PROPERTIES OF RUBBERISED GEOPOLYMER CONCRETE

By

YAJISH GIRI A/L PARAMA GIRI
18000834

Dissertation Submitted in Partial Fulfilment of
the Requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

SEPTEMBER 2022

Universiti Teknologi PETRONAS
32610, Bandar Seri Iskandar
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Properties of Rubberised Geopolymer Concrete

by

Yajish Giri a/l Parama Giri
18000834

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

____

(Assoc. Prof. Dr. Bashar S. Mohammed)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
MAY 2022

CERTIFICATION OF ORIGINALITY

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

____

(YAJISH GIRI A/L PARAMA GIRI)

ABSTRACT

Over the course of the past few years, the building and construction industry has been working to address the issue of integrating sustainability into production processes. This has been accomplished either through the utilization of solid waste materials as aggregates in concrete or the search for more environmentally friendly raw materials. In addition, the global trends group concentrated on finding an alternative to cement, which is a substantial contribution to the degradation of the environment owing to the greenhouse gas emissions it produces. When it comes to the use of all industrial by-products that include an alumino-silicate and sodium hydroxide source material, geopolymer is one of the most acceptable methods that can be implemented. However, used rubber tires may be recycled by incorporating them into geopolymer concrete in place of natural aggregates. According to the findings of the research, the use of waste rubber tire which is crumb rubber as a substitute for Sand is not only a cost-effective but also user- and eco-benevolent acceptable route for the development of rubberized geopolymer concrete without affecting its long-term viability. This is one way for recycling discarded rubber tires. Lately, the possibility of combining the benefits of geopolymer concrete with those of rubberized concrete to make rubberized geopolymer concrete as a feasible and sustainable construction material has been identified. Response surface methodology (RSM) from the Design Experts programme was used to calculate the number of trial mixtures and their respective constituents. Thirteen trial mixes were produced and evaluated for compressive strength, flexural strength, and tensile strength and the RSM model was created to predict the design mix based on the desired compressive strength. The design of the mixture was determined to be 10 M to 14 M for NaOH and 10 percent to 30 percent for the proportion of crumb rubber. This development came about as a result of the combination of the two materials. This article provides a comprehensive analysis of the current state of knowledge about the environmental and economic effect of waste rubber, as well as its resources, recycling methods, and classifications. In addition, the study presents comprehensive analyses of the characteristics and behaviors of rubberized geopolymer composites, including their fundamental elements, preparation and curing methods, physical properties, mechanical properties, durability qualities, and microstructures.

ACKNOWLEDGEMENT

First foremost, I would like to take this opportunity to wish my thankfulness to the people who have help me throughout this final year 1 and 2 project to be prosperous. Primarily, I wish my sincere gratitude to my project supervisor Assoc. Prof. Dr. Bashar S. Mohammed whom have guided and help me through out this project. Initially, I have faced many challenges to understand depth on the scope of topic, nevertheless through his guidance and explanation I manage to understand further on the topic. Besides, he has also spared his time despite busy schedule to motivate and encouragement to accomplished this project successfully. Next, I'd want to express my gratitude to Ms. Niraku Rosmawati binti Ahmad and Dr. Husna Takaijudin, the FYP course coordinators, for all of the help they've given me throughout the course by providing me with regular updates and helpful adjunct lectures. Because of this, I owe them my deepest gratitude.

In addition, I'd want to convey my gratitude to Isyaka Abdulkadir, who have been a valuable companions and teachers to me during my FYP journey. I am really grateful to him for all of the time and effort he put into helping me finish my experiments and for his support during this FYP.

Finally, I must express my gratitude enough to my family and UTP friends, who have not been actively participating in my FYP but have provided me with endless amounts of love and spiritual support instead to ensure that I am able to complete this project with the time given.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete serves as both the support structure and the deciding element in the construction industry. Concrete is an essential component of every construction that is built in the modern day because of its durability. Concrete is a material that can be found everywhere and is essential to the modern building industry. According to the history of concrete, the first-time concrete was used in the building industry was in the year 1756, which coincides with the commencement of the Industrial Era. The use of a hydraulic binder and water to bond the common components used in concrete, such as sand and gravel, has been done since Egyptian days (Fu, Ye et al. 2019). When compared to other materials used in construction, such as wood or clay, the major purpose of using concrete as a building material is to extend the lifespan of a structure by two or even three times longer than it would be with those other materials. In addition, there are technologies that aid to strengthen the resistance of concrete to the various loads that are applied to a building. Some examples of these technologies include the injection of admixtures and steel reinforcing bars. In the process of constructing structures, concrete is used for the formation of load-bearing components such as beams, slabs, columns, and foundations, among other things. Cement, coarse aggregates, fine aggregates, and water make up the individual components of concrete. It is referred to as the paste, and it is what binds the coarse aggregates and the fine aggregates together. The paste is made up of Portland cement and water. The hydration process, which starts after the individual components have been mixed together, is what gives concrete its needed level of quality and strength.

Along with the expansion of the building and construction sector over the course of the years, there has also been an increase in the use of a wider variety of building materials. In the building of roads, many types of binding materials besides concrete, such as asphalt or bitumen concrete and lime for lime concrete, are used (Al-Tameemi et al., 2015). In the same vein, rubberized geopolymer concrete is a type of concrete that differs from traditional concrete in that it incorporates a specific amount of crumb rubber into the geopolymer. This results in concrete that possesses different qualities than traditional concrete. Rapid population development, which in turn has led to a rise in the use of automobiles, has resulted in an increase in the quantity of solid waste disposed of, such as discarded tires, which will not disintegrate for hundreds of years into the foreseeable future.

Due to the fact that waste tires resist deterioration, it was discovered that the disposal of waste tires is a challenge for the environment. There is a substantial cause for worry over the accumulation of recycled waste tires. Recycling the goods that are made from used tires is the most effective method of waste management that can be used in the construction business. This strategy protects the environment by reducing the amount of pollution that is produced and preventing the depletion of natural aggregates. Waste tires have numerous unique qualities that are significant for engineering applications, especially geotechnical applications, including low density, low ground pressure, strong insulating properties, good drainage efficiency, good long-term durability, and high compressibility. End-of-life tire vulcanized rubber is robust and can hold its volume under stress, making it a good substitute for mineral particles in highly deformable concrete (Mohajerani et al., 2020).

The method of making crumb rubber from used tires, which are first crushed and then ground down into very small pieces as seen in figure 1.1, is shown here. In a nutshell, in comparison to conventional concrete, the rubberized concrete has more deformability, improved sound absorption, a lower density, and increased impact resistance. Rubberized concrete has recently been used in the construction of roadside barriers and pillars. This material may reduce the impact force and acceleration experienced by drivers who are at increased risk of harm. However, due to the rubberized concrete's inferior compressive strength in comparison to that of traditional concrete, it is not suitable for use in the building of structural elements. Hence, incorporating crumb rubber in geopolymer to produce rubberized geopolymer concrete can improve the strength while maintain its toughness and durability. Sodium hydroxide and sodium silicate are the most frequent soluble alkaline activators used in the development of geopolymer, which is made from fly ash and an alkaline activator solution. There are several benefits of using geopolymer binder, such as its high compressive strength at a young age and its strong fire and chemical resistance (S Mohammed et al., 2018).

FIGURE 1.1: The conversion of discarded tire chips into crushed rubber (Thomas et al., 2015)

In addition, as we move into more specific terms within this report and the project that lies ahead, there have been many investigations and tests conducted in order to study and comprehend the compressive and flexural strength of the rubberized geopolymer concrete. These investigations and tests can be found throughout this report. As a result, the purpose of this study is to investigate and analyze the tensile behavior of crumb rubber that has been combined with geopolymer concrete. It is anticipated that the compressive strength test, the flexural tensile test, direct tensile test, Field emission scanning electron microscopy, (FESEM) and Mercury intrusion porosimeter, (MIP) will be carried out during the beginning phase of Final Year Project 2; these tests will be performed after crumb rubber has been mixed with geopolymer concrete. The project period is approximately 2 months of experimental works that are properly planned and will be commenced during the beginning phase of Final Year Project 2.

1.2 Problem Statement

Numerous studies on the inclusion of crumb rubber and geopolymer concrete have been carried out. In addition, as the number of cars on the road increases, there will be a greater quantity of waste tires, and the disposal of waste tires in urban areas around the globe has been a significant contributor to environmental damage (Xu et al., 2020). Thus, the cost of concrete may be decreased by substituting recycled rubber crumb for a portion of the aggregates, which is beneficial to both the building sector and the depletion of natural resources. It is recognized that adding crumb rubber as a replacement for fine particles progressively reduces the concrete's stiffness and strength. Concrete that contains forty percent rubber has a density of 1950 kilograms per cubic meter, which is lower than the density of standard concrete, which is 2450 kilograms per cubic meter (Pham et al., 2019). However, the current technique of producing Ordinary Portland Cement (OPC) has been linked to negative environmental consequences due to massive CO_2 emissions - a key Green House Gas (GHG). This has prompted concrete scientists and the building industry to look for new, long-lasting, user-friendly, eco-friendly, and, of course, cost-effective alternatives to present binders and construction materials. Geopolymer binders have only relatively recently come to be recognized as a brightly promising alternative to conventional cement. In order to create geopolymer, fly ash is utilized as the source material, and an alkaline activator solution is also required. The most common soluble alkaline activator used in the production of geopolymer is sodium hydroxide (NaOH), which is then coupled with sodium silicate. The geopolymer binder has several benefits, such as strong compressive strength at a young age, excellent resistance to fire, good resistance to chemical assault, and low permeability. Hence when crumb rubber is combined with geopolymer concrete to make rubberized geopolymer, a lightweight concrete with improved impact capabilities, acoustic and thermal insulation qualities, and abrasion resistance is produced. Rubberized geopolymer is a consequence of the combination of crumb rubber with geopolymer concrete. Because of this, rubberized geopolymer is an excellent material for making hollow blocks, crash barriers for highways, railway sleepers and foundation pads, lightweight members, acoustic and thermal barriers for equipment, and structural insulated panels. In spite of the fact that increased crumb rubber replacement causes a loss in strength, unconfined rubberized geopolymer may be used in the construction of pavements and other non-structural parts. Columns and bridge piers, as well as low- to medium-rise structures in seismically active areas, are good candidates for the use of confined rubberized geopolymer.

1.3 Aims and Objective

The objective of this research is to sub-divided as follows:

1. To develop rubberized geopolymer concrete using RSM and determine the mechanical properties of rubberized geopolymer concrete.
2. To develop response surface model and determine the optimum mix design for rubberized geopolymer concrete using multi-objective-optimization of response surface methodology.

1.4 Scope of Work

As a partial replacement for fine aggregate and cement, the crumb rubber and alkaline solution which is sodium hydroxide will play a role as a variable material in this research project. The essence of the research objective has been determined to be the crumb rubber, and the research objective has been identified as the geopolymer concrete. The design of the mixture was determined to be 10 M to 14 M for NaOH and 10 percent to 30 percent for the proportion of crumb rubber. The reason why this ranges are chosen for the molarity of sodium hydroxide and crumb rubber percentage is because going beyond or below the limit that has been set will decrease the mechanical properties of the geopolymer concrete and lead to failure in specimen.

By making use of the RSM approach, thirteen distinct mixes including alkaline solution which is sodium hydroxide for making geopolymer and crumb rubber in varying proportions will be generated, and each mix will be put through its paces in terms of performance. Once that, the optimal mixture will be put through a series of tensile tests in a laboratory setting to determine its results in terms of its modulus of rupture and compressive strength. These measurements will be taken after the tests have been completed. Therefore, the objective is to identify the ideal ratio of crumb rubber to alkaline solution which is sodium hydroxide for making geopolymer concrete mixture that would result in the greatest amount of strength

CHAPTER 2

LITERATURE REVIEW

2.1 Geopolymer Concrete

Concrete is the most durable, adaptable building material. Concrete requires much Portland cement. Ordinary Portland Cement (OPC) usage generates CO2 emissions. Geopolymer concrete reduces Portland cement's environmental impact. Hence detailed research has been done regarding the geopolymer concrete below for better understanding.

2.2 Background Study of Geopolymer concrete

Geopolymer is a modem environmentally friendly cementitious material, and its development may help minimize carbon dioxide emissions produced by the cement industry's growth. Geopolymer materials provide outstanding mechanical qualities as well as a number of other desirable characteristics such as fire and corrosion resistance. The majority of industrial solid trash and waste incineration bottom ash is heaped up at will, wasting land resources and negatively impacting the ecosystem (Cong & Cheng, 2021). The geopolymerization process is a complex chemical process that investigators are still seeking to understand. Nevertheless, various studies have already shown that mechanical properties of geopolymer concrete are influenced by the composition of aluminosilicates and their source, curing regime, and alkaline solution type and concentration.

Geopolvmer is one of the most prominent Portland cement substitutes, however it is not a perfect substitute. When handled with alkali solutions, any waste material containing aluminosili cate mineral, such as fly ash, granulated blast furnace slag, rice husk ash, clay, and so on, forms geopolymer cement (Singh et al., 2020). Due to

the ongoing loss of the ozone layer and the problem of global warming, the building industry has recently become increasingly cognizant of the need to use more environmentally friendly construction materials Due to its advantages in utilizing by-product waste to replace cement and lowering greenhouse gas emissions during its manufacturing, geopolymer concrete has begun to attract substantial interest from research researchers and building practitioners (Ma et al., 2018). GPC utilises industrial/agricultural wastes and cuts CO_2 emissions by 80%. This is environmentally friendly. To summarize about geopolymer concrete figure 2.1 shows the Construction Benefits of geopolymer concrete.

