Durability of Rubbercrete Containing Fly Ash and Nano Silica in terms of Deterioration Mechanism through Chemical Attack

by

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19294

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons) Civil

September 2017

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

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September 2017

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.

____

(RAJA ROSENANI RAJA ABDULLAH)

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ABSTRACTS

Several researches have been conducted to determine the properties of rubbercrete, a concrete containing crumb rubber as partial replacement to fine aggregate. The benefits of rubbercrete includes lighter in weight, more ductile, better workability, and better sound absorption. However, crumb rubber hydrophobic properties cause rubbercrete to have a lower compressive strength and durability compare to normal concrete. Therefore, Nano silica and fly ash is added into the mixture to counter this problem. This thesis presents the study of rubbercrete durability in terms of its deterioration mechanism through chemical attack. The thesis details on the effect of acid attack, sulfate attack and efflorescence to the mixture. For this work, the strength of rubbercrete is improvised by addition of Nano Silica into the mixture. Thirty trial mixes were prepared to produce concrete cubes of dimension 100 mm x 100 mm x 100 mm. The composition of rubbercrete focus on 0%, 15%, and 30% crumb rubber (CR) as replacement of fine aggregate, 0%, 2.5% and 5% addition of Nano Silica to increase its compressive strength, 0%, 35% and 70% of fly ash to replace cement and 0.25%, 0.3% and 0.35% of water-cement ratio. By integrating Central Composite Design (CCD) in designing the experiment using Response Surface Method (RSM), six mix design of different rubbercrete grade were obtained to be tested. For acid attack, rubbercrete gives 12% of strength loss within one month of being exposed to acidic environment while normal concrete gives 18% of strength loss. For sulfate attack, rubbercrete gives expansion rate of less than 0.3% in comparison to normal concrete 0.8%. Rubbercrete also gives a lower efflorescence rate. It has been found that the innovated rubbercrete has the property to retard the ingress and movement of water transporting the chemical. This is due to the addition of Nano silica which improve the microstructure of rubbercrete and its porosity, thus, less chemical can seep into the concrete to attack it. Rubbercrete with the addition of Nano silica and fly ash in the mixture have a better durability in terms of its chemical deterioration.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Kyoto Protocol is an international agreement on climate change, appointing mandatory greenhouse gas emission limitations to the signatory nations. As one of the party in United Nation Framework Convention on Climate Change (UNFCCC), Malaysia has sanctioned to the Kyoto Protocol (Selamat, n.d.). Malaysia communicates its Intended Nationally Determined Contribution (INDC) which include reducing its carbon dioxide emission up to 45 percent by the year 2030 relative to the emissions intensity of GDP in 2005 (Hussain, 2009). Several development plans and policies are formed which include a strict plan on open burning in Environment Quality Act.

Although the measures taken has greatly reduce the emission, new issue has become a great concern to the country which is the abundance of waste tire. According to Ohio Administrative Code 3745-27-01, a scrap tire is a solid waste that includes any unwanted or castoff tire, that has been removed from its original use. Scrap tires come from three types of tire; passenger car tires, truck tires, and off-the-road tires. Scrap tire which are made up of polymeric materials are hard to dispose (unless by burning which will cause emission). The abundance of scrap tires not only occupy a lot of spaces when stockpile, but also harmful if exposed to fire. The improperly discarded tire can also become a breeding ground to rodents and mosquitoes, which could threaten our health. Thus, National Strategic Plan for Solid Waste Management 2005 is formed. One of the waste management option to solve this problem is by recycling the waste tires for advantageous use such as utilizing it into concrete production.

In a report by Cement Association of Canada, an annual global production of concrete is about 3.82 billion cubic meter which is equivalent to 5 billion cubic yards. This proves that the usage of concrete in construction industry is limitless and only continue growing. From environmental point of view, the usage of crumb rubber as partial replacement to fine aggregates could help in saving the natural resources, which in this case is sand itself. Spanne (n.d) discuss that the sand is in short supply as global demand increases every year. The seemingly infinite particles are a key ingredient in the production of concrete. U.S. Geological Survey figures suggest that about 30 billion tons a year of sand and gravel are used in construction industry worldwide. By partially replacing sand with crumb rubber, the life expectancy of sand in the world can be prolonged. Next, waste tire management problem is successfully reduced when re-using the crumb rubber from the scrap tires into the concrete production. Indirectly, the cost for waste management will be reduced and the surrounding environment as well as the aesthetic view of the country will be preserved.

