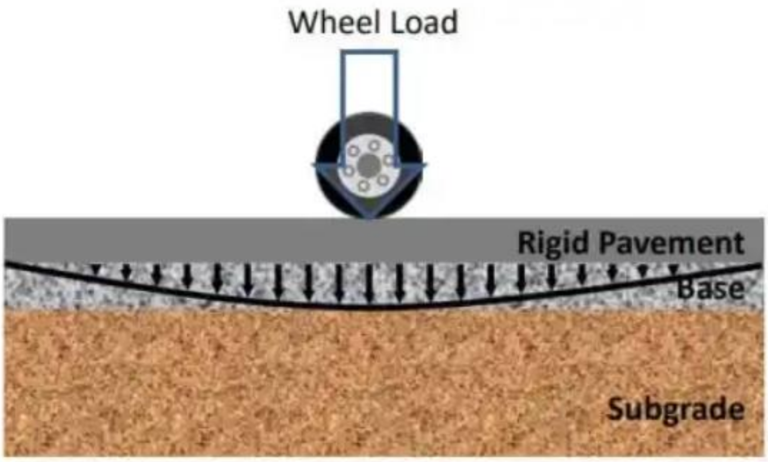


Figure 8 : Stress Distribution in Semi-Flexible Pavement

2.4 Why Semi-Flexible Pavement an Alternate Choice?

Semi-flexible pavements were developed on the concept to combine the advantage of both flexible and rigid pavements Additionally, the aim was to address the drawbacks that rigid and flexible pavements typically have. Table 2 shows the benefits of semi-flexible pavements over traditional flexible and stiff pavements. Comparison of stiff and flexible pavements with semi-flexible pavement in Table 2

Table 2: Semi-Flexible in Comparison with Flexible and Rigid Pavements

Type	**Advantages**	**Disadvantages**
Flexible Pavement	Low Initial Cost Good riding quality Flexible Joint less Easy Maintenance	Low durability and relatively short life Rutting, Fatigue failures Poor resistance to fuel High maintenance cost
Rigid Pavement	High bearing capacity Longer service life High durability and long design life No Rutting	High Initial Cost Rough riding and noisy surface Joints in pavement Extended construction time
Semi-Flexible Pavement	Joint less High Strength Improved durability Extended service life High bearing capacity Good fuel resistivity	Constructed in two stages

2.5 Effects of Concrete on Environment

Carbon trading entails the purchase and sale of carbon permits and certificates. Carbon trading is an important control mechanism for several businesses, like the cement industry, to reduce greenhouse gas emissions, which cause an increase in global temperature, resulting in climate change. These trading systems are used to incentivize companies to cut emissions in order to reach long-term objectives for the benefit of the world. "It is anticipated that one ton of CO2 emissions has a trade worth of around US $10." (V. Malhotra, 1999)

Cement output is increasing at a rate of roughly 3% per year (Mccaffrey, 2002). "With the manufacture of one ton of cement, about one ton of carbon dioxide (CO2) is discharged into the environment." OPC production is responsible for around 7% of world greenhouse gas emissions, or 1.35 billion tones. OPC, along with steel and aluminum, is one of the most energy-intensive construction materials.

The concrete industry is aware of these problems. As an illustration, take "Vision 2030: A Vision for the United States Concrete Industry." The article states that "concrete engineers are faced with the challenge of guiding future growth in a way that safeguards environmental quality while promoting concrete as a construction material of choice." We must adequately address climate change brought on by rising greenhouse gas concentrations. This vision effectively outlines opportunities for concrete to continue to be a popular building material for infrastructure projects while also becoming an environmentally friendly material.

2.6 Constituents of Semi-Flexible Pavement

The semi-flexible pavement surfacing is composed of an open-graded asphalt mixture (or porous asphalt mixture) injected with cementitious grout.As a result, the building was completed in two parts. Light compaction is used to build the porous asphalt layer, which is then allowed to cool. The pre-designed cementitious grout is placed to the surface and allowed to penetrate. To ensure that grouts are properly permeated through the depth, a gentle application of a steel roller with vibration can be used. The essential parameters to consider are the selection of acceptable aggregate gradation and mix design of porous mixes, as well as the formulation of cement grout -compositions.

2.6.1 Open Graded Asphalt Mixture

When creating porous asphalt mixes, open-graded asphalt gradation frequently uses single-sized gravel. For semi-flexible pavement paving, air spaces in porous asphalt mixtures must typically range from 25 to 35 percent. The aggregates used in porous asphalt mixtures need to be durable, reliable, and strong. On how well the final mix attributes perform, a lot depends on the aggregate gradation that is selected. On the basis of nominal aggregate size and the percentage passage of coarse particles, some of the aggregate gradations suggested in the literature for open-graded asphalt mixes used for semi-flexible paving surfaces are shown in the gradation chart With a small amount of fines, single-size aggregate in the 10–14 mm range can offer enough porosity in mixes, allowing the cement slurry to flow freely because of the connected voids. However, because to void interconnectivity and high porosity, the general goal is to establish a target air void level of 25–35% in the mixture, which will make it easier for grout to penetrate quickly..

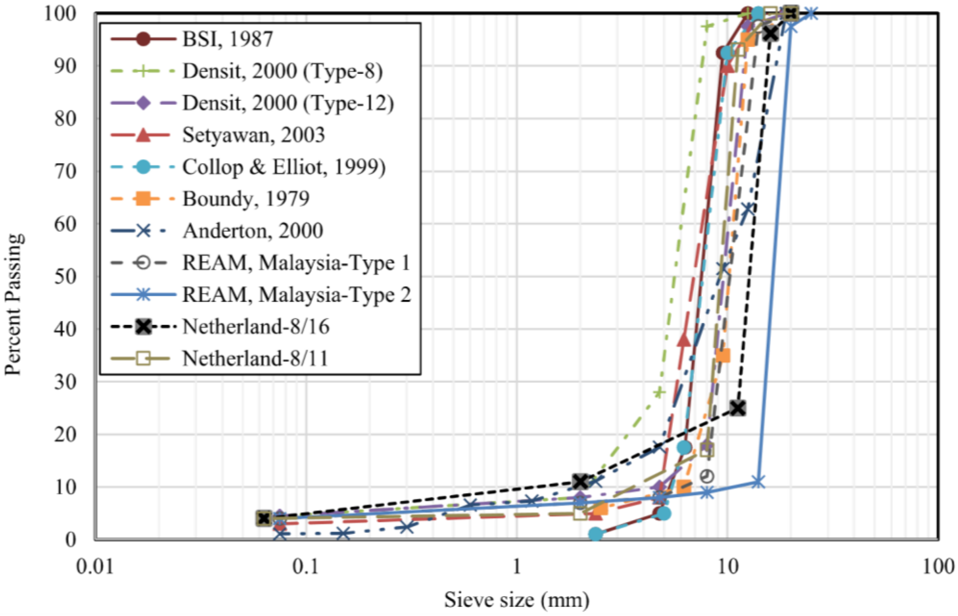


Figure 9 : Aggregate Gradation used in various Studies

Table 3 : Final Criteria for Porous Aggregate Gradation

Gradation	**Drain down (%)<0.30**	**Air Voids (%) > 25%**	**VCA ratio < 1**	**Permeability (m/day) > 100 m/day**	**Cantabro Loss (%) < 50%**	**ITS (kPa)**
BSI with 4% bitumen	0.30	33.05	0.95	362.90	33.20	113.35
Densiphalt – 12 with 4% bitumen	0.19	33.56	0.93	332.90	34.91	114.42
Denisphalt – 12 with 4.5% bitumen	0.30	32.08	0.+91	247.69	34.91	136.80

2.6.2 Cementitious Grouts

The creation of semi-flexible pavement surfacing relies heavily on cementitious grout. It makes the top layer more durable, strong, and impenetrable. The cementitious grouts must be extremely flowable in order to thoroughly permeate the open-graded asphalt mixture. Cement, water, superplasticizer, admixtures, and/or other substances that cement can all be found in grout. Superplasticizers and other admixtures are needed to increase the strength and flow of grouts in order to achieve the desired effects. In order to endure the pressures and strains created, the cementitious grouts must likewise be strong enough. The cement paste and mortars used in the concrete industry are distinct from the grouts used for semi-flexible pavement surfacing in terms of design and formulation. An open-graded asphalt mixture's voids can be easily penetrated by the grout ingredients because to their design. Additionally, the grouts must be resilient enough to withstand environmental and traffic-related stresses. In order for semi-flexible pavement surfacing to function properly, cement grout's flow ability (fluidity) and strength are essential. The air spaces in open-graded asphalt mixes will not be adequately filled if cement grout's fluidity is insufficient. As a result, the anticipated semi-flexible mixtures would be weak and short-lived. Grout fluidity is frequently assessed using a flow cone, where the geometry of the particular cone determines the flow-out time. Ordinary Portland cement (OPC), water (in different ratios), sand, fillers, and other supplementary cementing agents (such fly ash and silica fume) are widely used in the production of cement grouts for semi-flexible paving surfaces. Additionally, a superplasticizer can be used to boost fluidity at low w/c ratios. The components of cement grouts for semi-flexible pavement paving have been the subject of numerous studies.