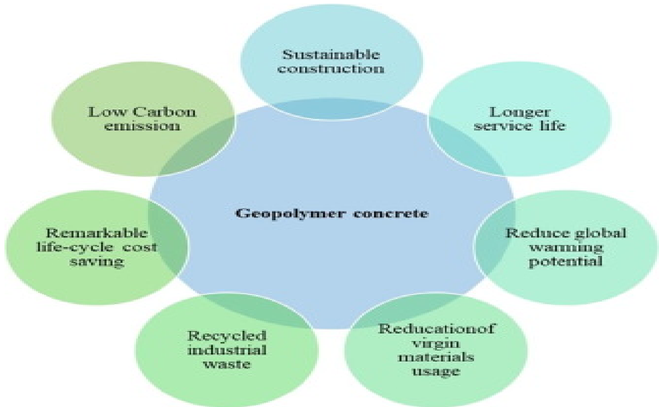

FIGURE 2.1: Construction Benefit of GPC (Singh et al., 2020)

2.3 Geopolymer Concrete Production

The standard process for making geopolymer concrete involves activating different alumino-silicate (Al-Si)-based waste materials with a highly alkaline solution, such as alkaline earth metal silicate components, alkali or alkaline earth metal hydroxide, fine or coarse particles, and water. This results in the formation of geopolymer concrete. In most cases, PC is not necessary in order to complete the manufacturing process of geopolymer concrete. Two of the most important elements of geopolymer concrete are alkaline solutions like sodium silicate (Na_2SiO_3), sodium hydroxide (NaOH), potassium silicate (K_2SiO_3), and potassium hydroxide (KOH), and alumino-silicate sources like rice husk ash, fly ash, Ground Granulated Blast-furnace Slag, fine and coarse aggregates. Alkaline solutions are one of the key components of geopolymer concrete. The method of geopolymerization produces geopolymer, which is a patchy silicate-alumino cementing substance. Geopolymer is created by poly condensation reaction of alkali and polyciliate geopolymeric precursor.(Amran et al., 2020). Figure 2.2 depicts the production of clean geopolymer concrete using by-products and alkaline solution (Amran et al., 2020).

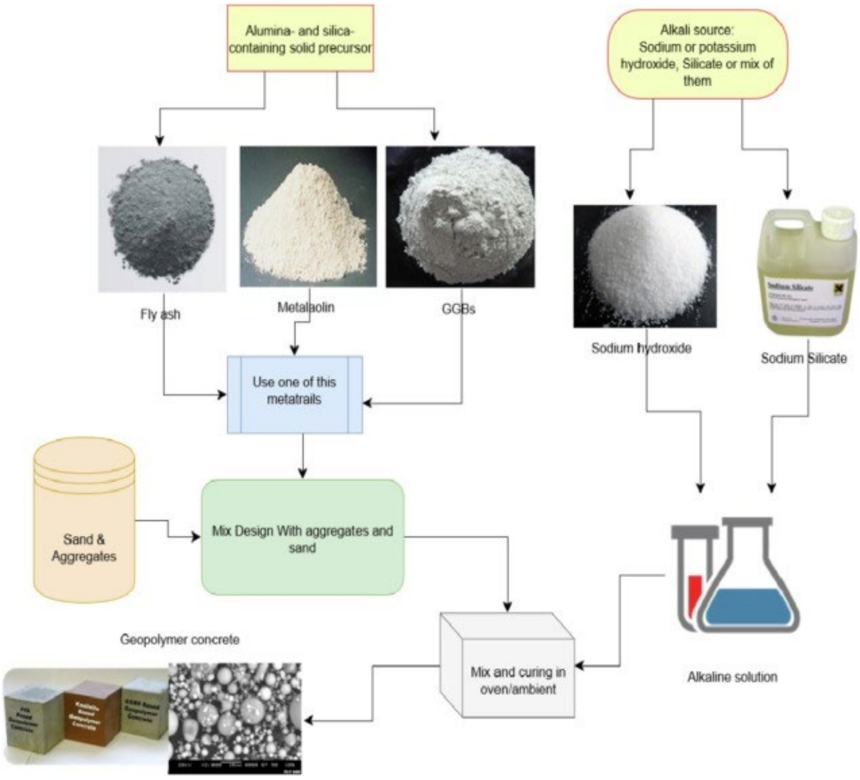

FIGURE 2.2: Geopolymer Production

2.4 Properties of Geopolymer concrete

Geopolymer is a kind of inorganic polymer that may be found in nature. Unlike other natural zeolitic minerals, it is amorphous rather than crystalline. One of the raw ingredients for geopolymer are fly ash and an alkaline activator solution, with sodium hydroxide (NaOH) mixed with sodium silicate being the most common soluble alkaline activator utilised in geopolymer development (Na2SiO3) or potassium hydroxide. The geopolymer binder has several benefits, including strong compressive strength at a young age, fire resistance, chemical resistance, and low permeability, low shrinkage, and freeze-thaw and as a result, they are suited for long-term confinement in surface disposal facilities (S Mohammed et al., 2018). When tested in line with the criteria applicable to hydraulic binder mortars, geopolymer cement hardens quickly at room temperature and delivers compressive strengths in the 20 MPa range after just hours at 20 degrees Celsius. The compression strength at the end of 28 days is between 70 and 100 MPa. It to be known that when the molarity of Na2Sio3 is high the geopolymerization prosses will be faster and produces a higher compressive strength compared to ordinary Portland cement (Amran et al., 2021). In comparison to ordinary concrete, geopolymer concrete has a higher tensile strength, is less brittle than OPC, and can sustain greater movement. The techniques of curing employed for geopolymer paste, mortar, and concrete distinguish it from conventional cement products. Instead of curing using water, heat curing is generally adopted for geopolymer products. Heat curing is used to accelerate the reaction of geopolymerisation. Geopolymer concrete cured at room temperature may not achieve the required strength. Thus, curing at high temperatures was used in several pieces of researches on geopolymer. Fly ash-based geopolymer products can achieve the desired strength when exposed to elevated temperature curing more than ambient curing conditions.

Heat curing has been utilized in a variety of studies to improve the geopolymerization response of geopolymer concrete; typically, the temperature varies from 60 to 100 degrees Celsius, and the ranges from 24 to 36 hours. The methods of heat curing need a particular setup that might be highly costly, which may restrict the usage of geopolymer goods in reality. Therefore, in order to expand the scope of applications for geopolymer goods in construction, researchers concentrated their efforts on the development of geopolymer products that could be utilised at room temperature and were both easy and economical to use. The heat technique of curing geopolymer goods may either be done by putting the samples directly without wrapping them first in an oven, or it could be done by covering the samples with a heat-resistant plastic sheet and then placing them in the oven. The wrapping of specimens with the intention of limiting excessive loss of moisture by evaporation. The heat technique of curing geopolymer products may either be done by putting the samples directly without wrapping them first in an oven, or it could be done by covering the samples with a heat-resistant plastic sheet and then placing them in the oven. The wrapping of specimens with the intention of limiting excessive loss of moisture by evaporation.

2.5 Advantages of Geopolymer Concrete

Despite the fact that OPC concrete contains chemical additives, geopolymer concrete needs roughly 30% less water for the same workability level. Apart from that geopolymer concrete is also resistance against the aggressive environment such as GPC has no gypsum deposition and obvious fissures, while OPC develops a white coating of crystals on an acidic surface. The fluffy, powdery covering that develops during the early stages of exposure and hardens afterwards. Besides that, Geopolymer materials have been given serious consideration as possible replacements for ordinary Portland cement (OPC) ever since the early 1980s. This is primarily due to the fact that geopolymer materials emit much less carbon dioxide and operate more effectively.

The geopolymer products do not dissolve in an acidic solution and do not cause a harmful reaction of alkali-aggregate even when there is a significant level of alkalinity present. Additionally, the geopolymer products have outstanding mechanical qualities. Lastly when compared to OPC, it has a third of the compressive strength and four times the strength.

2.6 Disadvantages of Geopolymer Concrete

Due to the chemical differences between geopolymers and Portland cement, and notably the high degree of alkalinity in the geopolymer system, the setting time of high-strength geopolymer concrete cannot be significantly delayed by adding commercially available admixtures. Geopolymer concrete is to be known to be found stickier when compared with normal strength OPC concrete which will result the process of mixing to be little harder and placement issue as well as more air pockets trapped in hardened concrete. The increased volume of paste and higher cohesiveness of geopolymer concrete cause this result. Due of the rheology and chemical differences between geopolymer concrete and OPC, Deb and Nath found increased cohesiveness. This increased entrapped air diminishes concrete strength by increasing porosity (Neupane et al., 2018). Figure 2.3 illustrates the visible trapped air inside the harden concrete.

FIGURE 2.3: Visible Trapped Air in Harden Concrete (Neupane et al., 2018)

Moreover, geopolymer concrete is exceedingly challenging to produce, since it has certain requirements for how it should be handled and is incredibly complex to make. It is necessary to make use of potentially hazardous chemicals, such as sodium hydroxide, which is harmful for the humans in order to do this. The geopolymerization Process is sensitive where by this area of research has proven to be inconclusive and extremely volatile. The curing of GPC requires a higher temperature. GPC that is cured at room temperature has significantly decreased strength and durability. The conditions of casting and curing have a significant impact on the characteristics of GPC (it is very sensitive to the moisture, temperature, pressure etc.). Efflorescence is another significant challenge for the GPC.

2.7 Crumb Rubber

Crumb rubber is a potential new building material. The substance promises to lessen environmental problems by substituting sand with rubber particles in concrete. Detailed research has been carried regarding the advantages, disadvantages and mechanical properties of crumb rubber.

2.8 Background Study of Crumb Rubber

Manufacturing, mining, residential, and agricultural operations have all created large amounts of solid waste as a result of urbanisation, technical progress, and industrialisation in numerous areas. The quantity of trash created yearly was estimated to reach 12 billion tonnes in 2002. (11 billion could be industrial waste and 1.6 billion would be municipal solid waste) (Thomas et al., 2015). The volume of trash generated globally is expected to reach 19 billion tonnes per year by 2025. The quantity of acreage required to dispose of such a massive volume of trash has proven to be a significant challenge for civil and environmental engineers. These wastes are one of the elements that contribute to numerous pollutions that lead to global warming, which has become a severe concern that threatens humanity's very survival and must be treated seriously in order to maintain this planet. The car sector is one of the industries that produces a lot of garbage. As the population grows, so does the manufacture of vehicles, which leads to a rise in tyre consumption and, in turn, an increase in waste tyre disposal.

Many trash tyres will be created as the number of cars rises, and waste tyre disposal has long been a serious environmental issue in cities across the globe. It is estimated that 1.5 billion discarded tyres are produced each year across the world (Xu et al., 2020). The increase in the number of motor vehicles is expected to result in the disposal of roughly 5 billion tyres by 2030. This increase in population has caused alarm across the globe because of the threat it presents to human health, safety, and environmental preservation directly and indirectly (Mohammed et al., 2016) .Tire disposal has become a major environmental concern all over the globe, posing a severe danger to the ecosystem. In landfills and dumpsites, the build-up of discarded tyres provides a good breeding environment for mice and parasites (Mohammed et al., 2016). This occurs because, as indicated in Figure 2.4, tyres are disposed of at a landfill.

FIGURE 2.4: Landfill Disposal of Waste Tires (Xu et al., 2020)

Apart from that, one of the most popular and cheapest methods of disposing of unwanted tyres is to burn them, which poses a severe fire threat. The waste left behind after tyre burning will contaminate the land, as will the oil created during the tyre burning. Furthermore, the tyre dump poses a serious environmental concern. The majority of underused tyre disposal sites reduce biodiversity. Components in the tyres are both soluble and poisonous.

2.9 Crumb Rubber Properties

Crumb rubber is as a partial substitute for fine aggregate in concrete. It has a lower specific gravity ranging from 0.51 to 1.2, bulk density ranging from 524 kg/m3 to 1273 kg/m3, lower water adsorption, strength, and stiffness than fine aggregate (Prajapati & Pitroda, 2020). The gradient of crumble rubber is lesser. As a result of the partial replacement of fine aggregate with crumb rubber, the gradation pattern will change to gap graded. Furthermore, compared to fine aggregate, which has a water absorption percentage of less than 2%, crumb rubber has a capacity for water absorption ranging from 2% to 4.3 percent. Also, the compressibility of tyre shreds may be used to determine landfill airspace. Vertical strains of up to about 25% may occur in tyre shreds with low vertical stress of up to about (48kpa), whereas vertical strains of up to about 40% can occur in tyre shreds with high vertical stress of up to about (414kpa) (Yang et al., 2002). As different strata of a municipal solid waste dump, tyre shreds might have an impact on the landfill's internal stability. Rubber shreds and concrete mixes have different shear strengths. They do, however, contain shear strength qualities that should ensure the landfill's stability (Koerner & Soong, 2000).

2.10 Crumb Rubber Production

Waste tyre rubber is generally classified into three basic types during study. As illustrated in Figure 2.5, the discarded rubber tyre has been turned into chipped, crumb, and ground rubber, which will be utilised to substitute various kinds of components in a concrete mix. Gravel will be replaced by chipped or shredded rubber particles (coarse aggregates). The tyres must be shredded in two phases to create these rubber particles. The chipped tyre rubber will be 300–430 mm long and 100–230 mm broad by the conclusion of stage one. Steel fibre was separated from tyre chips after primary granulation and before being introduced into secondary granulation. By cutting the rubber, the second step reduces the size to 100–150 mm. Only when shredding process is repeated, the particles generated with diameters of 13–76 mm are referred to as "shredded particles." Proceeding on, the crumb rubber that substitutes sand (fine aggregate) is made in special mills that turn large rubbers into little broken particles. Varying mills and temperatures may yield different sizes of rubber particles. Depending on the mill and temperature, different sizes of rubber particles may be produced. Simple technique creates uneven 0.425–4.75 mm particles.

The final category, ground rubber, which may be used to substitute cement, is dependent on the size reduction equipment. The tyres go through two phases of magnetic separation and screening. In increasingly complicated methods, different size percentages of rubber are recovered. Micro-milling produces particles with a diameter of 0.075–0.475 mm (Sofi, 2018).

FIGURE 2.5: Chipped, Crumb, and Ground Rubber (Thomas et al., 2015)

2.11 Advantages of Adding Crumb Rubber to Concrete

The addition of crumb rubber to concrete offers a number of benefits that have the potential to help advance the building and construction sector. Rubberized concrete, in addition to make use of recycled tyres as aggregates to lessen its effect on the environment, has the mechanical qualities that are necessary for and beneficial to its use in the area of building. It has been shown that rubberized concrete has a high capacity for the absorption of energy when subjected to impact loads. Because of its high strength and capacity to absorb a significant amount of sound energy, rubberized concrete has been utilized in the building of roadside blocks and barriers. To lessen the danger of harm to drivers and passengers, roadside barriers built of rubberized concrete may be used. Energy absorption potential of rubberized concrete under a dynamic charge has been studied in a number of impact studies.