From the engineering perspectives, the creation and innovation of rubberized concrete mixture gives many benefits to the world. It is lighter in weight, more ductile, more impact resistance, and better in soundproofing and workability. However, it has a major drawback which is lower in compressive strength which leads to lower durability. Therefore, the properties of rubbercrete is to be alter by adding Nano-silica and fly ash into the mixture.

Concrete tends to deteriorate when being exposed to harsh environment. The same goes to rubbercrete. Acid attack and sulfate attack are some of the deterioration mechanism that can jeopardize rubbercrete strength. This attack is due to the high alkaline properties of Portland cement which is being used as one of the major constituent of concrete. Dissolution of hydrogen ion and the present of sulfate ion in sulfuric acid caused the solution to be highly corrosive. Sulfur compound are formed from the reaction of sulfuric acid-cement paste, thus, other increase in sulfur content of concrete samples could be used as a measure of the chemical manifestation of deterioration.

Another chemical deterioration mechanism is efflorescence. Efflorescence is a whitish crystalline deposit on surfaces of concrete, usually water-soluble salts. Water from the concrete mixture carry the salts to the surface. When humidity is low, the water may evaporate before reaching the surface, leaving it beneath the surface and unseen. When humidity is high, water evaporation is slower allowing more opportunity for efflorescence. Efflorescence is normally related to aesthetical issue rather than a structural one. This thesis presents the study of chemical attack resistance of the rubbercrete containing fly ash and Nano silica. It details on the effect of acid attack, sulfate attack and efflorescence to the mixture and study on the changes in durability of rubbercrete with fly ash and Nano silica.

1.2 PROBLEM STATEMENT

The abundance scrap tires have become major problem in Malaysia. They are non-biodegradable waste with high durability and endurance that are difficult to break down. Moreover, they are bulky and occupy a lot of space when stockpile, thus, reducing the aesthetical value of that particularly large area. They pose major threat to the environment, health, and safety if caught on fire. These fires take long time to be diminish and can contaminate air because hazardous compounds are released to the atmosphere.

Sand is the world's second most severely exploited natural resources, after water. One way to estimate the global use of sand indirectly is through the production of concrete (which consist of cement, water, sand, and gravel). Concrete is used in the construction industry as it is strong, plentiful, reliable, and extremely versatile. For each ton of cement, the construction industry needs about six to seven times more tons of sand which is about 25.9 billion to 29.6 billion tons of sand per year (Peduzzi, 2013). Due to the increase in demand of the construction industry, the amount of sand available in the future has become a global concern.

The abundance of waste tire to be disposed and the lack of natural fine aggregates are two global issue that can be resolve when introducing the rubberized concrete mixture. By having crumb rubber from scrap tires as partial replacement to fine aggregate in concrete mixture, both problem stated before can be handled efficiently. Thus, it is safe to say that the innovation of rubberized concrete able to kill two birds with one stone.

Unfortunately, the innovated rubbercrete has a major drawback. It has lower compressive strength compare to the conventional concrete which in turn give lower durability property. Concrete is resistance to most natural environment and many chemicals. However, if exposed to aggressive chemical attacks, it may cause deterioration of structure and its durability is affected. The life span of concrete is reduced and may lead to failure. Rubbercrete has low resistance to chemical attack.

Therefore, the addition of varied materials such as Nano Silica and fly ash are introduced to alter the properties of rubbercrete and enhance its compressive strength as well as its durability. Hence, this thesis focuses on studying the durability of rubberized concrete containing Nano silica and fly ash in terms of its chemical attack resistance; acid attack, sulfate attack and efflorescence.

1.3 OBJECTIVE

The objective of the present study was to determine the durability of rubbercrete containing fly ash and Nano silica in terms of deterioration mechanism through chemical attack. To achieve this objective, comprehensive laboratory testing was considered to determine the chemical attack resistance of the rubberized concrete. The rubberized concrete was tested on its resistance towards acid attack, sulfate attack and efflorescence.