2.7 Design Parameters for of Cementitious Grouts for Semi-Flexible Pavements

The composition of the grout has a significant impact on the mechanical and physical properties of cement grouts. It is important to analyze the grouts' flow properties, drying shrinkage, compressive strength (at various curing ages), and flexural strength prior to their application in creating surfacing for semi-flexible pavements. The ability of cement grout to flow (or fluidize) into the depth of the porous asphalt surface layer without excessive compaction and vibration is one of these characteristics that should be carefully assessed. The compressive strength of the grout is the second crucial aspect to consider as it greatly influences the final strength and durability properties of a semi-flexible mixture

2.7.1 Flow ability

When creating cementitious grout compositions for semi-flexible pavement surfacing, flow or flow ability of grouts is a major challenge. To quickly saturate the crevices of the porous asphalt skeleton, the grout must have a suitable flow rate. The superplasticizer, w/c ratio, and other additives and cementing materials all affect how fluid grouts are. In the past, flow ability and fluidity have been measured using the flow-cone instrument. The necessary volume of grout is poured, and it is timed in seconds to see how long it takes for the grout to exit the flow cone. The greater the flow period, the less fluidity or capacity to flow there is. Conversely, a quicker time for grout to flow out suggests that cement grout has an excellent ability to flow The size and design of the die flow-cone, however, dictates the standard requirement for cement grout flow-out time. Three different flow cones—the Malaysian, the Marsh, and the ASTM—are utilized in the literature. Figure shows a schematic illustration. Using a Malaysian flow-cone, the flow-out time for 1000 ml. of grout should be between 11 and 16 seconds. SFP surface can be grouted with cement grouts that have a flow rate of 11 to 16 seconds since they are sufficiently fluid. Likewise, 1000 cc of grout is required for the Marsh flow-cone; however, due to the change in shape, the flow-out duration should be between 8 and 10 seconds. However, the flow cone used in ASTM C939 has a different shape as well as a different flow-out time requirement. The recommended flow-out time of cement grout is 11 to 16 seconds while enabling 1725 mL of grout to run off the funnel, according to the standard.

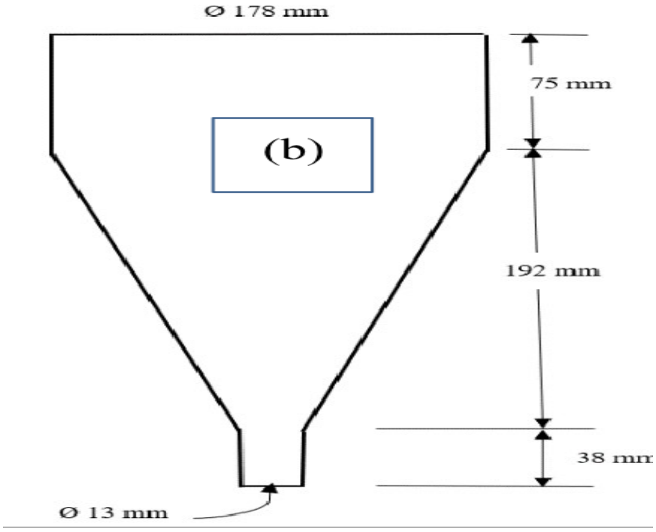


Figure 10 : ASTM Flow Cone

2.7.2 Compressive Strength

When selecting cement grout for SFP surfacing, the compressive strength of grouts becomes the second most important factor to consider. The water-to-cement (w/c) ratio, along with additional cementitious components and additives, significantly influences the compressive strength. Fly ash, silica fume, ground granulated blast furnace slag (GGBS), gypsum, and mineral powders have all been utilized in the development of cement grouts suitable for SFP surfacing requirements. According to Zhang et al. (2016), the compressive strength at 7 and 28 days exhibited a significant decline as the w/c ratio increased from 0.48 to 0.63. Conversely, flexural strength showed a slight decrease. To address this, the use of additional admixtures and cementing additives such as calcium carbonate is necessary. Superplasticizers, fly ash, silica fume, and bentonite can all help enhance the strength properties at a low w/c ratio while maintaining the required flowability. By combining silica fume with a superplasticizer, grouts with sufficient fluidity and strength for semi-flexible pavement paving can be achieved. Thus, a recommended composition would be silica fume with a

5% replacement and a polycarboxylate-based superplasticizer at a w/c ratio of 0.30. This grout demonstrates a flowability of 15 seconds (as measured by Malaysian flow cone) and a compressive strength of 92.5 MPa after 28 days. Such a grout can be recommended for high-traffic semi-flexible pavement surfaces that demand high-strength cement grouts. Additionally, commercially available cement grouts specifically designed for semi-flexible pavement surface applications are accessible, such as those offered in Canada, the UK, and other countries. However, the exact composition of some cement grouts remains unclear.

CHAPTER: 3 RESEARCH METHODOLOGY

3.1 Methodology

The First Phase describes the collection of materials and the study of their basic characteristics. The Second Phase focuses on the production of cementitious grouts, performance evaluation, morphological characterization, and eventually determining the optimal combination of grout compositions. The experimental design, analysis, and optimization of cementitious grout formulations were carried out using response surface methodology (RSM), an experimental design and analysis approach. Preparing and testing semi flexible specimens for grouting ability, Marshall stability, and fuel resistance is the fourth process. The next sections go through the specifics of these four steps.

3.2 Materials used in this Study

For our project, the following materials were obtained from various vendors / places.

3.2.1 Bentonite

Bentonite is frequently created when volcanic glass (obsidian, rhyolite, and deceit) found in the ash is converted (devitrified) into clay particles by weathering in seawater or by hydrothermal circulation through the porous nature of volcanic ash deposits.

Figure 11 : Bentonite

3.2.2 Fine Aggregate

We used the fine aggregates made accessible in the concrete laboratory in this investigation. These aggregates had a loose bulk density of around 1600 kg/m3. The fine aggregate sieve analysis is provided below.

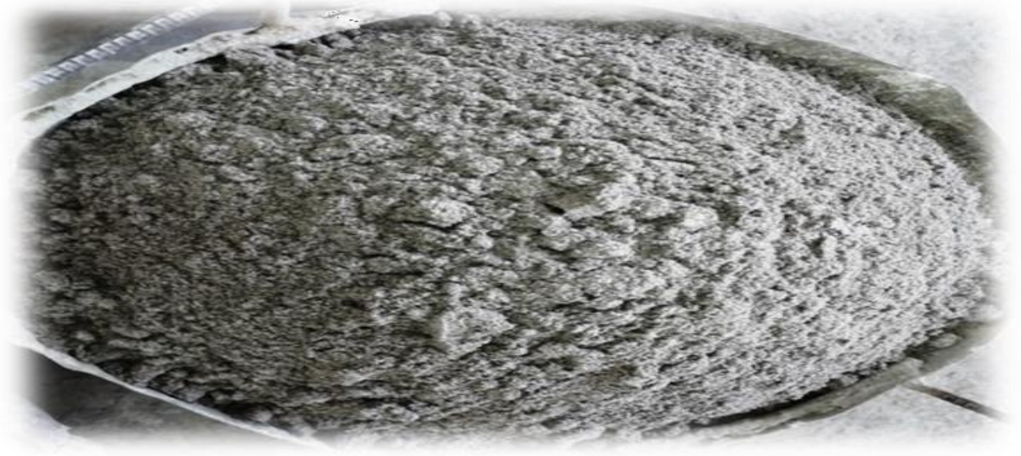


Figure 12 : Fine Aggregates

Table 4 : Sieve Analysis of Fine Aggregate

Sieve No.	**Weight retained**	**% Retained**	**Cumulative % Retained**	**% Passing**
No.	mm	(g)	(%)	(%)
#4	4.75	2	0.38	0.38
#8	2.36	3	0.60	0.98
#16	1.18	59	11	11.98
#30	0.6	132	24.9	36.88
#50	0.3	253	47.75	84.63
#100	0.15	56	10.60	95.23
#200	0.75	9	1.75	96.98
Pan	0	16	3	99.98

3.2.3 Coarse Aggregate

With a bulk density of 1794 kg/m3 and an aggregate size range of 20 mm to 7 mm, coarse aggregate from the concrete lab was used in the same way as fine aggregate. The aggregate sample had a 22.73 percent aggregate impact value and a 22.55 percent aggregate crushing value. The sieve analysis for coarse aggregate is shown in Table 3.3

Figure 12 : Coarse Aggregates

Table 5 : Coarse Aggregate Sieve Analysis

Sieve No.	**Weight retained**	**% Retained**	**Cumulative % Retained**	**% Passing**
No.	(kg)	(%)	(%)	(%)
3/8	1	0.7	0.7	99.28
½	2.5	1.74	2.44	97.54
¾	5	3.48	5.92	94.06

3.2.4 Cement

Our project will make use of Cherat Cement.

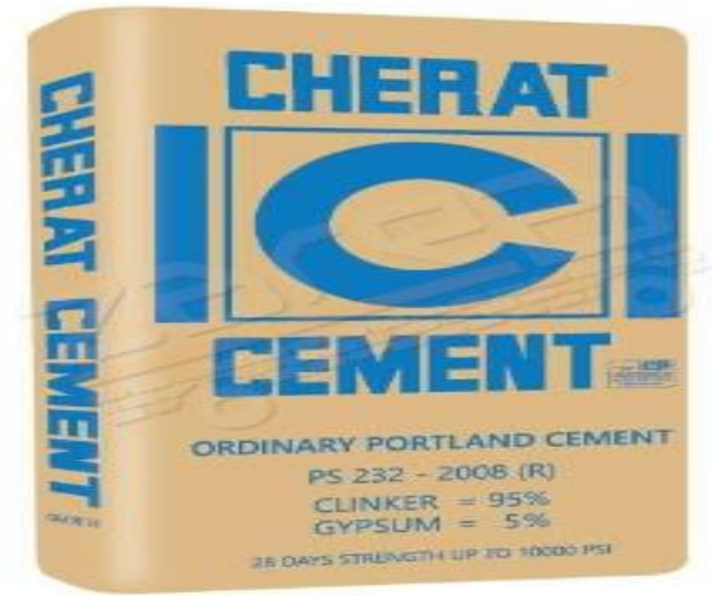


Figure 13 : Cement

3.2.5 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 14 : Super Plasticizer – Liquid Form