The impact efficiency of columns made of rubberized concrete has been found to have much greater energy absorption capacity under impact loading. A 63% improvement in the column's capacity to absorb energy has been achieved by increasing the rubber material percentage from 0% to 30%. Before they failed, the conventional concrete column had roughly twice the displacement that the rubberized concrete column had. The rubberized concrete column also failed (Pham et al., 2019). In addition to this, the results of the impact tests that were performed on rubberized concrete that included 25 percent crumb rubber indicated that the energy absorption increased as the rubber concentration rose. In addition, the use of rubber may increase the impact resistance capability of rubberized concrete by as much as sixty percent. The peak impact force might be significantly reduced and the duration of the impact could be increased by adding rubberized concrete, according to impact tests performed on rubberized concrete using an Instron machine. The maximum impact force may be reduced by up to 50% and the duration of the impact can be increased using rubberized concrete, according to drop-weight experiments on rubberized concrete cylinders conducted in the axial direction. In addition, the rubber element in concrete might slow the spread of fractures in the material. As a result, rubber-containing concrete has stronger flexural strength, ductility, and damping capacity than normal concrete. Rubberised concrete, which incorporates rubber particles, has the advantages of low density, acid resistance, chloride permeability resistance, excellent sound absorption, freeze-thaw resistance, increase, and toughness. Rubberized concrete's qualities make it suitable for applications such as lightweight concrete, pavements, noise screens, rubberized beams with excellent impact resistance, and reinforced columns for earthquake-resistant constructions.

Adding crumb rubber into the concrete mixture has been shown to increase sound absorption, damping capabilities, and heat resistance, according to a review of the literature on the subject. It has been shown that the pore water pressure in steel fibre reinforced concrete is decreased due to the voids formed by the decomposition of crumb rubber at high temperatures. In addition, concrete with 8-12 percent crumb rubber has enhanced post-thermal hardness.

2.12 Disadvantages of Adding Crumb Rubber to Concrete

2.12.1 Compressive Strength

It is possible to see a slow but steady decline in compressive power as the amount of crumb rubber in the material rises. The following are the elements that contribute to a reduction in the compressive strength of rubberized concrete:

- A crumb rubber binder will keep the particles together in the cement paste. It has been compared to the bonding between cement paste and natural aggregate in concrete, the bonding between crumb rubber and cement paste is weaker. Because of unequal pressure distribution, fractures occur more rapidly.
- Crumb rubber will bond the cement paste's aggregates. This cement paste is more flexible than one without rubber. It causes quick fractures around rubber particles upon loading, leading to rapid specimen failure. (Sofi, 2018).

- Concrete's compressive strength depends on its chemical, biological, and mechanical properties. If rubber is utilised to partially replace the concrete mix, the strength will decrease.

2.12.2 Tensile Strength

Tensile strength is the highest amount of stress that a material can endure when being pushed or stretched before it gives way and breaks. The tensile strength may gradually decrease as the amount of crumb rubber in the material grows, which is something that we may notice. This results in the concrete having a lower rigidity compared to concrete made in the traditional manner. The tensile strength is directly proportional to the strength of the matrix as well as the adhesion between the cement and the particles (Karimipour et al., 2021). Due to the poor inadequate connection between rubber particles and cement paste, stress will build up in the concrete's tensile zone, lowering its tensile strength.

2.12.3 Flexural Strength

The amount of force needed to shatter a test sample with a certain measurement diameter is indicated by the property known as flexural strength. If this value is achieved, the specimen being tested will be broken. When the value is greater, the material is able to tolerate more impacting pressures. It was found that the flexural strength of rubberized concrete decreased with an increase in the replacement amount of crumb rubber. This was one of the observations that was made. With an increase in the percentage of rubber replacement from 5 percent to 8 percent, the flexural strength of CRC decreased from 5.2 MPa all the way down to 2.3 MPa which can be observed in Table 2.1 below. The replacement of the mixture resulted in a greater decrease in the material's flexural strength (Mutar et al., 2018).

TABLE 2.1: Flexural Strength Test of Mixes (Mutar et al., 2018)

Type of Mix	w/c	Flexural Strength	
		7 Days	28 Days
R	0.42	2.8	5.2
5 % C.R.C	0.42	2.5	3.1
6 % C.R.C	0.42	2.6	3.2
7 % C.R.C	0.42	2.3	2.8
8 % C.R.C	0.42	2.1	2.3

2.13 In cooperating Crumb Rubber in Geopolymer Concrete

Based on the research that has be done when crumb rubber and geopolymer is combined and the following conclusion can be made which is rubberized concrete improves ductility and impact resistance, but somewhat diminishes compressive, tensile, and flexural strengths, according to the conclusions of this review. Since the strength of rubberized concrete has gradually decreased, it has been recommended that it be adjusted by partly substituting geopolymer concrete for cement to increase the strength of the concrete. The research demonstrates that using scrap rubber tyre fibre as a substitute for sand is not only cost-effective, but also a user- and eco-friendly pathway for generating rubberized Geopolymer concrete without jeopardising its sustainability.

To create and maintain crumb rubber as a partial replacement for fine or coarse natural aggregate materials, however, clear and additional proofs are required, as only limited information is available on the mechanical properties of rubberized geopolymer concrete containing rubber or crumb rubber as synthetic aggregates.(Luhar & Luhar, 2021). Even though there isn't much information about how rubber and some of the other substances in rubberized geopolymer concretes interact, its mixes have been found to have good strength, ductility, and impact resistance when used in structural elements that are subject to both impact and dynamic loads, such as bridge approach slabs, airport runways, railway buffers, and so on. From the properties of geopolymer , the geopolymer is very brittle, hence to enhance the geopolymer by in cooperating the crumb rubber it increases the ductility. In only seven days, geopolymer concrete gains 95 percent compressive strength. OPC concrete has a lower compressive strength than geopolymer concrete. Moreover because of the strong connection between the geopolymer paste and aggregate, geopolymer concrete has a greater tensile strength than OPC concrete. Apart from that rubber inclusion will increases the flexural strength of rubberized geopolymer concrete (Luhar et al., 2019).

CHAPTER 3

METHODOLOGY

3.1 Introduction

Numerous researchers are breaking new ground in the field of environmentally friendly engineering, and there are many research papers accessible on the topic of the use of rubberized geopolymer concrete and its variations. A plethora of research papers that may be accessed via many internet sites as well as printed documents. Therefore, in order to have an idea about the parameters that need to be considered in this project, such as compressive strength and tensile strength, a multitude of research papers were required to fully understand the role of crumb rubber in geopolymer in determining the compressive, flexural and tensile properties. This was necessary in order to get an idea about the parameters that need to be considered in this project. Researching these publications led to the discussion of new, cutting-edge concepts that may be put to the test in future investigations. Reading a variety of journals may be beneficial for a more in-depth selection of testing procedures, where factors such as generalizability, test efficiency, and the availability of relevant equipment were all key considerations.

3.2 Methodology Flow Chart

The goal of this research is to explore the tensile characteristics of rubberized geopolymer concrete that has been combined with crumb rubber that works as fine aggregate replacement and cement replacement with geopolymer, alternately, using the Response Surface Methodology software (RSM). RSM is a set of mathematical and statistical approaches for developing empirical models that will be employed in this project. The collected data will be determined and documented using laboratory tests such as compressive strength testing, direct tensile testing, and flexural tensile testing. Figure 3.1 depicts a flowchart of the procedure of all the tasks and testing included in this project.

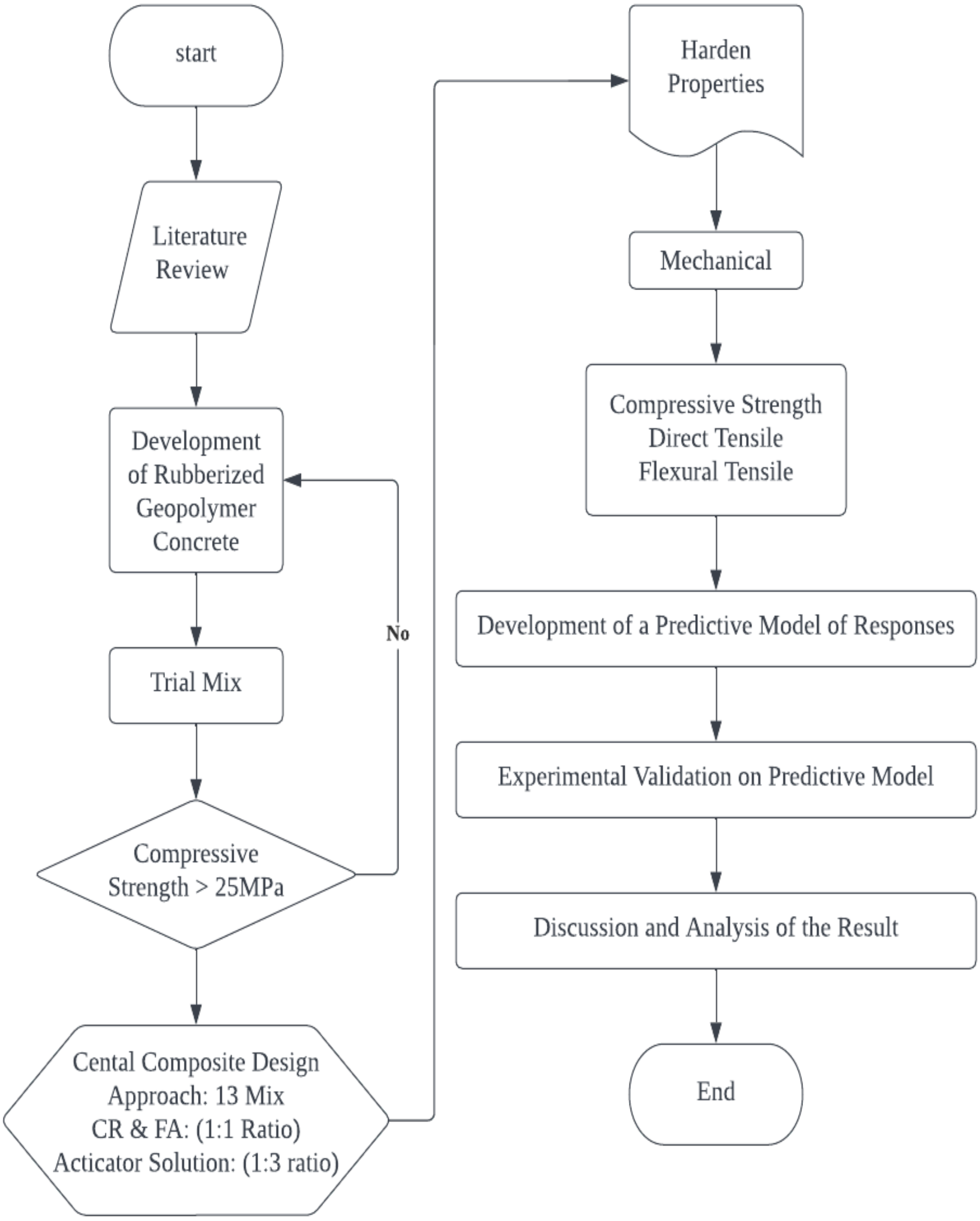

FIGURE 3.1: Flowchart of Methodology of Final Year Project

3.3 Materials

In this experiment, concrete with a standard mix design will be modified by replacing the concrete with geopolymer and the addition of crumb rubber. The materials are described in depth in the following sections.

3.3.1 Crumb Rubber

To begin the process of preparing crumb rubber, discarded tyres are first shredded into pieces of between 100 and 50 millimetres. The first step of the granulation process is called the main stage, and the second stage, which is known as the secondary stage, is responsible for further reducing the size of the rubber particles to between 5mm and 0.6mm. During the primary granulation step, the steel wire that is included inside the tyre chips is extracted and removed before the secondary granulation stage begins. After that, the tyre chips are ground up into smaller mesh sizes, which ultimately results in the production of crumb rubber that has the requisite gradation after being ground up or cracked in the rolling mills. During the manufacturing process, gravity separators and aspiration equipment were used to remove metal and fibres from the product. Table 3.1 future illustrates the properties of crumb rubber.

TABLE 3.1: Properties of Crumb Rubber(Mohammed, 2010)

Properties	Crumb Rubber
Specific Gravity	0.54
Fineness Modulus	2.36
Water Absorption (%)	-

3.3.2 Fly Ash

Fly ash is produced in electric and steam production units that use coal as their primary fuel source. In most cases, the coal is ground into a fine powder before being blasted together with air into the combustion chamber of the boiler. Once there, the coal ignites quickly, resulting in the production of heat and a molten mineral residue. For this study, we are making use of a fly ash that belongs to the Class F category. Table 3.2 shows the chemical composition and properties of fly ash.

TABLE 3.2: Chemical Composition and Properties of Fly Ash (Mohammed, 2010)

Oxide/Property	FA (%)
CaO	6.57
SiO_2	62.4
Fe_2O_3	9.17
Al_2O_3	15.3
K_2O	1.49
MgO	0.77
SO_3	0.65
P_2O_5	1.23
TiO_2	1.32
MnO	0.77
Na_2O	0.39
Loss on ignition %	1.25
Specific gravity	2.38
Blaine Fineness (m^2/Kg)	290

3.3.3 Aggregates

Fine aggregates are an essential component of every form of concrete mixture. This experiment uses ordinary, locally procured, cleaned river sand according to ASTM C33 (ASTM, 2055i). The aggregate size is defined as sand particles no bigger than 4.75 millimetres (passing no.16 sieve). Before being utilised, the sand must be meticulously dried and processed in accordance with the specifications. It is vital to notice that the aggregate must not contain any moisture prior to mixing, and that the sand must not be heavily polluted by external chemicals. Crushed stone aggregates sieved via sieves measuring 14mm to 20mm will be utilised for coarse aggregates. Before use, the coarse aggregates manufactured in accordance with ASTM C33 (ASTM, 2055i) must be thoroughly dried. The river sand and coarse aggregates sieve analysis was done in accordance with ASTM C136 (ASTM, 2005d).

3.3.4 Sodium silicate

In the geopolymerization process, sodium silicate (Na_2SiO_3) is employed as an alkaline activator. Na_2SiO_3 is a key component in geopolymerization technique. This material may be found in both a solid state and a liquid state, earning them the names "water glass" and "liquid glass," respectively.

$$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2 \qquad \text{(Eq 1)}$$

In this experiment sodium silicate that had roughly a 2:1 ratio of SiO_2 to Na_2O in its composition is utilised. This equates to 14.7% sodium oxide, 29.4% silicon dioxide, and 55.9% water.

3.3.5 Sodium Hydroxide

Lye and caustic soda are other names for the inorganic chemical sodium hydroxide. The most common alkaline activator is a combination of sodium hydroxide and sodium silicate, and when NaOH is included in the activating solution, the reaction happens more quickly and the gel is less smooth. Sodium hydroxide is a white solid and a highly caustic metallic base and alkali that may be purchased in powder, granules, and as prepared solutions of varying concentrations.