1.4 SCOPE OF STUDY

For this work, the strength of rubbercrete is controlled by addition of Nano Silica and reduction of its water-cement ratio. Thirty trial mixes were prepared to produce concrete cubes of dimension 100 mm x 100 mm x 100 mm. The composition of rubbercrete focus on 0%, 15%, and 30% crumb rubber (CR) as replacement of fine aggregate. This is because replacement of more than 30% of crumb rubber will greatly reduce the compressive strength, thus, defeat the purpose of the rubbercrete of being more beneficial and economical. 0%, 2.5% and 5% addition of Nano Silica is used since the range are optimum percentage for Nano silica to react and promote the increase of rubbercrete compressive strength (Mohamed, 2014). 0%, 35% and 70% of fly ash to replace cement and 0.25%, 0.3% and 0.35% of water-cement ratio. This is to control the water-cement ratio of the mixture, as the addition of 10% of fly ash should allow water reduction of at least 3% (Thomas, n.d.).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCING CRUMB RUBBER AS PARTIAL REPLACEMENT TO SAND IN CONCRETE

Concrete is the most commonly used material in the construction industry. It is estimated about 12.6 billion tons of concrete are generated annually (Selvakumar & Venkatakrishnaiah, 2015). Concrete basically is made up of cement, water, fine aggregate, and course aggregate. The usage of sand in concrete has become a great concern as it is to belief that the natural resources has depleted. To overcome the problem, crumb rubber has been introduced as a partial replacement to sand in the concrete production (Selvakumar & Venkatakrishnaiah, 2015).

Crumb rubber are waste materials taken from scrap tire. Scrap tire which are tedious to dispose are recycled. Scrap tire are shredded apart in the cracker mill to produce irregular shaped particles known as crumb rubber (Antil, Verma, & Singh, 2012). Preparation of crumb rubber started with shredding process that reduced the scrap tire into 100 mme50 mm. This was followed by granulation process in two stages where primary and secondary granulation further reduced the size from 50 mm to 10 mm. Separation of steel wire from the tire chips occurred after primary granulation before fed into secondary granulation. Tire chips were then grinded into smaller mesh sizes to produce crumb rubber of required gradation by cracking or grinding in rolling mills. Screens/gravity separators and aspiration equipment were used to remove metal and fibers, respectively in the production process (Mohammed, Anwar Hossain, Eng Swee, Wong , & Abdullahi, 2012).

Previous studies have shown that the rubberized concrete carry properties that are beneficial and better than the conventional concrete. Some of them include that the rubbercrete performed better in freezing and thaw environment, it is lighter and has good aesthetical value (Bani-Hani & Senoouci, 2015). Other study (Antil, Verma, & Singh, 2012) proves that rubbercrete possess higher toughness and acts as plastic which is good in controlling and damping the effect of cracking. Another study (Alam, Mahmood, & Khattak, 2015) justifies that rubbercrete shows ductile behaviour before failure which help to avoid destruction of the structure.

Although rubbercrete possesses many attributes that is better than conventional concrete, it has major drawback that sparks concerns among researchers. Rubbercrete strength is reduced significantly with the increment of crumb rubber into the mixture (Antil, Verma, & Singh, 2012). This is due to the properties of crumb rubber which is hydrophobic. The crumb rubber repels water and entrapped the air during the mixing of concrete (Mohammed, Anwar Hossain, Eng Swee, Wong, & Abdullahi, 2012). The substitution of mineral aggregates with tire–rubber particles in concrete results in large reductions in ultimate strength and the tangential modulus of elasticity (Al-Fadhli & Alhumoud, 2017). Due to the considerable decrease in ultimate strength, rubber concentrations exceeding 25% are not recommended. Pretreatment of tire particle surfaces should be considered for possible improvement of tire–rubber concrete mechanical properties. Therefore, to produce rubbercrete with higher strengths and durability, researchers have tried to improve the bond between CR and cement matrix through additional of fly ash and Nano silica.

2.2 NANO SILICA IN CONCRETE

To enhance the compressive strength and durability of rubbercrete, Nano-silica is added into the mixture. Silica fume in Nano size has the filling effects that can densify the pore system of the concrete (Mohammed, Anwar Hossain, Eng Swee, Wong, & Abdullahi, 2012). Proper amount of Nano-silica could further enhance the compressive strength of the rubbercrete, thus, result in a better innovation of concrete. The usage of rubbercrete is limited due to its poor compressive strength and durability. To avoid additional cement into the mixture, Nano-silica is added to produce C-S-H gel which improve the strength of the rubberized concrete (Mohammed, Nuruddin, & Syafiq, 2016).