3.2.6 Flow cone

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

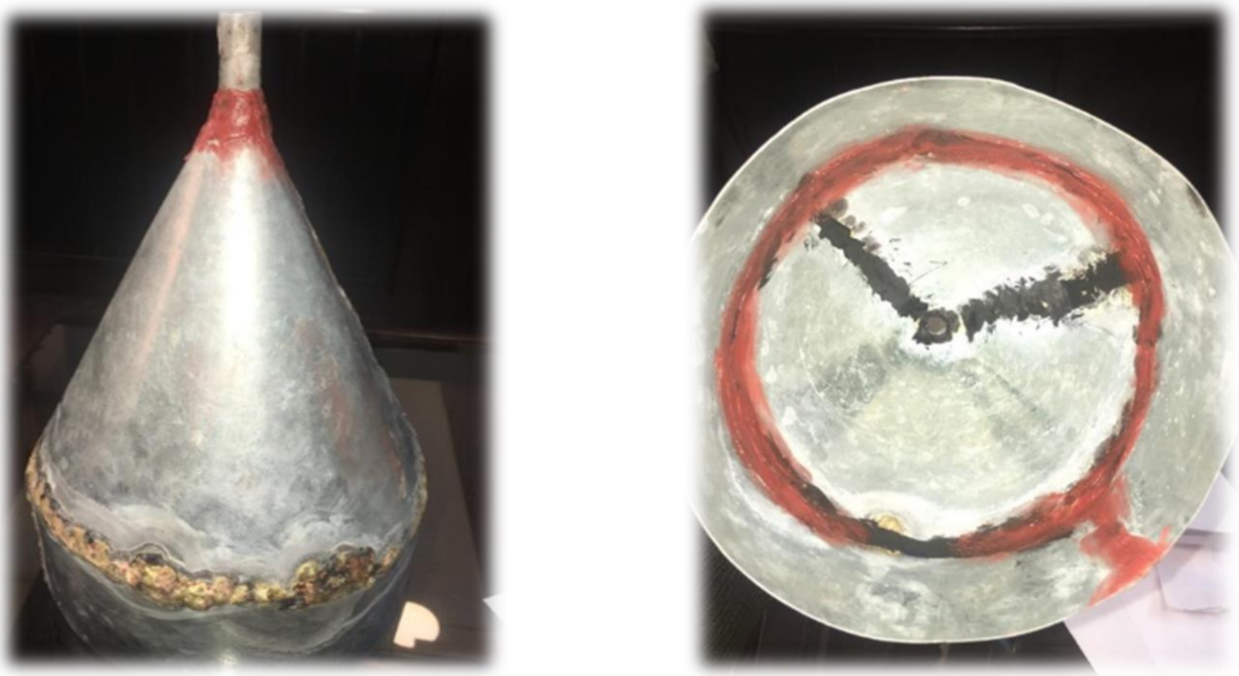


Figure 15 : Welded Flow Cones – Max V = 1725ml.

3.2.7 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 16 : Bitumen – Liquid form

3.3 Sample Preparation

Following types of samples were prepared:

3.3.1 Preparation of control samples

Control samples with only cement, water and super plasticizer were prepared without any Bentonite percentages. According to ASTM C305 requirements, the control samples were made in a Hobart mortar mixer. In this procedure, the mixture was dry mixed slowly for 1 minute. The dry mixture received the second-third of the water and was then stirred slowly for two minutes. The remaining was then added, along with super plasticizer (SP), and the mixture was mixed for five minutes at low speed. The grout was also mixed at high speed for an additional three minutes. The debris that had accumulated on the sidewalls was removed and mixed again. After that, the sample was quickly blended for an additional minute.

Figure 17 : Preparation control samples

Table 7 : 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

Semi-flexible mixtures were created using pre-designed cement grouts with specified compositions. Three different types of cement grouts with variable w/c ratios and percentages of bentonite were employed to create semi-flexible combinations; one of the compositions utilizing the RSM technique was chosen and is discussed in chapter 4. Cementitious grouts are used to fill in the spaces left by the open-graded asphalt mixture. The main components of cementitious grouts are cement, water and the material being used which partially replaces the cement. Super plasticizer is also added just to increase the flow ability so the grouts can easily penetrate the open-graded asphalt mixture.

Figure 18 : Preparation Cementitious Grout

Table 8 : Different combinations of cementitious grouts

w/c ratio	Cement (g)	Bentonite (%)	Water (ml)	SP (%)
0.30	3000	10	945	1%
	3000	20	1102.5	1%
	3000	30	1260	1%
	3000	40	990	1%
0.35	3000	10	1155	1%
	3000	20	1320	1%
	3000	30	1035	1%
	3000	40	1207.5	1%
0.40	3000	10	1380	1%
	3000	20	1080	1%
	3000	30	1260	1%
		40	1440	1%

According to the requirements of ASTM C305, the cementitious grouts were made in a Hobart mortar mixer. In this procedure, the mixture was dry mixed slowly for 1 minute. The dry mixture received the second-third of the water and was then stirred slowly for two minutes. After adding the remaining, super plasticizer (SP) was added, and the mixture was then mixed for five minutes at low speed. The grout was also mixed at high speed for an additional three minutes. The debris that had accumulated on the sidewalls was removed and mixed again. The grout was then thoroughly combined for a last minute at high speed.

3.4 Test Performed

3.4.1 Flow Cone Test

Fill the flow cone with water, let it drain for a minute, then dump the grout sample inside to moisten the interior. Use a stopper or your finger to seal the discharge tube's exit. Introduce the grout until the grout's surface rises to touch the point gauge. As you start the stopwatch, take away the stopper or finger. When the grout has flowed sufficiently for light to pass through it, the stopwatch should be stopped at the first break in the grout's continuous flow. At that point, the grout's efflux time will be recorded. This flow cone is not appropriate for this consistency of grout if there is no visible light. Each grout mixture must undergo at least two tests. The time of efflux test must be performed within 1 minute of pulling the grout from the mixer.

Figure 18 : Flow Cone Test

3.4.2 Compressive Strength Test

Prepare cement mortars first. Once the flow test is completed, return the mortars from the flow table back into the mixing bowl. Quickly scrape the sides of the bowl, add to the batch, and mix the entire batch for 15 seconds at medium speed. Consolidate the mortars completely in molds using manual tamping or another suitable technique. Within a single day, prepare 6 or 9 batches of cubes using one of the cements, and cast a minimum of 36 cubes. After seven days, all cubes should be subjected to testing. The specimens are demolded before 24 hours. When using 24-hour specimens, immediately test them after removing them from the wet closet. Each specimen should be carefully cleaned, dried, and free of any loose sand particles on the surfaces that will come into contact with the bearing blocks of the testing device. Gently place the specimen in the testing device beneath the center of the upper bearing block. Apply the load at a rate equivalent to loading the specimen between 200 and 400 pounds per second. Calculate the compressive strength using the maximum load reached. The compressive strength of all valid test specimens created from the same sample should be averaged.

Figure 19 : Compressive Strength Test

Table 9 : Compressive Strength Test

W/C Ratio	Bentonite	Flow Time	7-day CS	28-day CS
0.3	10	15	32.025	47.798
0.3	10	15	34.254	51.125
0.3	10	15	33.856	50.532
0.3	20	16	37.254	55.597
0.3	20	16	37.015	55.238
0.3	20	16	34.124	45.393
0.3	30	17	30.145	44.993
0.3	30	17	30.859	46.058
0.3	30	17	29.854	44.552
0.3	40	18	29.364	43.826
0.3	40	18	27.214	40.617
0.3	40	18	29.214	43.602
0.35	10	12.6	33.853	50.522
0.35	10	12.6	34.981	52.208
0.35	10	12.6	33.656	50.223
0.35	20	13	33.657	50.149
0.35	20	13	34.858	52.014
0.35	20	13	33.964	50.686
0.35	30	13.7	27.245	40.664
0.35	30	13.7	28.963	43.228
0.35	30	13.7	27.458	40.982
0.35	40	14.3	28.247	42.159
0.35	40	14.3	29.254	43.662
0.35	40	14.3	27.251	40.673
0.4	10	13.5	34.022	50.776
0.4	10	13.5	33.216	49.567
0.4	10	13.5	36.211	54.044
0.4	20	14	31.547	51.256
0.4	20	14	32.258	48.134
0.4	20	14	30.986	46.247
0.4	30	14.6	29.256	43.656
0.4	30	14.6	27.258	40.683
0.4	30	14.6	25.852	38.585
0.4	40	15.2	26.235	39.1492
0.4	40	15.2	24.258	36.205
0.4	40	15.2	25.368	37.850

3.5 Preparation of Semi-Flexible Specimen

The bitumen and aggregates were warmed to the necessary mixing temperature before being combined. The needed amount of aggregates and bitumen were combined while maintaining the temperature in accordance with ASTM D6925 (ASTMD6925, 2015) regulations. The samples were compacted with 25 blows on one side only to obtain air voids in the range of 25-35%. These air voids were then employed to create the open-graded asphalt mixtures that would later be used to create Grouted Macadam specimens. The HMA (Flexible) specimens, on the other hand, underwent 75 blows on each side of compression. They were made solely for comparative purposes with semi-flexible ones. The finished specimens (open-graded) were left to cool for 24 hours before being taken out of the molds. Open-graded specimens' void content was calculated to be between 25 and 35 percent. Three HMA samples and a total of six open-graded samples were created. Three were used for fuel resistivity testing and three were used for the Marshall Stability Test out of the six open-graded ones. Out of the 4200g of total aggregates, 3% of bitumen was added to open-graded mixtures and 4.1% to HMA.