3.3.6 Water

Water is an important part of the mix because it brings together all the other components that make up concrete. The strength of concrete comes from the reaction between the cement and water, which is called "hydration." Even though tap water can be used in this experiment, the pH levels of the water must not be too acidic or alkaline. If they are, the properties of the rubberized concrete will be changed. Utilizing the correct quantity of water is crucial for determining the best service life of rubberized concrete.

3.4 Response Surface Method

In order to construct empirical models, mathematicians and statisticians developed the Response Surface Methodology (RSM). The basic purpose of well-planned experiments is to generate independent reactions to the input factors entered in, which would then be measured by analyzing the output variables. One way to learn what factors influence a system's output is via a controlled set of experiments known as an experiment. According to RSM, the optimal response value may be determined by establishing an empirical link between the process parameters and the output response. Utilizing a design specialist allowed us to include RSM optimization, which smoothed up the process of reaching our goal. Crumb rubber (CR) and sodium hydroxide ($NaOH$) concentrations range from 10-34.14% and 10-14.82%, respectively, in this experiment. Using the central composite design (CCD) method, the RSM tested 13 various proportions of crumb rubber to sodium hydroxide. All of the mixtures were made in the lab, and the fresh and hardened characteristics of the rubberized geopolymer concrete were determined as described in Section 3.5. The data collected from the experiments was inputted back into the programme for further evaluation.

TABLE 3.3: The Number of Runs of Response Surface Method (RSM) using CR and NaOH

Run	Factor A: NaOH (M)	Factor B:CR (%)	Fly Ash (Kg)	Crumb Rubber (Kg)	Fine Aggregate (Kg)	Sodium Hydroxide (Kg)	Sodium Silicate (Kg)	Water (Kg)
1	10	10	12.96	0.65	5.83	1.15	3.4	1.29
2	12	20	12.96	1.29	5.19	1.15	3.4	1.29
3	12	30	12.96	2.21	4.27	1.15	3.4	1.29
4	14	10	12.96	0.65	5.83	1.15	3.4	1.29
5	12	20	12.96	1.29	5.19	1.15	3.4	1.29
6	12	20	12.96	1.29	5.19	1.15	3.4	1.29
7	12	10	12.96	0.38	6.10	1.15	3.4	1.29
8	12	20	12.96	1.29	5.19	1.15	3.4	1.29
9	14	30	12.96	1.94	4.54	1.15	3.4	1.29
10	12	20	12.96	1.29	5.19	1.15	3.4	1.29
11	10	20	12.96	1.29	5.19	1.15	3.4	1.29
12	10	30	12.96	1.94	4.54	1.15	3.4	1.29
13	14	20	12.96	1.29	5.19	1.15	3.4	1.29

3.5 Experimental work (Hardened Properties)

3.5.1 Compressive Strength

In compliance with these standards, the compressive strength test has been carried out base on (BS EN 12390-3: 2019). Before conducting the compressive strength test, nine samples in the form of cubes measuring 50 millimetres on each side will be created. After the curing process, the compressive strength test is performed on the third day, seventh day, fourteenth day, and the twenty-eighth day. The compressive strength test will be carried out using the techniques that are outlined in (BS EN 12390-3: 2019).

FIGURE 3.2: Compressive Strength Test

3.5.2 Direct Tensile Strength

The dog bone sample used in the direct tensile test have dimensions of 50 millimetres by 130 millimetres by 420 millimetres This research study applies uniaxial stress to specified cementitious composites to assess their tensile strength in line with a standard set by the Japan Society of Civil Engineers. This test involves shaping customised cementitious composite briquettes into the required shape before placing them in a device that may apply a tension force. By measuring the force required to split a sample in half and then averaging those two results, the tensile strength of a material may be calculated. Utilizing a 200 kN load-capable equipment from the Universal Testing Machine, the tension test was performed. Two samples of each combination were examined for their tensile strength at a loading rate of 0.15 millimetres per second after curing in the environment for 28 days. Equation 1.0 is used to get the tensile as the modulus of rupture (R).

$$f_u = \frac{Fu}{A} \qquad \text{(Eq 2)}$$

Where:

f_u = Tensile Strength (N/mm²)

F_u = Tensile Capacity (N)

A = Nominal cross-sectional area of a test piece (mm²)

FIGURE 3.3: Direct Tensile Test

3.5.3 Flexural Tensile Strength

A beam sample with the dimensions 500mm x 100mm x 100mm is subjected to a flexural test. The flexural strength is measured using the four-point loading (ASTM D5045-14) technique, and is reported in megapascals (MPa) for units of measurement. After 28 days, a flexural test was performed. A universal testing equipment with a 200-kN force capability and built-in data logging and computer display was used for the evaluation. Figure 10 depicts the placement of the sample on the two stands. The sample was subjected to a load of 0.051 mm/s until it broke. The screen showed both the failure load and the deflection. Next, we used Equation 2.0 to get the flexural strength as the modulus of rupture (R).

$$R=\frac{PL}{bd^2} \qquad \text{(Eq 3)}$$

Where:

R = modulus of rupture, (MPa),

P = maximum applied load (N),

L = specimen length, [mm]

b = width of specimen, [mm]

d = average depth of specimen, [mm], at the fracture.

FIGURE 3.4: Flexural Strength Test

CHAPTER 4

RESULT & DISCUSSION

4.1 Test Result

This chapter describes the outcomes of the experimental studies that were carried out on 13 RSM produced mixes of the rubberized geopolymer concrete as described in chapter three. These mixes were tested in accordance with the procedures stated in chapter three.

4.1.1 Compressive Strength of Rubberized Geopolymer Concrete

The results of a compressive strength test that was performed on the samples after 7 and 14 days of curing are shown in figure 4.1, respectively.

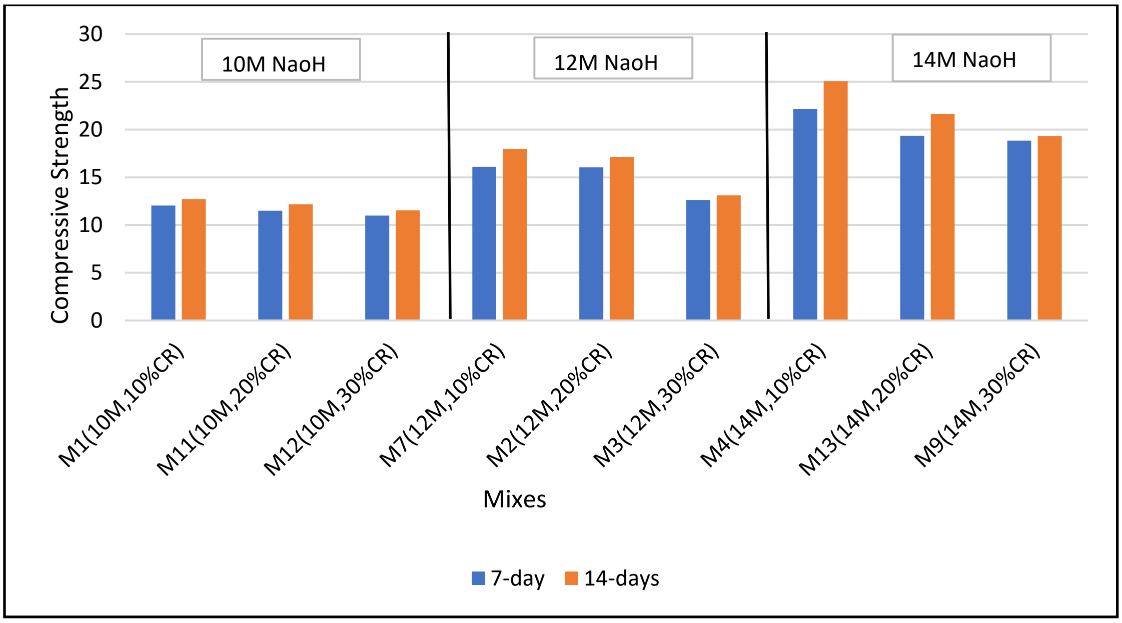

FIGURE 4.1: Compressive Strength Results

According to the experiments conducted, the concrete reaches its optimum strength on the 14th day. After 14 days, mix 4 has the highest compressive strength because to its 10% crumb rubber content and 14 M sodium hydroxide which is 25.073Mpa. However, mix 12 with 30% crumb rubber and 10 M of sodium hydroxide now holds the record for the lowest 14-day compressive strength which is 11.540Mpa. Compressive strength is greater in mixtures with a greater Sodium Hydroxide molarity. This is due to the fact that a higher sodium hydroxide concentration in the mixture causes a larger degree of dissolution, which enhances the microstructure. The overall findings indicate that a greater replacement level for crumb rubber resulted in a decrease in compressive strength. When compared to mixes with varied amounts of crumb rubber but the same sodium hydroxide molarity, mixes with more crumb rubber replacement exhibited lower compressive strength. Due of the pozzolanic reaction of fly ash, it is anticipated that the mixes' compressive strength would increase after 28 days. The hydration response is the dominant one at young ages of curing, and the fly ash reactivity is low, according to reports in the literature (Ammasi 2018).

In accordance with JKR 20800(2005), the minimum amount of pressure that a slab or other minor load-bearing item must be able to resist is 17 MPa. As shown in the graph above, as long as the sodium hydroxide concentration is between 12M and 14M, five out of the thirteen mixes that have a crumb addition of 10-20% are found to be compliant. As a result of capillary porosity, which permits the mortar strength to erode, the addition of 30% crumb rubber lowers the concrete's compressive strength. Since crumb rubber particles are less dense and have a lower elastic modulus than sand particles, they act as soft patches inside the composite, causing its compressive strength to be lower overall. Furthermore, rubbercrete strength declines due to insufficient cement matrix-to-crumb-rubber-particle bonding (Mohammed, Awang et al. 2016).

4.1.2 Flexural Strength Result

Flexural tests are used to measure the composite's flexural strength (modulus of rupture) and deflection behavior. It provides a proximate measurement of the concrete's tensile behavior. The primary parameter of interest in this study is the rubberized geopolymer concrete's flexural behavior. Figure 4.2 shows the flexural strength of the rubberized geopolymer concrete measured at 28 days of curing. Flexural strength results exhibit a decreasing trend with rising crumb rubber substitution. The cause of the decrease in flexural strength is mostly due to the low adherence of crumb rubber particles to the matrix. Nevertheless, replacing the molarity of sodium hydroxide also has a greater impact on strength than replacing the crumb rubber. The same explanation stated for the decrease in compressive strength is also used to explain the decrease in flexural strength with crumb rubber.

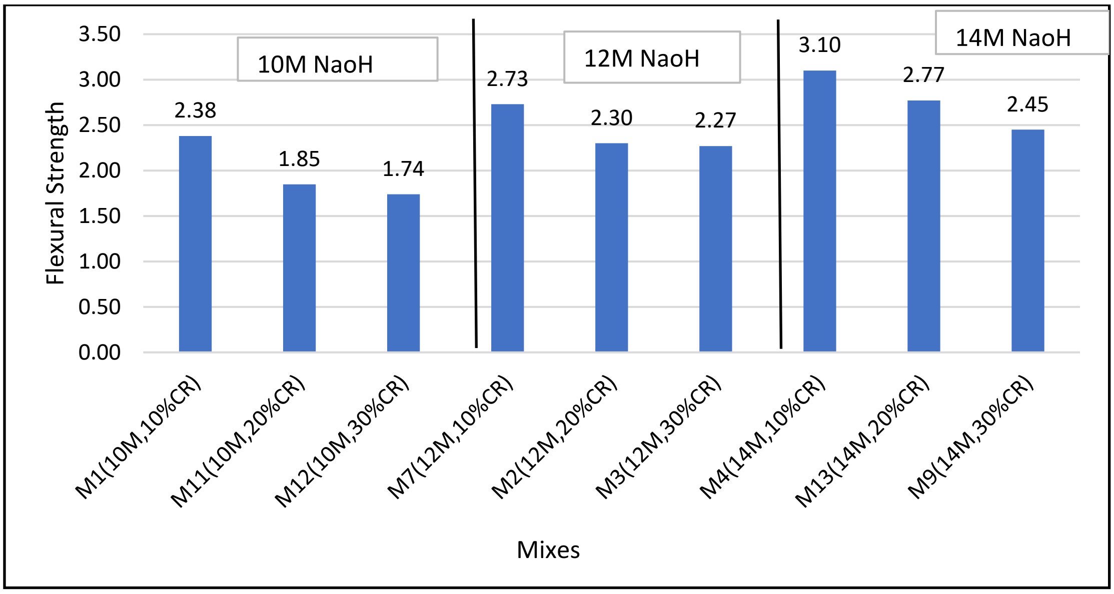

FIGURE 4.2: Flexural Strength Result

It was discovered that after 28 days, the flexural strength of Mix 4, which includes 10% crumb rubber and 14M sodium hydroxide, is the greatest, at 3.1 MPa, while the flexural strength of Mix 12, which contains 30% crumb rubber and 10M sodium hydroxide, is the lowest, at 1.74 MPa. The structural design of concrete relies heavily on its flexural strength. It determines a material's resistance to bending or stiffness by measuring the force needed to bend a beam. As a result, it is possible to comprehend why there is a proportional decline in the flexural strength of the concrete when there is a rise in the percentage of crumb rubber component. Moreover, it was found that samples with larger crumb rubber replacements showed greater energy absorption capabilities and, therefore, higher deflection values than mixes with lower replacements during the flexural test. Moreover, it was found that samples with larger sodium hydroxide molarity with same amount of crumb rubber substitution showed greater energy absorption capabilities and, therefore, higher deflection values than mixes with lower replacements during the flexural test.

4.1.3 Tensile Strength Result

Tensile strength is determined after the samples have been cured for 28 days. The findings of the splitting strength test performed on the samples on the 28th day are shown in Figure 4.3.

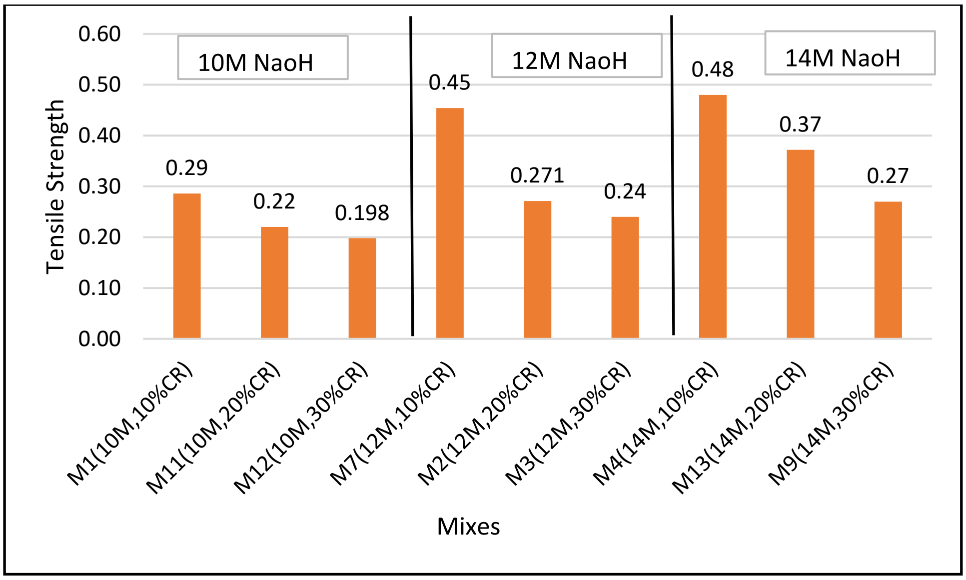

FIGURE 4.3: Tensile Strength Result

According to the Table 10 and Figure 14 it can be observed that the highest tensile strength will be held by mix 4 with 10% crumb rubber and 14M of sodium hydroxide while the lowest tensile strength is held by mix 12 which contains 30% crumb rubber with 10M of sodium hydroxide. From this we can suggest that the tensile strength decreases when the percentage of crumb rubber increases in a sample. This is because the rubber particle itself has a flaky particle size, which gives it a spring-like behaviour. It is also observed that as the molarity of the sodium hydroxide is increased with the same amount of crumb rubber replacement there is an increase in the tensile strength. Therefore, it is possible to demonstrate that a sample consisting of 10% crumb rubber mixed with 14M sodium hydroxide has a greater splitting tensile strength than a sample consisting of 20% crumb rubber mixed with the same molarity of sodium hydroxide. The explanation stated for the lower values of tensile strength, which are attributed to the use of crumb rubber and sodium hydroxide as a substitute, is identical to the one stated for the compressive strength.

4.2 Response Surface Methodology (RSM) Analysis

4.2.1 Response Surface Model

As part of the examination of the study's data, RSM is used to both evaluate and develop models for response prediction. The concentration of NaOH and the CR replacement levels of fine aggregate expressed as a percentage are the two independent variables that were examined as input elements at the very beginning of the process. The responses that are being taken into account are the mechanical properties (compressive, flexural, and tensile strengths). To create empirical data on the responses at 14 and 28 days, experimental runs were built using the central composite (CCD) alternative, as is shown in Table 4.1. These data were derived from the experimental runs themselves.

TABLE 4.1: Response Against variable

Run	NaOH, (M)	CR, %	Compressive Strength (MPa)	Flexural Strength (MPa)	Tensile Strength (MPa)
			14-days	28-days	
1	10	10	12.713	2.38	0.29
2	12	20	17.13	2.3	0.27
3	12	30	13.127	2.27	0.24
4	14	10	25.073	3.1	0.48
5	12	20	17.967	2.3	0.27
6	12	20	17.967	2.3	0.27
7	12	10	17.967	2.73	0.45
8	12	20	17.967	2.3	0.27
9	14	30	19.317	2.45	0.28
10	12	20	17.967	2.3	0.27
11	10	20	12.187	1.85	0.22
12	10	30	11.54	1.74	0.198
13	14	20	21.637	2.77	0.37

According to Equation 4.0 through Equation 6.0, it has been determined that linear models provide an adequate fit for each of the responses. Similar to this, A and B stand in for the input factors, respectively, the NaOH concentration and the CR replacement amounts. The coded factor equation may predict reaction for given factor values. High factor levels are coded as +1 and low levels as -1. The coded equation compares factor coefficients to determine the factors' relative influence.

$$CS= +16.86 + 4.19*A - 1.72*B \quad \text{(Eq 4)}$$

$$FS= +2.33 + 0.2530*A - 0.2426*B \quad \text{(Eq 5)}$$

$$TS= +0.2700 + 0.0605*A - 0.0736B - 0.0270*A*B + 0.0105*A^2 + 0.0355B^2 \quad \text{(Eq 6)}$$

4.2.2 Analysis of Variance of The Response Models

The parameters for model validation are shown in Table 4.2. The coefficient of determination (R^2) is the most crucial variable since it indicates how well the constructed model fits the experimental data. It is to be known that when the R^2 value is higher better model will be produced. These can be written in percentage or expressed as $0 \leq R^2 \leq 1$. R^2 values of 92%, 72%, and 99% are achieved for the developed models in this case for the compressive, flexural, and tensile strength of the models, respectively. Moreover, the signal-to-noise ratio of a model can be quantified with the help of the Adequate precision (Adeq. Presc.) value. A ratio greater than 4 is desirable and can be used to navigate the design space for a model. Based on the model validation the adequate precision value which was obtained are 20.0219 , 10.6227 , and 43.9728 for compressive , flexural and tensile strength.

Analysis of variance was used to validate the constructed models (ANOVA). The study was carried out with a 95% level of confidence, which means that any model or model term with a probability of less than 5% is statistically significant. Since all three models had probability values of less than 5%, it may be concluded that the ANOVA result shown in Table 4.3 is significant. Across all of the generated models, the effect of the NaOH, denoted by A, is the most important model term.

TABLE 4.2: Model Validation

Model Validation Parameter	**Compressive Strength (MPa)**	**Flexural Strength (MPa)**	**Tensile Strength (MPa)**
Std.Dev.	1.23	0.194	0.0091
Mean	16.86	2.33	0.2983
C.V %	7.30	8.34	3.05
R^2	0.9154	0.7226	0.9932
Adj.R^2	0.8984	0.6671	0.9883
Pred.R^2	0.815	0.3912	0.9516
Adeq.Precision	20.021	10.622	43.972

TABLE 4.3: ANOVA Result

Response	Source	Sum of Squares	df	Mean Square	F-value	p-value	Significance
Compressive Strength (MPa)	**Model**	164.01	2	82.00	54.07	< 0.0001	significant
	A-NaOH	140.29	1	140.29	92.51	< 0.0001	
	B-CR	23.71	1	23.71	15.64	0.0027	
	Residual	15.17	10	1.52			
	Lack of Fit	15.17	6	2.53			
	Pure Error	0.0000	4	0.0000			
	Cor Total	179.17	12				
Flexural Strength (MPa)	**Model**	0.9828	2	0.4914	13.03	0.0016	significant
	A-Naoh	0.5121	1	0.5121	13.57	0.0042	
	B-CR	0.4707	1	0.4707	12.48	0.0054	
	Residual	0.3772	10	0.0377			
	Lack of Fit	0.3772	6	0.0629			
	Pure Error	0.0000	4	0.0000			
	Cor Total	1.36	12				
Tensile Strength (MPa)	**Model**	0.0846	5	0.0169	204.48	< 0.0001	significant
	A-NaOH	0.0293	1	0.0293	354.13	< 0.0001	
	B-CR	0.0434	1	0.0434	524.13	< 0.0001	
	AB	0.0029	1	0.0029	35.25	0.0006	
	A^2	0.0008	1	0.0008	9.27	0.0187	
	B^2	0.0088	1	0.0088	105.97	< 0.0001	
	Residual	0.0006	7	0.0001			
	Lack of Fit	0.0006	3	0.0002			
	Pure Error	0.0000	4	0.0000			
	Cor Total	0.0852	12				

Figures 4.4,4.5 and 4.6 exhibit Actual vs. Predicted comparisons for the compressive, flexural and tensile strength of the models respectively, which will be used to further evaluate the models' strengths. The graphs illustrate the relationship between the experimental data and the predicted outcome of the generated models. The way the data points line up along the 45 lines of fit shows that the predicted response and the actual response are pretty close to each other. As a result, the models' strength and accuracy are validated.