Table 10: 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)
3/4” (19 mm)	100	0	0
1/2” (12.5 mm)	97.5	2.5	17.5
3/8” (9.5 mm)	18	79.5	556.5
#4 (4.75 mm)	10	8	56
#8 (2.36 mm)	8	2	14
# 200 (0.075 mm)	4.5	3.5	24.5
Filler (Passing # 200 sieve)		4.5	31.5
Total		100	700

*Bitumen Content = 3% by weight of Agg

*Compaction with 25 blown on one side only

**Total of 6 Specimens shall be made

Table 11 : Gradation for HMA

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

Figure 20 : Preparation of Semi Flexible Specimen

3.6 Grouting and Fabrication of Semi-Flexible Mixtures

To prevent the cementitious grout from leaking, telic sheets were used to seal all of 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 created using the 0.40 w/c ratio and 22% Bentonite, which provided the highest compressive strength and shortest flow time, as well as control samples made up entirely of cement. After 24 hours, the semi-flexible specimens were removed from the molds, and the amount of cementitious grout was calculated using equation (1).

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

Figure 21 : Pouring of Grout

3.7 Testing on Semi-Flexible Specimens

3.7.1 Marshal Stability Test

The fundamental Marshall test entails crushing a cylinder of bituminous material between two semicircular test heads and measuring both the maximum load achieved (i.e., stability) and the deflection at which the maximum load occurs (i.e., the flow). The Marshall Test is a well-known and reliable technique for figuring out how much pressure and how fast asphalt specimens flow. It starts by being compacted into molds using Marshall Compactors, which can be manual or automated. After that, it is conditioned in a water bath at the proper temperature.

Figure 22 : Martial Stability Test

Table 12 : Martial Stability Test (a) Semi-Flexible Specimen and (b) HMA

(a) (b)

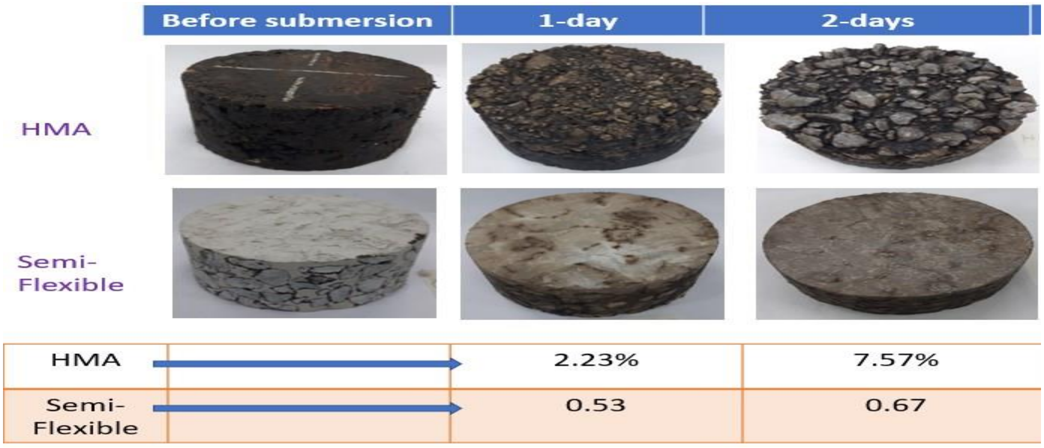
Ser	Sample	Marshal Stability KN	Flow mm
1	A	31.5	4.6
2	B	22.72	4.2
3	C	39.1	4.3

Ser	Sample	Marshal Stability KN	Flow mm

1	A	11.9	5.1
2	B	12.13	6.2
3	C	10.58	4.0

3.7.2 Fuel Resistivity Test

In order to study the fuel effect on the material, a suitable strategy for creating a continuous kerosene head on the specimen surface was studied. A semi flexible pavement containment ring with the same diameter as the specimen was hermetically sealed with silicone on the specimen's surface to actualize the fuel head, especially Diesel fuel on cylindrical specimens.



	Before submersion	1-day	2-days
HMA	→	2.23%	7.57%
Semi-Flexible	→	0.53	0.67

Figure 23 : Fuel Resistivity Test

CHAPTER : 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Based on the flow and results of compressive strength of 12 grouts with varied w/c ratios (0.30 - 0.40) and Bentonite percentages (10 - 40%), a single w/c ratio and Bentonite percentage combination was chosen. One set of w/c ratio of 0.40 and 22% Bentonite was chosen by "Response Surface Methodology" technique in order to achieve the goal of a flow range of 11 - 16 seconds and maximize the compressive strength. Software dubbed "Design Expert 10" carried out RSM operations.

4.1.1 Response 1 : Flow

Software shows that there is a considerable decrease in flow-out time with the increase in w/c ratio.

Table 13 : Relation between Bentonite and Flow Time

w/c ratio	Bentonite	Flow Time
0.3	10	15
	20	16
	30	17
	40	18
0.35	10	12.6
	20	13
	30	13.7
	40	14.3
0.4	10	13.5
	20	14
	30	14.4
	40	15.2

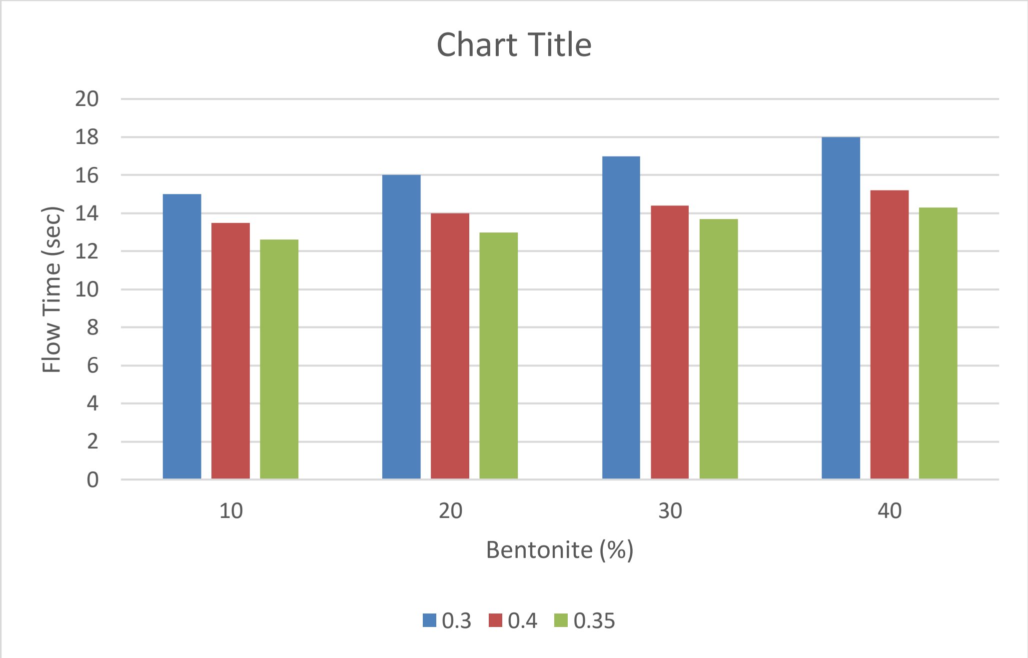
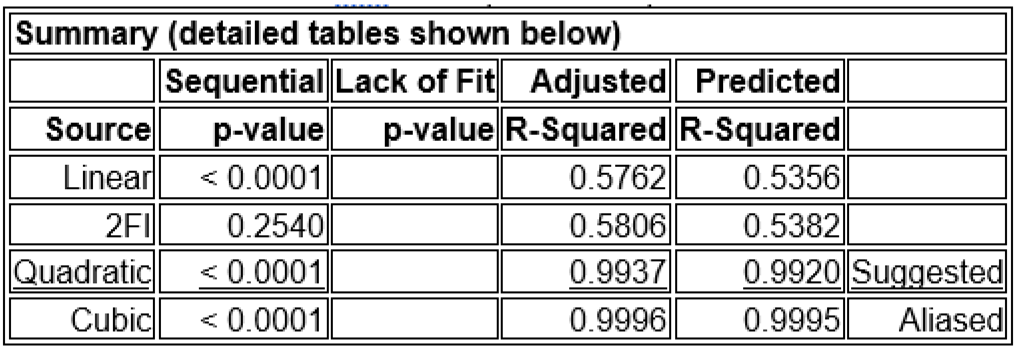


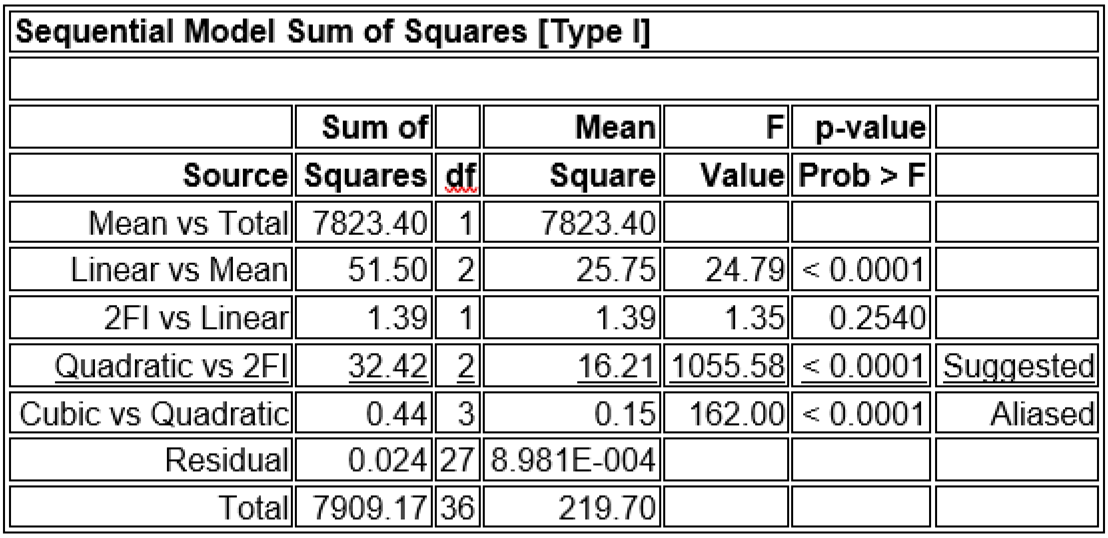
Figure 24 : Relation between Bentonite and Flow Time