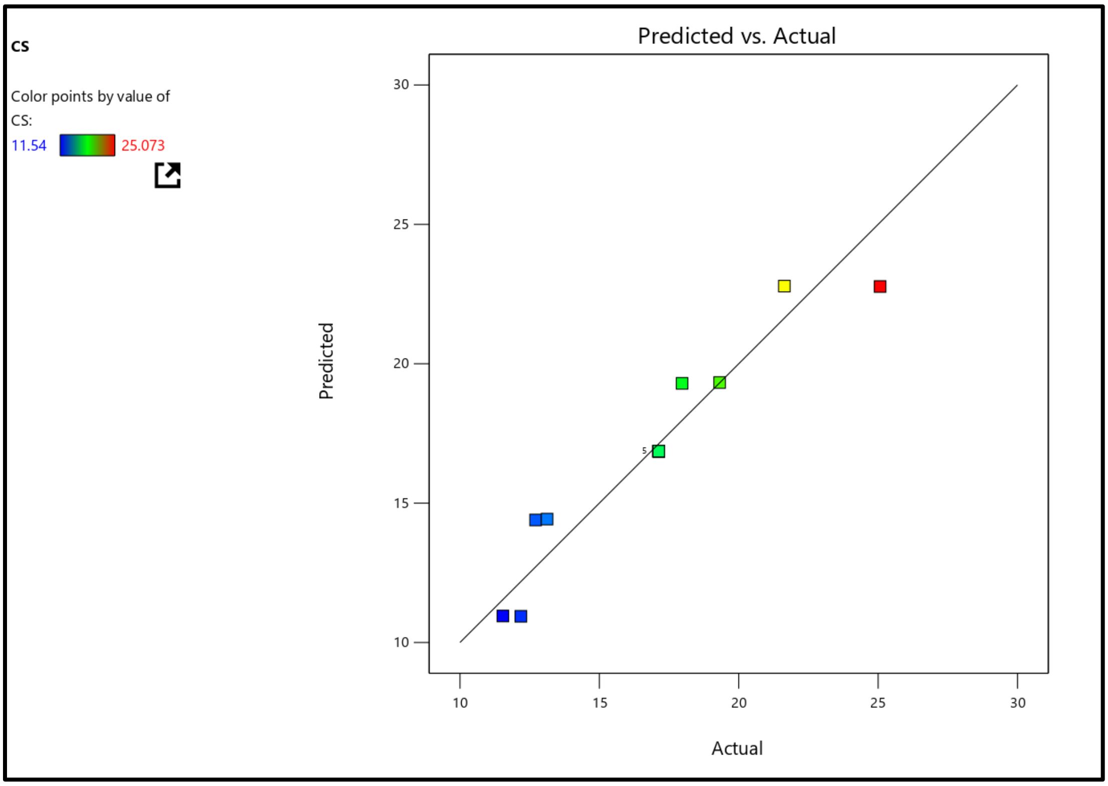

FIGURE 4.4: Actual vs Predicted Graph for Compressive Strength

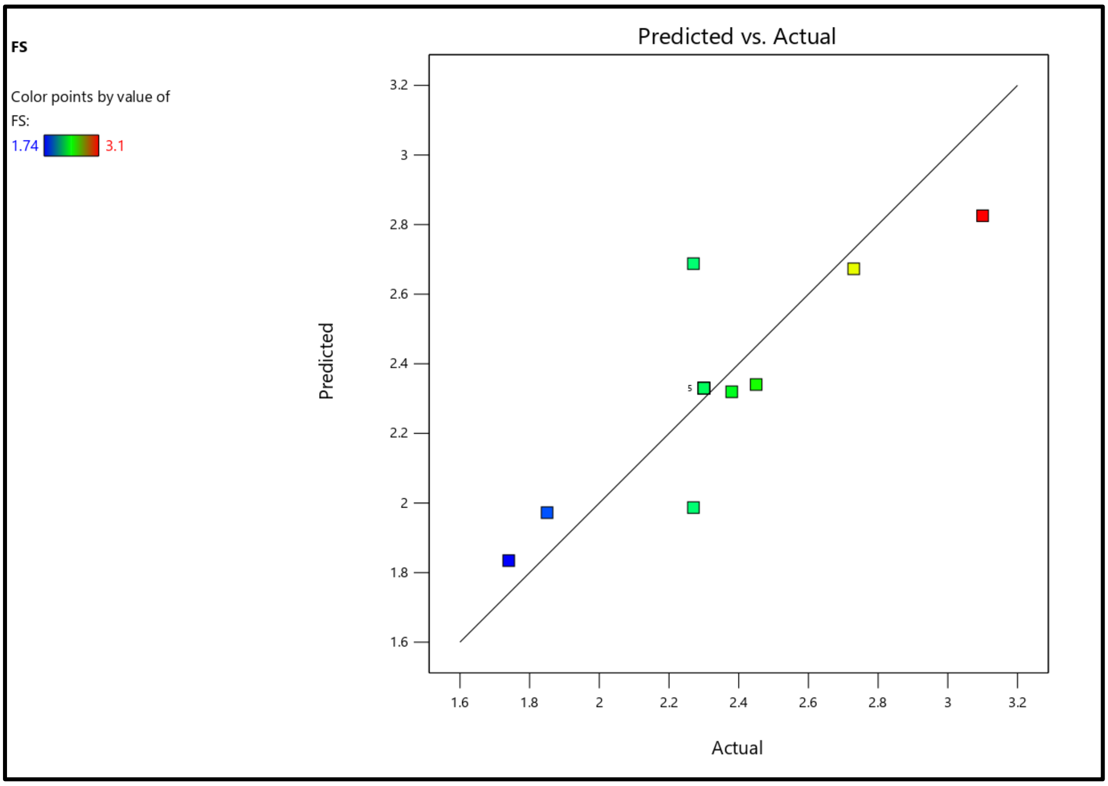

FIGURE 4.5: Actual vs Predicted Graph for Flexural Strength

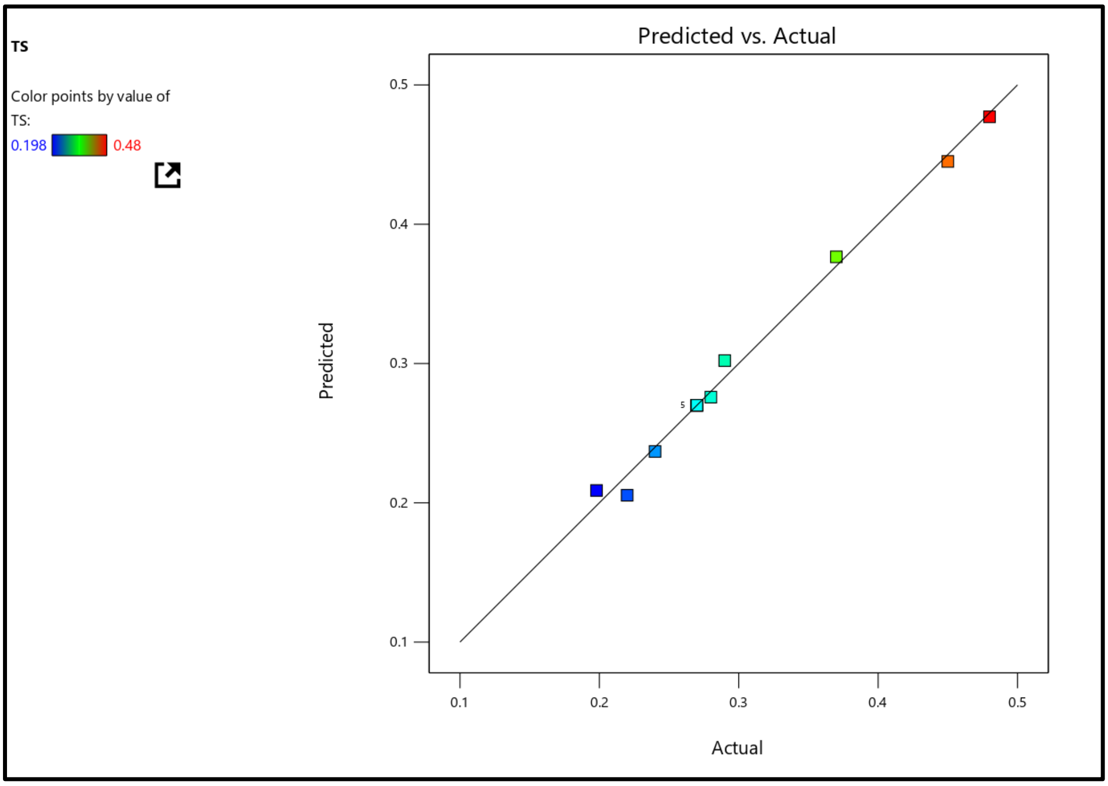

FIGURE 4.6: Actual vs Predicted Graph for Tensile Strength

The 2D-contour and 3D-response surface diagrams is be used to visually show the interaction of the input elements and their individual and combined effects on the responses from figure 4.7 to 4.12 below. Both 2D and 3D graphs provide the same information; however, they are shown in different dimensions. Intensity is shown on the graphs as a scale that ranges from red, indicating maximum intensity, to blue, indicating minimum intensity.

The graphs clearly show that when the NaOH molarity was raised, the composites improved in quality. All of the tested strengths, including compression, flexure, and tensile, match these findings. The mechanical characteristics of the CR were improved due to the NaOH's physical and chemical impacts, as was previously mentioned. The CR surface is physically etchered by the NaOH, which strengthens its connection with the cement paste.

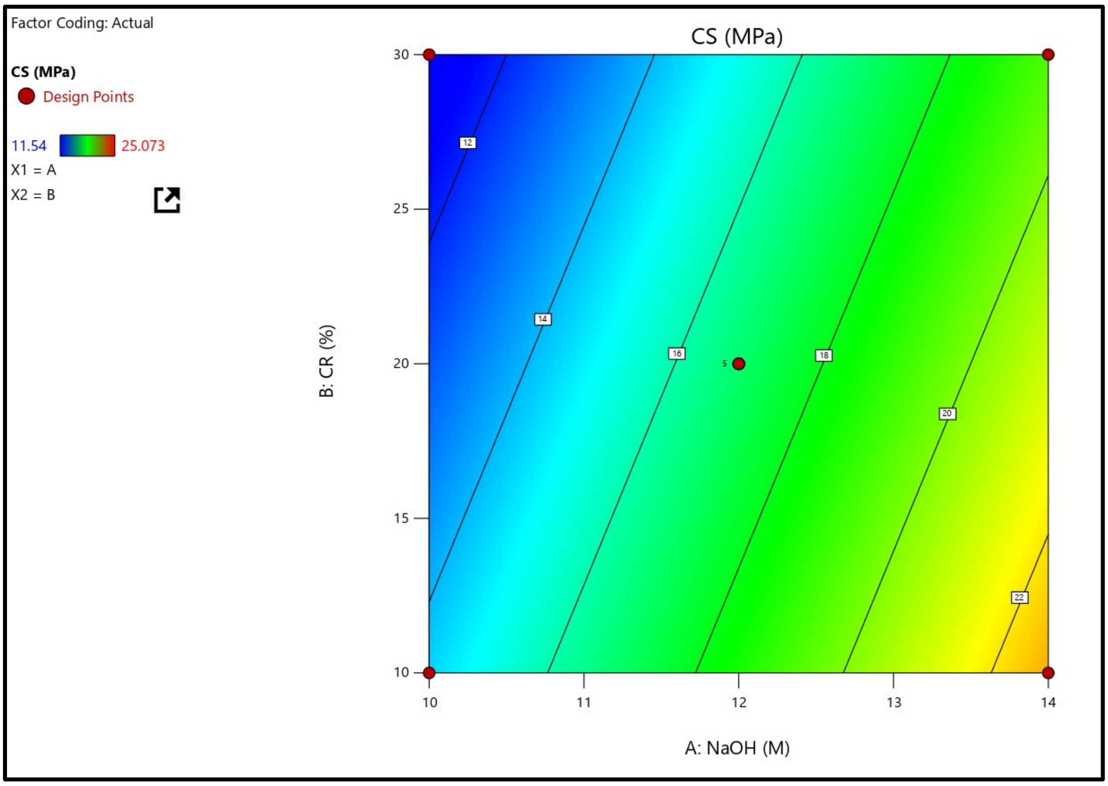

FIGURE 4.7: Response Surface Contour Graph (Compressive Strength)

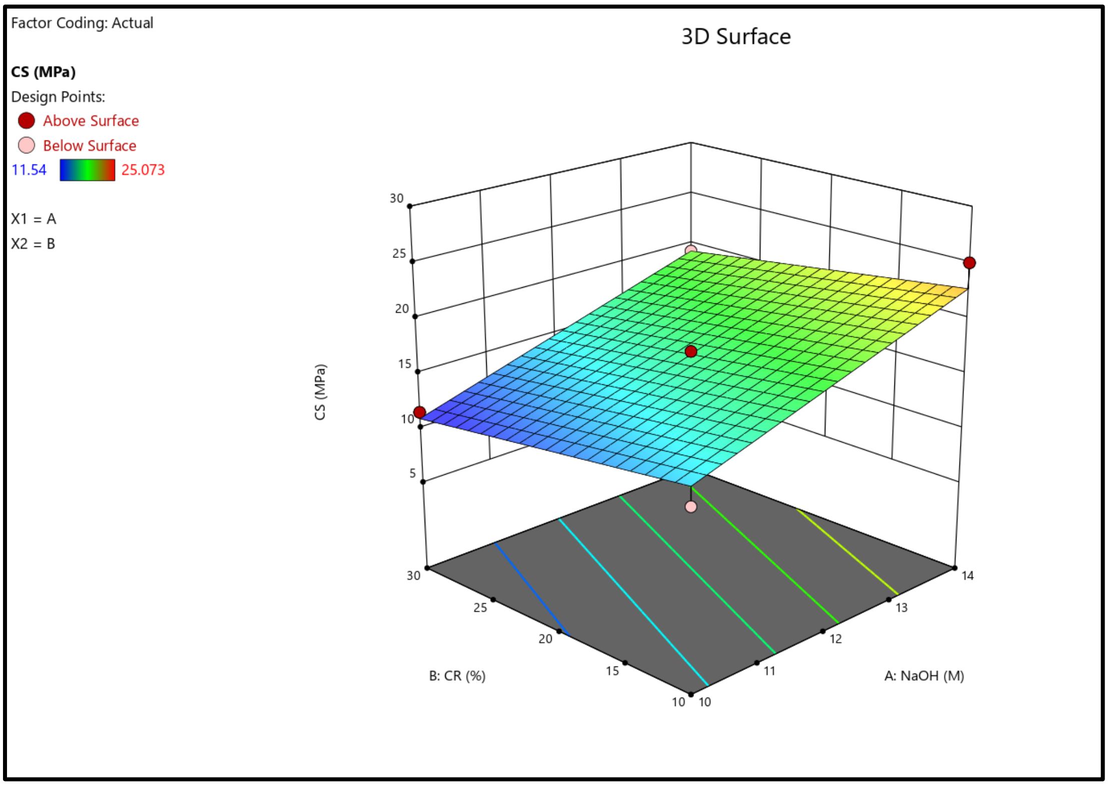

FIGURE 4.8: 3D Response Surface Graph (Compressive strength)

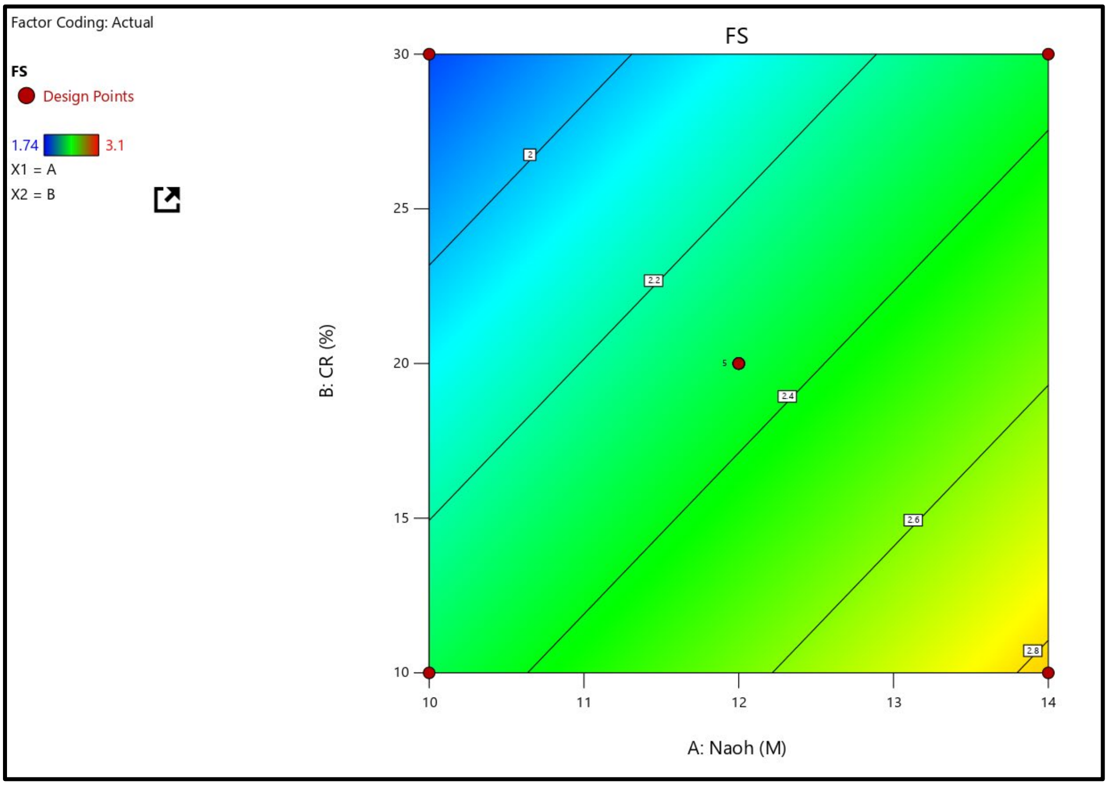

FIGURE 4.9: 2D Contour Graph (Flexural Strength)

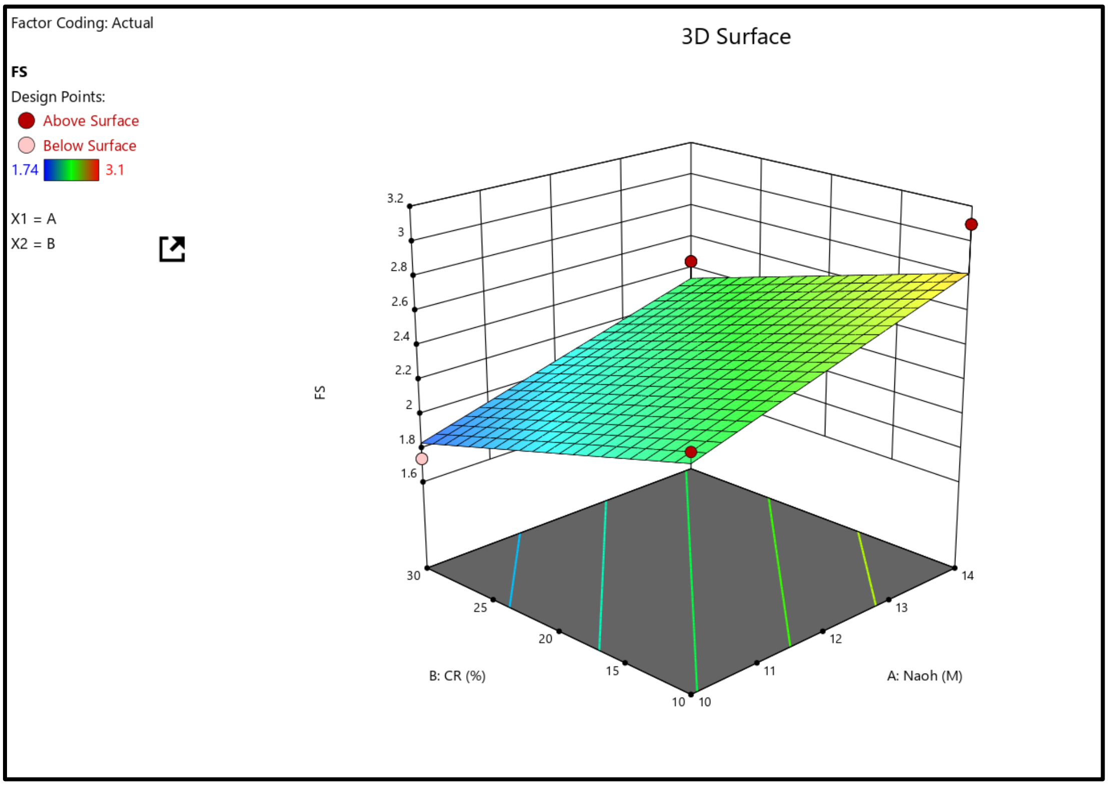

FIGURE 4.10: 3D Response Surface Graph (Flexural strength)