Table 14 : R – Squared and p - Value



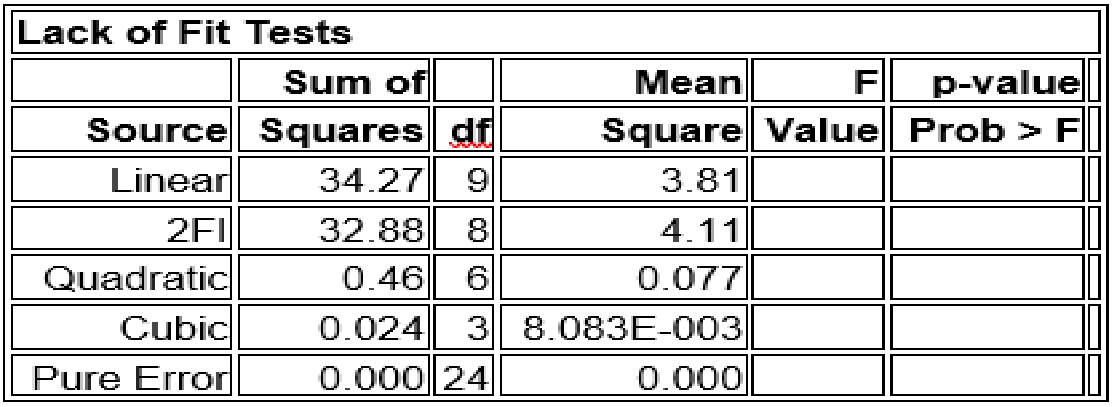
Summary (detailed tables shown below)					
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	< 0.0001		0.5762	0.5356	
2FI	0.2540		0.5806	0.5382	
Quadratic	< 0.0001		0.9937	0.9920	Suggested
Cubic	< 0.0001		0.9996	0.9995	Aliased

Table 15 : Sequential Model Sum of Squares



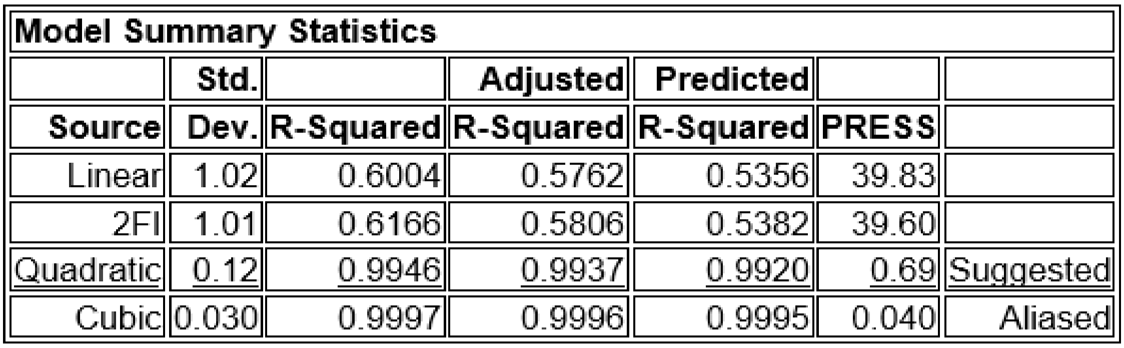
Sequential Model Sum of Squares [Type I]						
	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Mean vs Total	7823.40	1	7823.40			
Linear vs Mean	51.50	2	25.75	24.79	< 0.0001	
2FI vs Linear	1.39	1	1.39	1.35	0.2540	
Quadratic vs 2FI	32.42	2	16.21	1055.58	< 0.0001	Suggested
Cubic vs Quadratic	0.44	3	0.15	162.00	< 0.0001	Aliased
Residual	0.024	27	8.981E-004			
Total	7909.17	36	219.70			

Table 16 : Lack of Fit Test



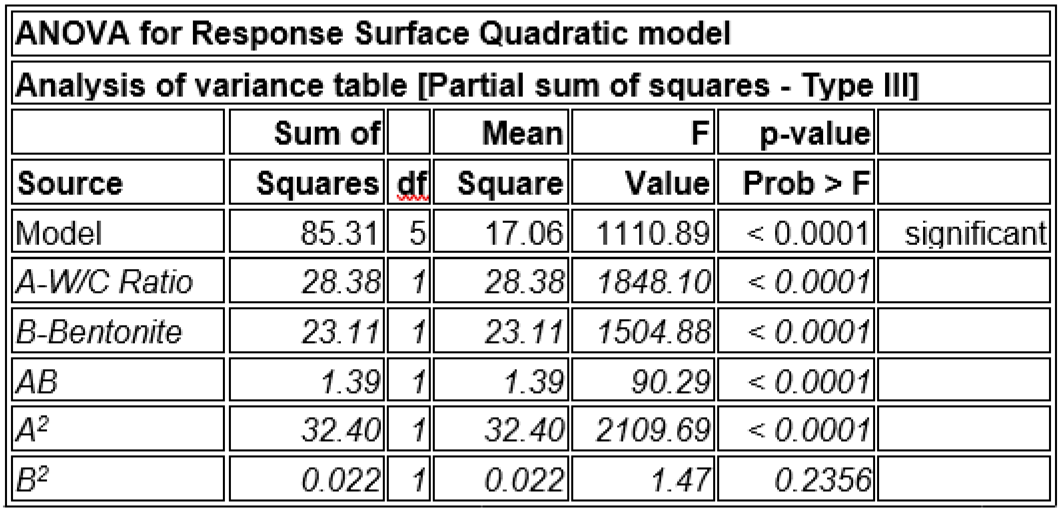
Lack of Fit Tests					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Linear	34.27	9	3.81		
2FI	32.88	8	4.11		
Quadratic	0.46	6	0.077		
Cubic	0.024	3	8.083E-003		
Pure Error	0.000	24	0.000		

Table 17 : Model Summary Statistics



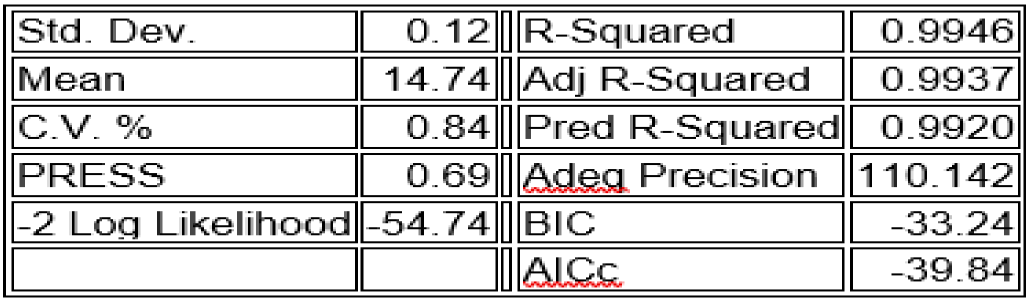
Model Summary Statistics						
	Std.		Adjusted	Predicted		
Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	1.02	0.6004	0.5762	0.5356	39.83	
2FI	1.01	0.6166	0.5806	0.5382	39.60	
Quadratic	0.12	0.9946	0.9937	0.9920	0.69	Suggested
Cubic	0.030	0.9997	0.9996	0.9995	0.040	Aliased

Table 18 : ANOVA Response



ANOVA for Response Surface Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	85.31	5	17.06	1110.89	< 0.0001	significant
A-W/C Ratio	*28.38*	*1*	*28.38*	*1848.10*	*< 0.0001*	
B-Bentonite	*23.11*	*1*	*23.11*	*1504.88*	*< 0.0001*	
AB	*1.39*	*1*	*1.39*	*90.29*	*< 0.0001*	
A^2	*32.40*	*1*	*32.40*	*2109.69*	*< 0.0001*	
B^2	*0.022*	*1*	*0.022*	*1.47*	*0.2356*	

Table 19 : R – Squared and Adequate Precision



Std. Dev.	0.12	R-Squared	0.9946
Mean	14.74	Adj R-Squared	0.9937
C.V. %	0.84	Pred R-Squared	0.9920
PRESS	0.69	Adeq Precision	110.142
-2 Log Likelihood	-54.74	BIC	-33.24
		AICc	-39.84

The difference is less than 0.2 between the "Pred R-Squared" of 0.9920 and the "Adj R-Squared" of 0.9937.

The signal-to-noise ratio is measured using "Adeq Precision". A ratio of at least 4 is preferred. Your ratio of 110.142 indicates an adequate signal. This model can be used to navigate the design space.

Table 20 : Factor Table

	Coefficient		**Standard**	**95% CI**	**95% CI**	
Factor	**Estimate**	**df**	**Error**	**Low**	**High**	**VIF**
Intercept	13.37	1	0.044	13.28	13.46	
A-W/C Ratio	-1.09	1	0.025	-1.14	-1.04	1.00

B-Bentonite	1.08	1	0.028	1.02	1.13	1.00
AB	-0.32	1	0.034	-0.39	-0.25	1.00
A^2	2.01	1	0.044	1.92	2.10	1.00
B^2	0.056	1	0.046	-0.039	0.15	1.00

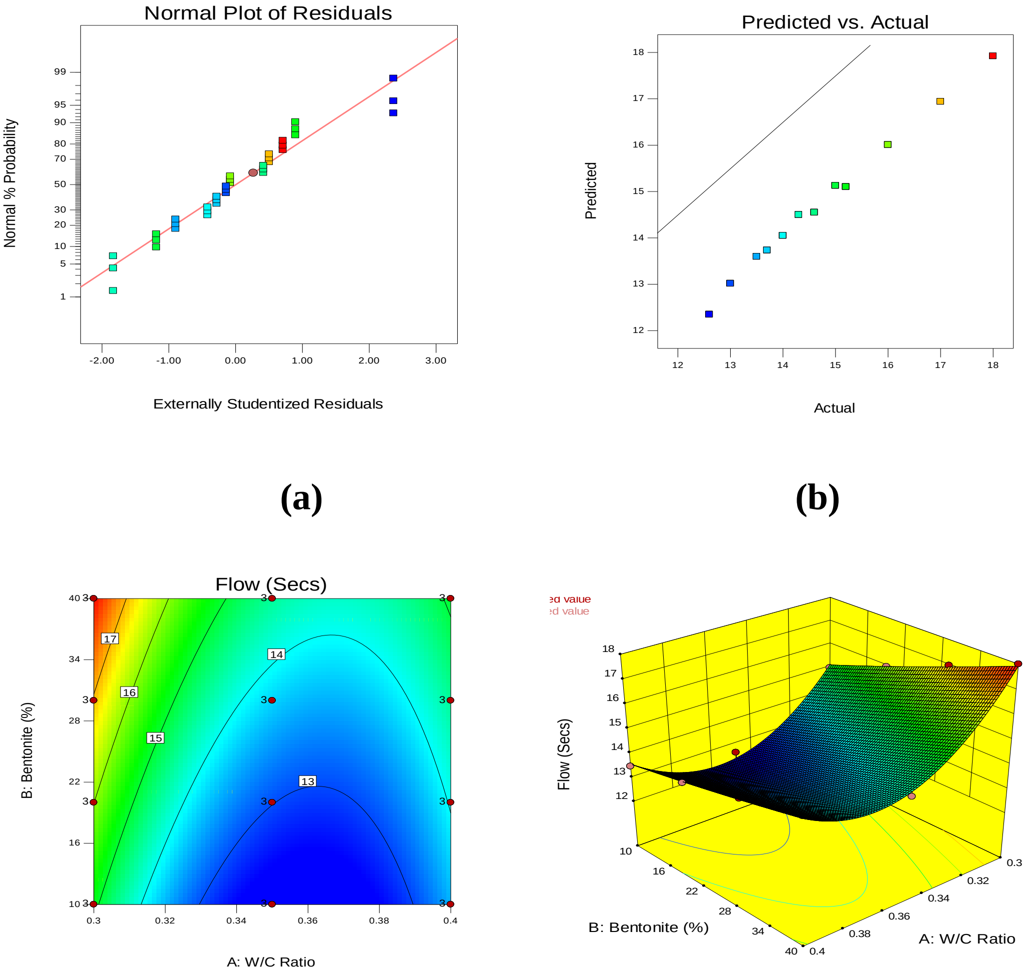
Table 21 : Equation in Terms of Coded Factors

Final Equation in Terms of Coded Factors:	
Flow	=
+13.37	
-1.09	* A
+1.08	* B
-0.32	* AB
+2.01	* A^2
+0.056	* B^2

Table 22 : Equation in Terms of Actual Factors

Final Equation in Terms of Actual Factors:	
Flow	=
+114.19583	
-574.50000	* W/C Ratio
+0.20967	* Bentonite
-0.43000	* W/C Ratio * Bentonite
+805.00000	* W/C Ratio^2
+2.50000E-004	* Bentonite^2

It is possible to anticipate the reaction for specific levels of each factor using the equation expressed in terms of the real factors. Here, the levels for each factor should be stated in their original units. Because the coefficients are scaled to account for the units of each element and the intercept is not at the center of the design space, this equation should not be used to estimate the relative importance of each factor.



(a) (b)

(c) (d)

Figure 25 : Graphs of Response Flow

4.1.2 Response 2 : 7 Days Compressive Test

It can also be seen that compressive strength decreases at a high percentage of Bentonite therefore we selected the optimal content by doing RSM. The lowest 7-days and 28-days strength was at a combination of 0.40 w/c ratio and 40% Bentonite whereas the highest was at 0.40 w/c ratio and 20% Bentonite.

Table 23 : Relation between Bentonite and Compressive Strength

w/c ratio	Bentonite	7-day CS	28-day CS
0.3	10	33.38	49.82
	20	36.12	52.08
	30	30.28	45.20
	40	28.60	42.68
0.35	10	34.16	50.99
	20	34.14	50.95
	30	27.89	41.62
	40	28.25	42.17
0.4	10	34.48	51.46
	20	31.59	48.54
	30	29.16	43.53
	40	25.28	37.74

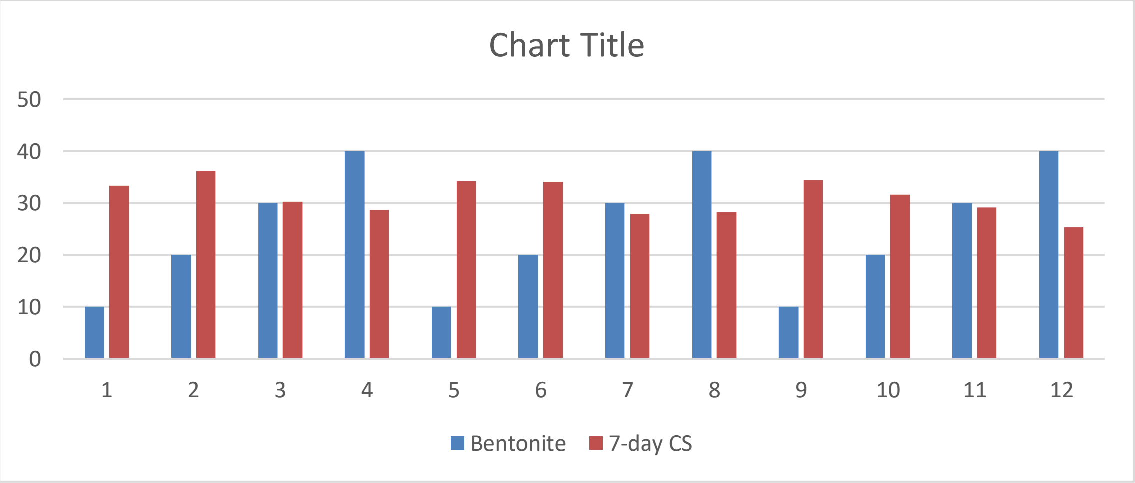


Figure 26 : Relation between Bentonite and Compressive Strength

Table 24 : R – Squared and p – Value

Summary (detailed tables shown below)					
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	< 0.0001	0.0001	0.7339	0.7017	
2FI	0.0799	0.0002	0.7511	0.7174	Suggested
Quadratic	0.6153	< 0.0001	0.7429	0.6928	
Cubic	< 0.0001	0.0521	0.8702	0.8212	Aliased

Table 25 : Sequential Model Sum of Squares

Sequential Model Sum of Squares [Type I]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Mean vs Total	34526.22	1	34526.22			
Linear vs Mean	322.30	2	161.15	49.27	< 0.0001	
2FI vs Linear	10.01	1	10.01	3.27	0.0799	Suggested
Quadratic vs 2FI	3.12	2	1.56	0.49	0.6153	
Cubic vs Quadratic	51.73	3	17.24	10.81	< 0.0001	Aliased
Residual	43.07	27	1.60			
Total	34956.44	36	971.01			

Table 26 : Lack of Fit Tests

Lack of Fit Tests						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Linear	76.51	9	8.50	6.49	0.0001	
2FI	66.50	8	8.31	6.35	0.0002	Suggested
Quadratic	63.38	6	10.56	8.07	< 0.0001	
Cubic	11.65	3	3.88	2.97	0.0521	Aliased
Pure Error	31.42	24	1.31			

Table 27 : Model Summary Statistics

Model Summary Statistics						
	Std.		**Adjusted**	**Predicted**		
Source	**Dev.**	**R-Squared**	**R-Squared**	**R-Squared**	**PRESS**	
Linear	1.81	0.7491	0.7339	0.7017	128.32	
2FI	1.75	0.7724	0.7511	0.7174	121.57	Suggested
Quadratic	1.78	0.7796	0.7429	0.6928	132.16	
Cubic	1.26	0.8999	0.8702	0.8212	76.92	Aliased

Table 28 : ANOVA Response

ANOVA for Response Surface 2FI model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	332.30	3	110.77	36.20	< 0.0001	significant
A-W/C Ratio	*34.36*	*1*	*34.36*	*11.23*	*0.0021*	
B-Bentonite	*287.93*	*1*	*287.93*	*94.09*	*< 0.0001*	
AB	*10.01*	*1*	*10.01*	*3.27*	*0.0799*	

Table 29 : R – Squared and Adequate Precision

Std. Dev.	1.75	R-Squared	0.7724
Mean	30.97	Adj R-Squared	0.7511
C.V. %	5.65	Pred R-Squared	0.7174
PRESS	121.57	Adeq Precision	17.118
-2 Log Likelihood	138.19	BIC	152.52
		AICc	147.48

The difference is less than 0.2 between the "Pred R-Squared" of 0.7174 and the "Adj R-Squared" of 0.7511. Signal-to-noise ratio is measured by "Adeq Precision". The ideal ratio is greater than 4. Your signal is sufficient, according to your ratio of 17.118. The design space can be explored using this model.