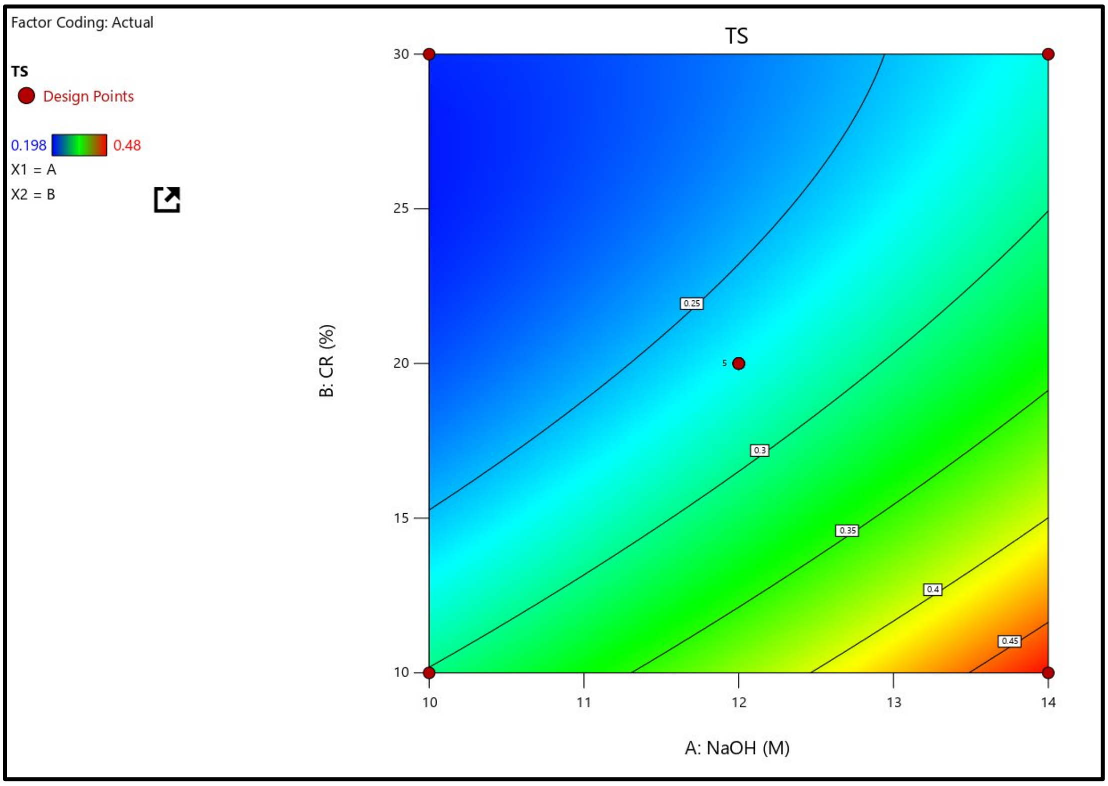

FIGURE 4.11: 2D Contour Graph (Tensile Strength)

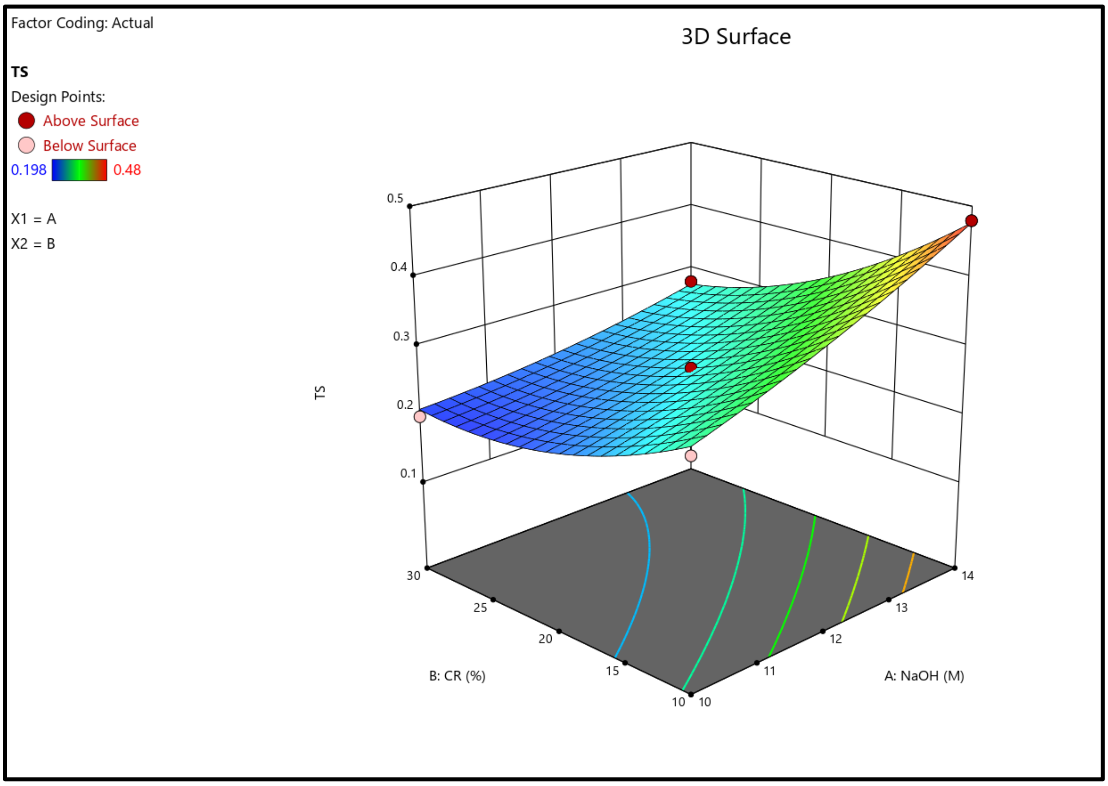

FIGURE 4.12: 3D Response Surface Graph (Tensile Strength)

4.2.3 Optimization

As part of the RSM studies, optimization was undertaken to determine the optimal quantity of NaOH and CR replacement levels that would result in the best mechanical characteristics of the rubberized geopolymer concrete. To accomplish the objective function, goals are specified for the variables (input factors and response) with varying criteria and degrees of relevance. The optimization result is graded on a scale of 0 to 1 (or 0% to 100%) called the desirability value.

Table 14 presents the objectives for this study. In accordance with the predetermined criteria and degree of significance, the system developed an optimum mixture as shown in Table 4.4 for the input components and the desired responses at 83, 80, and 99 percent for compressive, flexural, and tensile strength, respectively. Given that the experiment is subject to various factors and hence outcomes might vary widely, this figure of desirability is quite high. The optimization technique has determined that the values 14M and 10% for sodium hydroxide and crumb rubber, respectively, represent the optimal levels of the input components. The optimum mechanical properties value for the compressive, flexural and tensile strength are 22.77 MPa, 2.83 MPa and 0.477 MPa respectively. From figure 4.13 and 4.18, the optimization solution is shown as ramps and the desirability value is shown as a 3D-response surface diagram.

TABLE 4.4: Optimization Goals and Results

Factors		Input Factors		Responses (Output Factors)		
		NaOH (M)	CR (%)	CS (MPa)	FS (MPa)	TS (MPa)
Value	Minimum	10	10	12.713	2.38	0.29
	Maximum	14	30	19.317	2.45	0.28
Goal		In Range	In Range	Maximize	Maximize	Maximize
Optimization Result		14	10	22.77	2.83	0.477
Desirability				0.83 (83%)	0.80 (80%)	0.99 (99%)

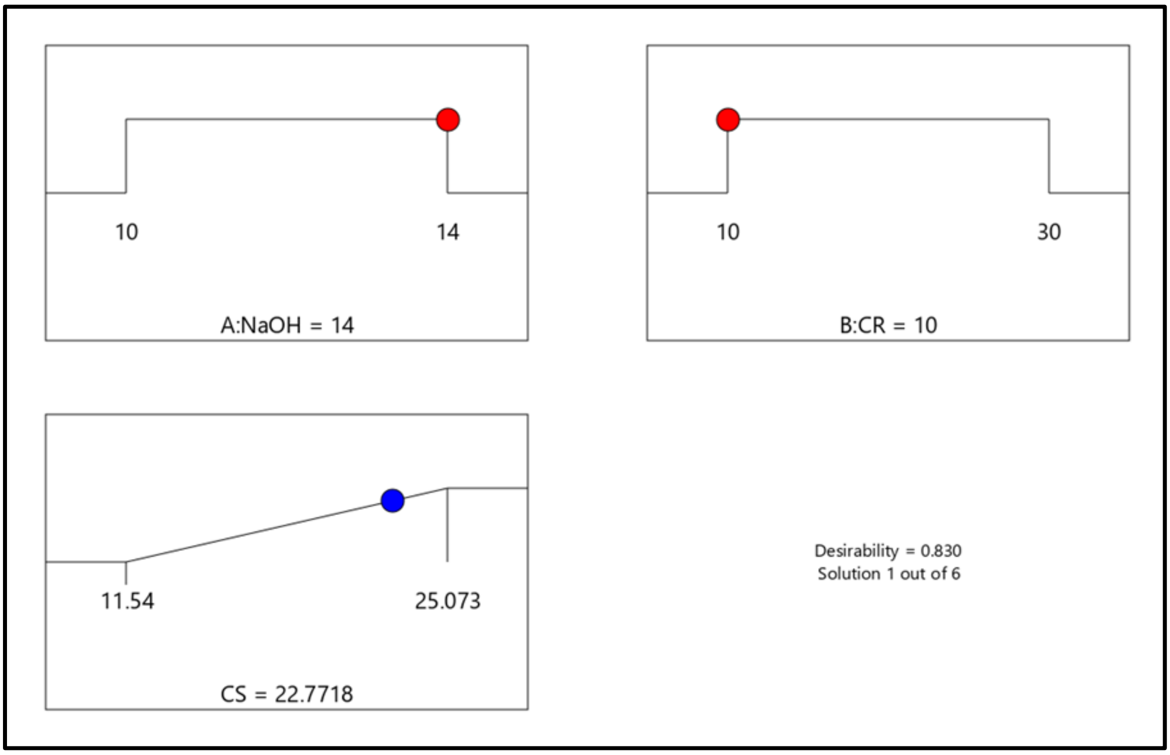

FIGURE 4.13: Optimization Ramp (Compressive Strength)

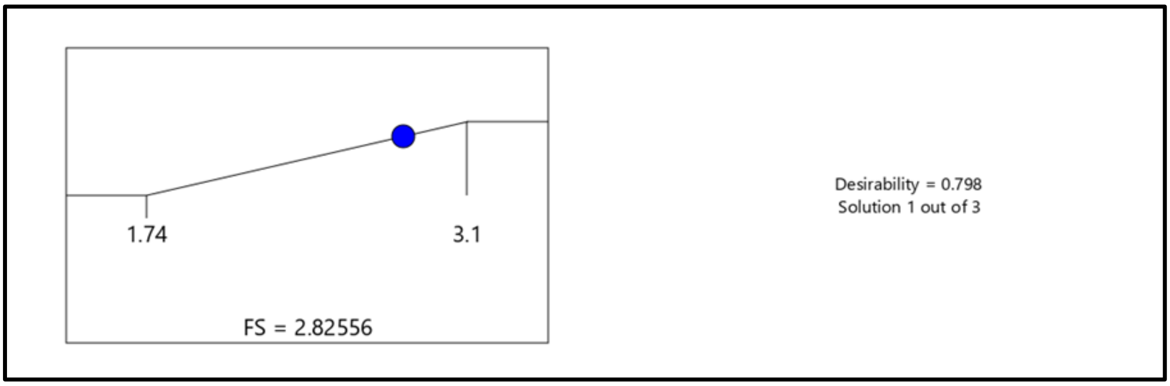

FIGURE 4.14: Optimization Ramp (Flexural Strength)

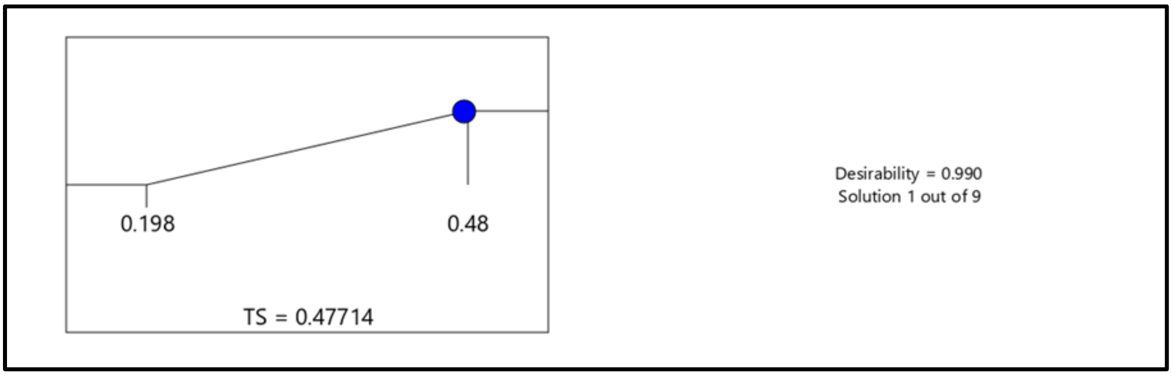

FIGURE 4.15: Optimization Ramp (Tensile Strength)