Table 30 : Factor Table

	Coefficient		**Standard**	**95% CI**	**95% CI**	
Factor	**Estimate**	**df**	**Error**	**Low**	**High**	**VIF**
Intercept	30.97	1	0.29	30.37	31.56	
A-W/C Ratio	-1.20	1	0.36	-1.92	-0.47	1.00
B-Bentonite	-3.79	1	0.39	-4.59	-3.00	1.00
AB	-0.87	1	0.48	-1.84	0.11	1.00

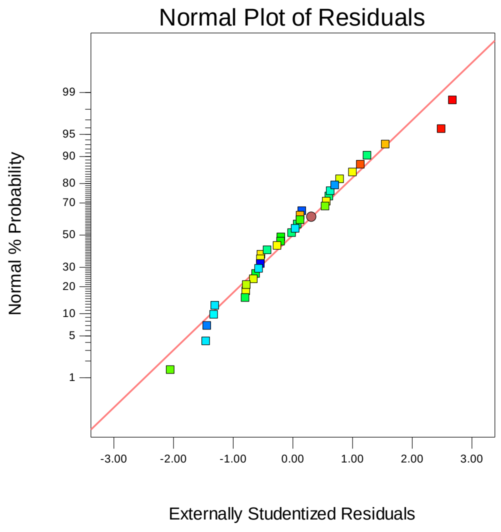
Table 31 : Equation in Terms of Coded Factors

Final Equation in Terms of Coded Factors:	
7 Days Compressive Strength	=
+30.97	
-1.20	* A
-3.79	* B
-0.87	* AB

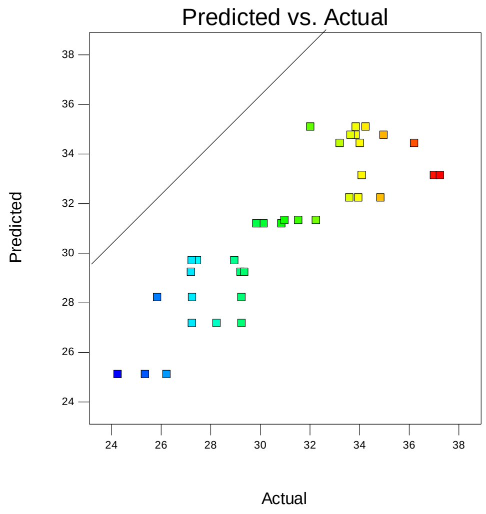
Table 32 : Equation in Terms of Actual Factors

Final Equation in Terms of Actual Factors:	
7 Days Compressive Strength	=
+35.56109	
+4.94700	* W/C Ratio
+0.15135	* Bentonite
-1.15514	* W/C Ratio * Bentonite

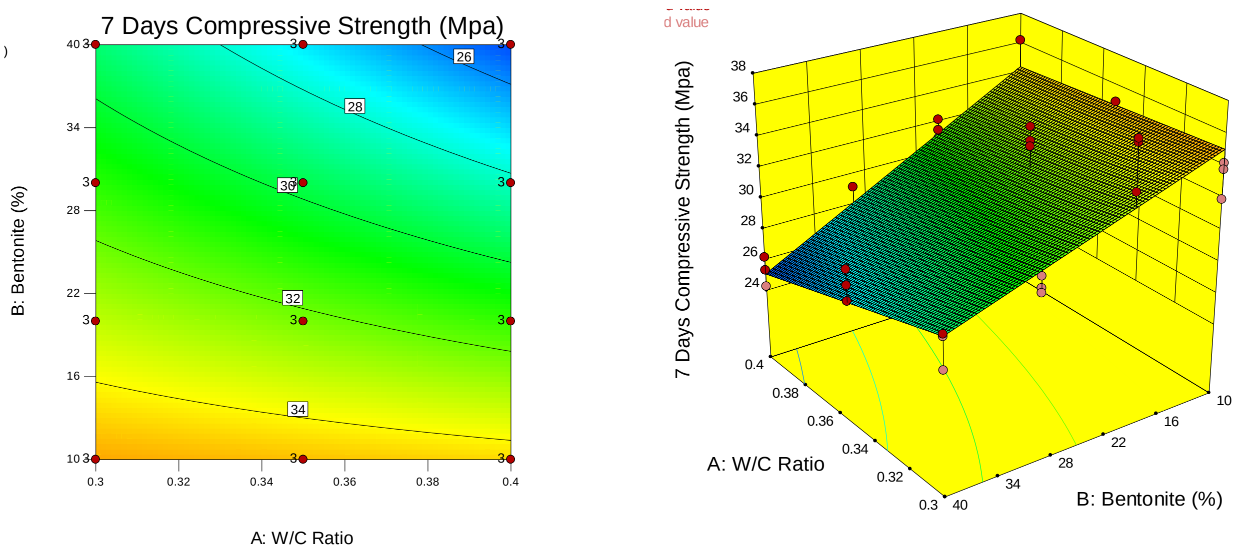
Making predictions about the response for specific levels of each element can be done using the equation expressed in terms of actual factors. Here, each factor's levels must be stated in their original units. The coefficients are scaled to fit the units of each factor, and the intercept is not near the center of the design space, therefore using this equation to estimate the relative importance of each factor should be avoided.



(a)



(b)



(c) **(d)**

Figure 27 : Graphs of Response 2 : 7 days Compressive Strength

4.1.3 Response 3 : 28 Days Compressive Strength

Additionally, it can be shown that compressive strength reduces at a high percentage of bentonite; hence, we performed RSM to choose the ideal amount. A 0.40 w/c ratio and 40% bentonite combination produced the weakest 7-days and 28-days strength, while a 0.40 w/c ratio and 20% bentonite combination produced the strongest results.

Table 33 : Relation between Bentonite and Compressive Strength

w/c ratio	Bentonite	7-day CS	28-day CS
0.3	10	33.38	49.82
	20	36.12	52.08
	30	30.28	45.20
	40	28.60	42.68
0.35	10	34.16	50.99
	20	34.14	50.95
	30	27.89	41.62
	40	28.25	42.17
0.4	10	34.48	51.46
	20	31.59	48.54
	30	29.16	43.53
	40	25.28	37.74

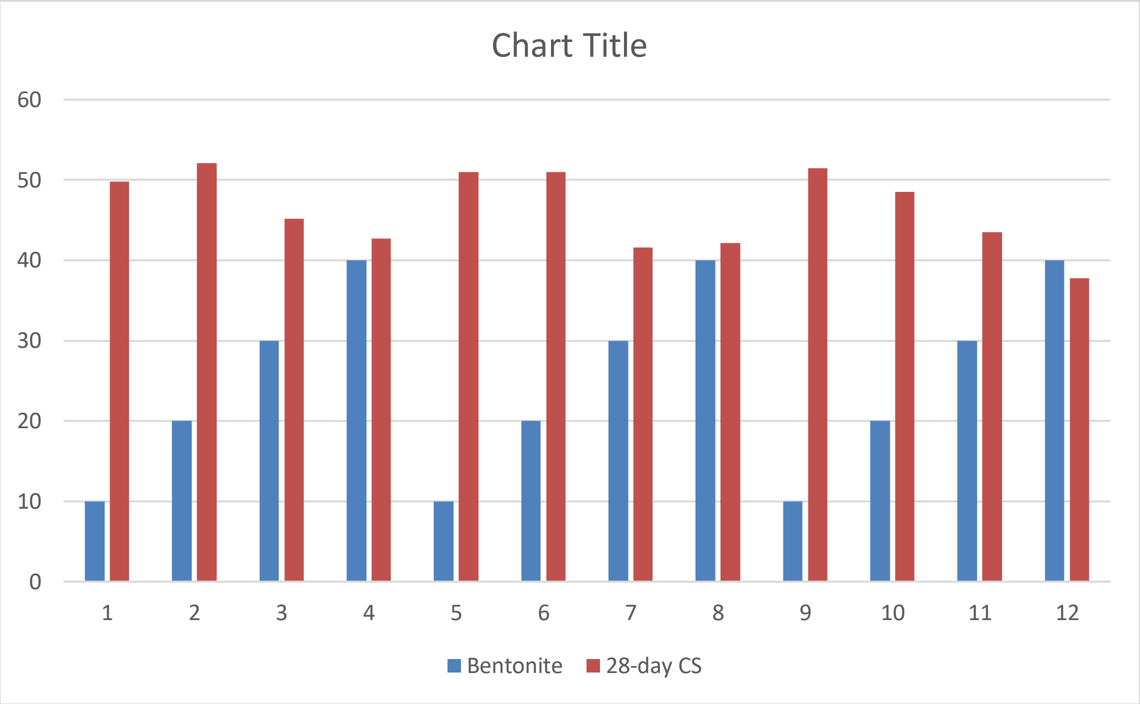


Figure 28 : Relation between Bentonite and Compressive Strength

Table 34 : R – Squared and p – Value

Summary (detailed tables shown below)					
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	< 0.0001	0.0185	0.6918	0.6564	
2FI	0.0526	0.0369	0.7179	0.6850	Suggested
Quadratic	0.6839	0.0188	0.7067	0.6562	
Cubic	0.0034	0.5302	0.8019	0.7355	Aliased

Table 35 : Sequential Model Sum of Squares

Sequential Model Sum of Squares [Type I]						
	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Mean vs Total	76790.37	1	76790.37			
Linear vs Mean	682.31	2	341.15	40.29	< 0.0001	
2FI vs Linear	31.42	1	31.42	4.05	0.0526	Suggested
Quadratic vs 2FI	6.20	2	3.10	0.38	0.6839	
Cubic vs Quadratic	94.83	3	31.61	5.81	0.0034	Aliased
Residual	147.00	27	5.44			
Total	77752.12	36	2159.78			

Table 36 : Lack of Fit Tests

Lack of Fit Tests						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Linear	145.12	9	16.12	2.88	0.0185	
2FI	113.71	8	14.21	2.54	0.0369	Suggested
Quadratic	107.51	6	17.92	3.20	0.0188	
Cubic	12.68	3	4.23	0.76	0.5302	Aliased
Pure Error	134.32	24	5.60			

Table 37 : Model Summary Statistics

Model Summary Statistics						
	Std.		**Adjusted**	**Predicted**		
Source	**Dev.**	**R-Squared**	**R-Squared**	**R-Squared**	**PRESS**	
Linear	2.91	0.7094	0.6918	0.6564	330.41	
2FI	2.78	0.7421	0.7179	0.6850	302.97	Suggested
Quadratic	2.84	0.7486	0.7067	0.6562	330.66	
Cubic	2.33	0.8472	0.8019	0.7355	254.39	Aliased

Table 38 : ANOVA Response

ANOVA for Response Surface 2FI model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	713.73	3	237.91	30.69	< 0.0001	significant
A-W/C Ratio	*45.89*	*1*	*45.89*	*5.92*	*0.0207*	
B-Bentonite	*636.42*	*1*	*636.42*	*82.11*	*< 0.0001*	
AB	*31.42*	*1*	*31.42*	*4.05*	*0.0526*	

Table 39 : R – Squared and Adequate Precision

Std. Dev.	2.78		R-Squared	0.7421
Mean	46.19		Adj R-Squared	0.7179
C.V. %	6.03		Pred R-Squared	0.6850
PRESS	302.97		Adeq Precision	15.465
-2 Log Likelihood	171.64		BIC	185.98
			AICc	180.93

The difference is less than 0.2 between the "Pred R-Squared" of 0.6850 and the "Adj R-Squared" of 0.7179.

The signal-to-noise ratio is measured using "Adeq Precision". A ratio of at least 4 is preferred. Your signal is strong enough based on your ratio of 15.465. To move around the design space, utilize this model.

Table 40 : Factor Table

	Coefficient		**Standard**	**95% CI**	**95% CI**	
Factor	**Estimate**	**df**	**Error**	**Low**	**High**	**VIF**
Intercept	46.19	1	0.46	45.24	47.13	
A-W/C Ratio	-1.38	1	0.57	-2.54	-0.23	1.00
B-Bentonite	-5.64	1	0.62	-6.91	-4.37	1.00
AB	-1.53	1	0.76	-3.09	0.018	1.00

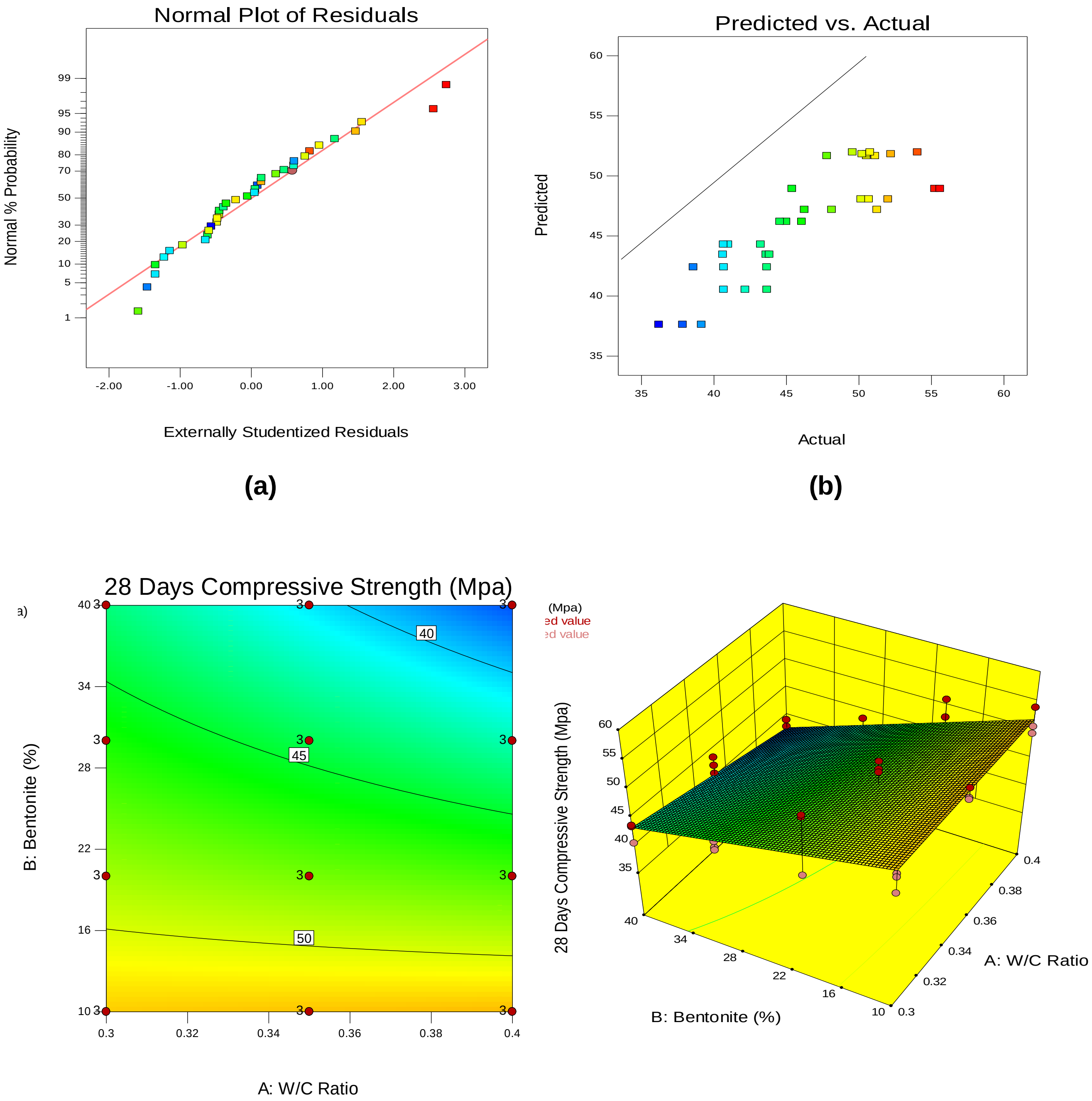
Table 41 : Equation in Terms of Coded Factors

Final Equation in Terms of Coded Factors:	
28 Days Compressive Strength	=
+46.19	
-1.38	* A
-5.64	* B
-1.53	* AB

Table 42 : Equation in Terms of Actual Factors

Final Equation in Terms of Actual Factors:	
28 Days Compressive Strength	=
+47.35761	
+23.51205	* W/C Ratio
+0.34026	* Bentonite
-2.04666	* W/C Ratio * Bentonite

Making predictions about the response for specific levels of each element can be done using the equation expressed in terms of actual factors. Here, each factor's levels must be stated in their original units. The coefficients of this equation have been scaled to take into account the units of each factor, and the intercept is not located in the middle of the design space, therefore it should not be used to estimate the relative importance of each factor



(a)

(b)

(c)

(d)

Figure 28 : Graphs of Response 3 : 28 days Compressive Strength

4.2 Marshal Stability Test

The stability of semi-flexible mixtures was evaluated and compared to the stability of HMA. It is logical that semi-flexible mixtures exhibit higher Marshall stability values compared to HMA. The stability of densely graded HMA was 16.55 KN, whereas semi-flexible mixes demonstrated a two to three-fold increase in this value. Cement grout plays a more significant role in semi-flexible mixtures compared to HMA mixes, resulting in improved stability. While this analysis was conducted for comparative purposes, there are currently no established design stability criteria for semi-flexible pavement surfacing materials. Furthermore, investigations have shown that semi-flexible mixtures have stability values more than twice as high as those achieved with HMA mixes.

Table 43 : Marshal Stability HMA Specimen

Ser	Sample	Marshal Stability KN	Flow mm
1	A	11.9	5.1
2	B	12.13	6.2
3	C	10.58	4.0
4	D	10.66	5.8
5	E	11.93	7
6	F	16.55	5.7

Table 44 : Marshal Stability Semi-Flexible Specimen

Ser	Sample	Marshal Stability KN	Flow mm
1	A	31.5	5.1
2	B	22.472	6.2
3	C	39.1	7.3
4	D	23.91	4.9
5	E	35.26	5.1
6	F	27.86	5.3

CHAPTER: 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this work, semi-flexible pavements built with the appropriate cementitious grout were tested and compared for fuel resistance and performance. Their performance was likewise assessed using the standard HMA combinations. According to publications about Semi-Flexible Pavements, this sort of pavement can generate a high-performance pavement surface. The following are the study's principal conclusions. The measured voids in the open-graded asphalt mixture were within the design range, i.e. 22%, meeting the semi-flexible pavement design criterion.

1. Fuel spillage resistance is one of the most distinctive uses of semi-flexible pavements. In the current investigation, semi-flexible pavements performed better while partially submerged in diesel. In contrast, HMA specimens had low resistance to fuel. The influence of diesel oil on semi-flexible mixes was insignificant.
2. It is possible to deduce that the durability and performance attributes of Semi-Flexible Pavements are heavily influenced by the mix design of the porous asphalt skeleton and the composition of cementitious grouts. The choice of aggregate gradation and bitumen type is critical.
3. The grouts generated must be very flowable in order to permeate the porous asphalt skeleton. According to the ASTM C939 standard, a flow-out duration of 11 to 16 seconds is suggested when utilising a flow cone. To produce great fluidity at a low w/c ratio (0.30 to 0.4), a superplasticizer (1%) is utilised. Along with the sustainability aims, Bentonite is utilised to generate medium-to-high-strength grouts and hence medium-to-high-strength Semi-Flexible Pavements. Up to 22% Bentonite can be utilised to replace cement while maintaining the appropriate strength qualities.
4. Cementitious grout performance is closely connected to Semi-Flexible Specimen performance. As a result, the grouts are meticulously engineered to provide high-performance Semi-Flexible Pavement surfaces.
5. $R^2 > 0.7$ and P value < 0.05 so model is significant
6. Optimum Bentonite replacement : 22.080
   W/C Ratio : 0.40
   Flow Time : 14.14
7. Semi-Flexible exhibit improved and excellent performance in terms of Marshal

stability as compared with HMA

8. Semi-Flexible showed good resistance against fuel spillage in terms of loss mass (<2%).

5.2 Recommendations

1. Using advanced software, numerical analysis may be undertaken to simulate a broader spectrum of material combinations in relation to the mechanical performance of semi-flexible pavement surfaces
2. Field verification may be used to assess the life cycle cost as well as the performance against traffic and environmental challenges.
3. Furthermore, during this field verification time, the serviceability and distresses may be analysed, and correct maintenance methods can be established accordingly.

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