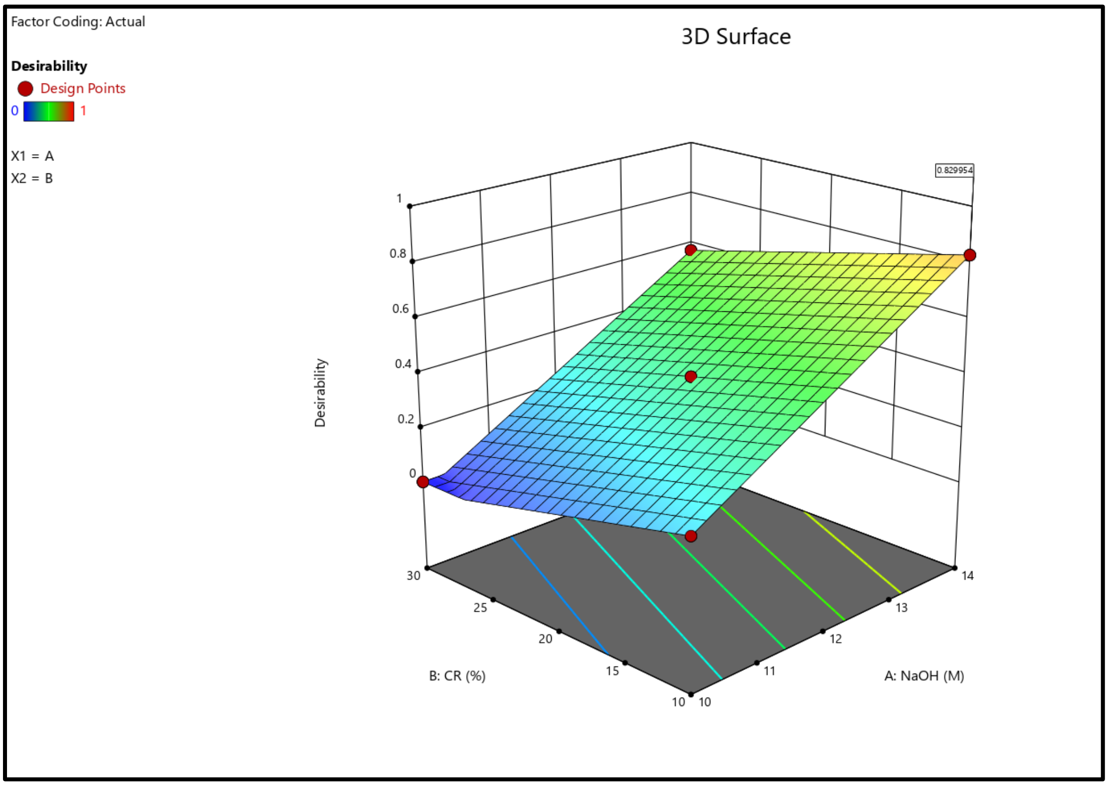

FIGURE 4.16: Response Surface Diagram for Desirability (Compressive Strength)

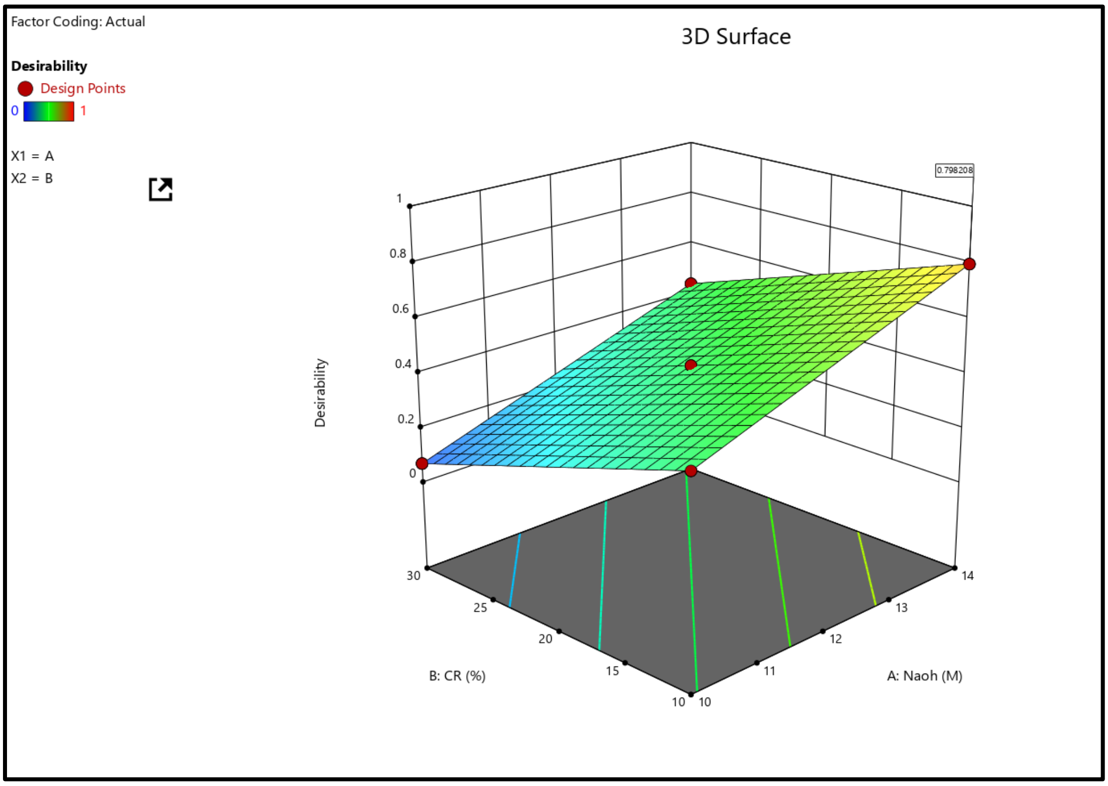

FIGURE 4.17: Response Surface Diagram for Desirability (Flexural Strength)

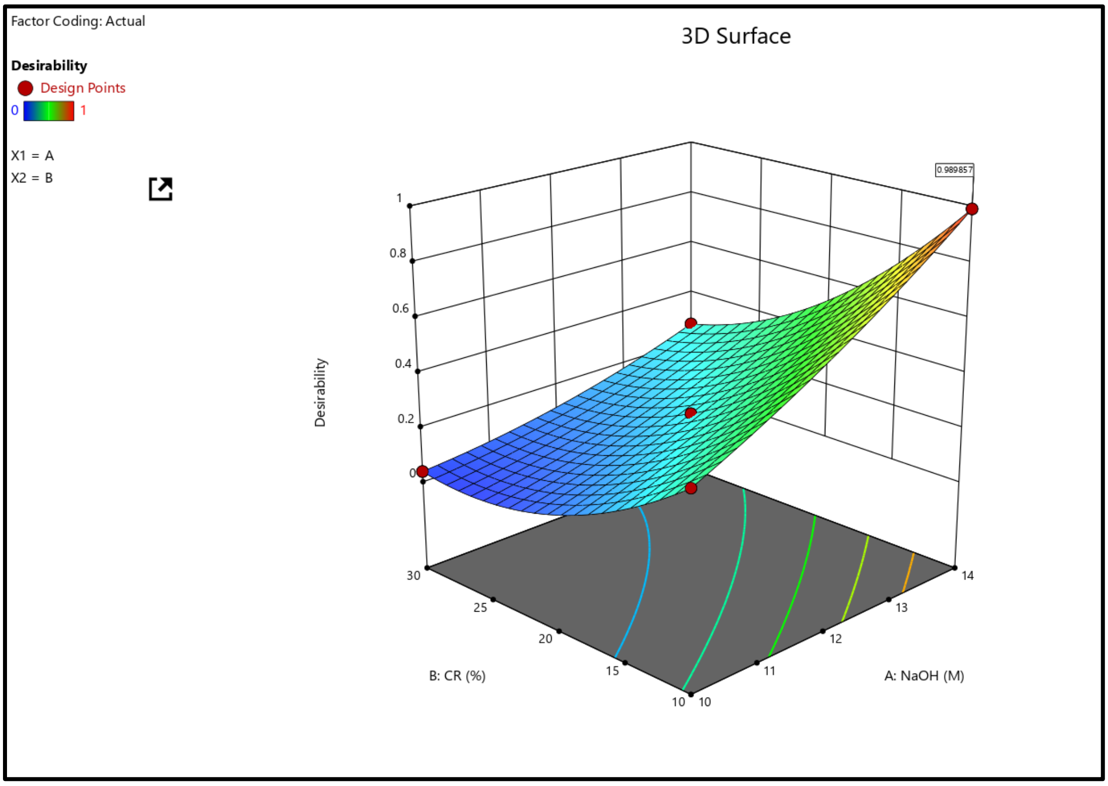

FIGURE 4.18: Response Surface Diagram for Desirability (Tensile Strength)

CHAPTER 5:

CONCLUSION & RECOMMENDATIONS

5.1 Conclusions

At the end of this research, the following conclusions are drawn:

1. Increasing CR replacement has been observed to reduce the composite's mechanical strengths, whereas increasing the NaOH concentration increases those strengths. The compressive strength increased by 49% at 14M of NaOH compared with a mix a lower concentration of 10M of NaOH. The increased concentration of NaOH solution results in a faster dissolving process from silica and alumina leaching. This rapid dissolution will lead to an increase in the geopolymerization reaction and hence increases the strength.

2. As the percentage of crumb rubber used in replacement of fine aggregate rises, the material loses strength in all three aspects (compressive, flexural, and tensile). In addition, the tensile strength at the point of fracture correlates strongly with the flexural strength at the point of fracture. This is because of the high internal stress that runs perpendicular to the direction of the applied load, which is caused by the increased porosity or weakness areas in the geopolymer concrete mix (lack of bonding between crumb rubber and fly ash with alkaline activator).

3. The responses were empirically modelled as linear function for compressive and flexural and as quadratic functions for tensile. The models were validated using ANOVA, and the results showed a high level of accuracy (R2 values between 72.0 and 99.0%).

4. According to the results of the response surface modelling, the optimum mechanical qualities of rubberized geopolymer concrete can be achieved by combining 30% crumb rubber with 14M sodium hydroxide.

5.2 Recommendations

1. To improve the bonding between the CR hardened cement paste, it is recommended to utilize NaOH up to 10M.

2. To develop a rubberized geopolymer concrete for structural purposes, it is advised that the combined sodium hydroxide concentration and crumb rubber concentration should not exceed 10 to 20% for 12M NaOH and 10 to 30% for 14M NaOH, respectively.

3. To ensure the validity of the produced models, it is advised to carry out an experimental validation of the optimised results.

REFERENCES

Al-Tameemi, A. F., Wang, Y., & Albayati, A. (2015). Influence of Hydrated Lime on the Properties and Permanent Deformation of the Asphalt Concrete Layers in Pavement. *Romanian Journal of Transport Infrastructure*, *4*(1), 1-19. https://doi.org/doi:10.1515/rjti-2015-0027

Amran, M., Al-Fakih, A., Chu, S. H., Fediuk, R., Haruna, S., Azevedo, A., & Vatin, N. (2021). Long-term durability properties of geopolymer concrete: An in-depth review. *Case Studies in Construction Materials*, *15*, e00661. https://doi.org/https://doi.org/10.1016/j.cscm.2021.e00661

Amran, Y. H. M., Alyousef, R., Alabduljabbar, H., & El-Zeadani, M. (2020). Clean production and properties of geopolymer concrete; A review. *Journal of Cleaner Production*, *251*, 119679. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.119679

Karimipour, A., Ghalehnovi, M., Edalati, M., & de Brito, J. (2021). Properties of Fibre-Reinforced High-Strength Concrete with Nano-Silica and Silica Fume. *Applied Sciences*, *11*(20). https://doi.org/10.3390/app11209696

Luhar, I., & Luhar, S. (2021). Rubberized Geopolymer Composites: Value-Added Applications. *Journal of Composites Science*, *5*(12). https://doi.org/10.3390/jcs5120312

Luhar, S., Chaudhary, S., & Luhar, I. (2019). Development of rubberized geopolymer concrete: Strength and durability studies. *Construction and Building Materials*, *204*, 740-753. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.01.185

Ma, C.-K., Awang, A. Z., & Omar, W. (2018). Structural and material performance of geopolymer concrete: A review. *Construction and Building Materials*, *186*, 90-102. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.07.111

Mohajerani, A., Burnett, L., Smith, J., Markovski, S., Rodwell, G., Rahman, M. T., Kurmus, H., Mirzababaei, M., Arulrajah, A., & Maghool, F. (2020). Recycling waste rubber tyres in construction materials and associated environmental considerations: A review. *Resources Conservation and Recycling*, *155*. https://doi.org/10.1016/j.resconrec.2020.104679

Mohammed, B. S. (2010). Structural behavior and m–k value of composite slab utilizing concrete containing crumb rubber. *Construction and Building Materials*, *24*(7), 1214-1221. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2009.12.018

Mohammed, B. S., Awang, A. B., Wong, S. S., & Nhavene, C. P. (2016). Properties of nano silica modified rubbercrete. *Journal of Cleaner Production*, *119*, 66-75. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.02.007

Mutar, M., Hussein, T., & Samer. (2018). EFFECT OF CRUMB RUBBER AGGREGATES ON THE CHARACTERISTICS OF CEMENT CONCRETE AS PARTIAL REPLACEMENT.

Neupane, K., Chalmers, D., & Kidd, P. (2018). High-Strength Geopolymer Concrete-Properties, Advantages and Challenges. *Advances in Materials*, *7*. https://doi.org/10.11648/j.am.20180702.11

Pham, T., Chen, W., Khan, A. M., Hao, H., Elchalakani, D. M., & Tran, T. (2019). Dynamic Compressive Properties of Lightweight Rubberized Concrete. *Construction and Building Materials*, *238*. https://doi.org/10.1016/j.conbuildmat.2019.117705

Prajapati, H., & Pitroda, D. J. (2020). UTILIZATION OF CRUMB RUBBER IN RIGID PAVEMENT. *7*, 2072-2082.

S Mohammed, B., Liew, M. S., S Alaloul, W., Al-Fakih, A., Ibrahim, W., & Adamu, M. (2018). Development of rubberized geopolymer interlocking bricks. *Case Studies in Construction Materials*, *8*, 401-408. https://doi.org/https://doi.org/10.1016/j.cscm.2018.03.007

Singh, N. B., Kumar, M., & Rai, S. (2020). Geopolymer cement and concrete: Properties. *Materials Today: Proceedings*, *29*, 743-748. https://doi.org/https://doi.org/10.1016/j.matpr.2020.04.513

Sofi, A. (2018). Effect of waste tyre rubber on mechanical and durability properties of concrete – A review. *Ain Shams Engineering Journal*, *9*(4), 2691-2700. https://doi.org/https://doi.org/10.1016/j.asej.2017.08.007

Thomas, B. S., Gupta, R. C., Mehra, P., & Kumar, S. (2015). Performance of high strength rubberized concrete in aggressive environment. *Construction and Building Materials*, *83*, 320-326. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2015.03.012

Xu, J., Yao, Z., Yang, G., & Han, Q. (2020). Research on crumb rubber concrete: From a multi-scale review. *Construction and Building Materials*, *232*, 117282. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.117282

Yang, S., Lohnes, R. A., & Kjartanson, B. H. (2002). Mechanical properties of shredded tires. *Geotechnical Testing Journal*, *25*(1), 44-52.