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow CaH_2SiO_4 + 2H_2O \text{ -- (1)}$$

The overall performance of rubbercrete has been greatly improved with the addition of Nano-silica. A research (Said, Zeidan, Bassuoni, & Tian, 2012) identifies that the ultrafine particles of Nano-silica able to speed up hydration process in concrete. In another study, Nano-silica particles have high surface area which will acts as nucleation sites for the reaction (Said, Zeidan, Bassuoni, & Tian, 2012). Better bonding can be achieved when adding Nano-silica as it refines the pore system and densify the interfacial transition zone between the mix (Mohammed, Awang, Wong, & Nhavene, 2016). Nano silica also reduce the capillary porosity and permeability of rubbercret which leads to a higher strength and durable rubbercrete. (Mohammed, Awang, Wong, & Nhavene, 2016). Even when placed at a small volume Nano silica able to improve the property of rubbercrete. Its mechanical properties, durability, setting time and overall operational cost are improved (Gici, Rashid et al, 2010 stated by Adamu, M et al, 2016). However, the usage of Nano-silica may reduce rubbercrete workability due to its large surface area (Adamu, Mohammed, & Shafiq, 2016).

Rubbercrete with Nano silica has better compressive strength compared to the one without Nano silica. This is due to the positive interaction between the limestone and Nano silica which enhanced the bond and matrix of the rubbercrete. Its large area-to-volume ratio allow it to act as filler between larger particles within cement aggregates (Mohammed, Awang, Wong, & Nhavene, 2016). The chemical effect is due to ability of Nano silica in reacting with $Ca(OH)_2$ released resulting in more production of C-S-H gel which densify the interfacial transition zone between the cement matrix and aggregates including crumb rubber.

The porosity of the rubbercrete is increased with the increment of the percentage of crumb rubber replacement (Thomas and Gupta, 2015 cited in Mohammed, Awang , Wong, & Nhavene, 2016). This is because the non-polarity of crumb rubber which increases the air voids and pores in the interfacial transition zone. However, the porosity of rubbercrete decreases as the Nano silica addition increases. Nano silica acts as filler to the voids inside the matrix and react with portlandite to further filling up the holes in the interfacial transition zone.

2.3 FLY ASH AS REPLACEMENT TO CEMENT

Fly ash is used as a supplementary cementitious material (SCM) in the production of concrete. A supplementary cementitious material, when used, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both. Factually, fly ash is used in concrete by replacing cement at levels ranging from 15% to 25%. The amount used varies based on the concrete application, the properties of the fly ash, specification limits, and the site location. 30% to 50% of fly ash replacement are used widely for in huge structures such as foundations and dams. This is to control temperature rise during hydration process and avoid thermal cracking. Researchers also demonstrated that about 40% to 60% of fly ash replacement can be used in structural applications as the concrete produce will have a better mechanical properties and durability (Marceau, 2002 cited in Thomas, n.d.).

Fly ash is a by-product of burning pulverized coal in an electrical generating station. Specifically, the unburned remainder is transferred from the burning zone in the boiler by the flue gases and collected by separators. The heavier particles will fall to the bottom of the furnace, thus known as fly ash. Fly ash is a fine amorphous aluminosilicate with fluctuating amounts of calcium. If mixed with Portland cement and water, will react with the calcium hydroxide to produce various calcium-silicate hydrates (C-S-H) and calcium-aluminate hydrates (Veerendrakumar , Mohammed, & Nuruddin , 2016). These reactions are advantageous to the concrete as the quantity of the binder is increased, improving the strength and reducing the permeability of the produced concrete (Thomas, n.d.). Both helps in enhancing the durability of the concrete.

2.4 CHEMICAL ATTACK IN CONCRETE

Concrete performance is in threat when exposed to harsh environment. The integrity on concrete should be able to withstand the deleterious forces of nature. The penetration of different chemical into concrete member may lead to failure such as strength-loss, cracking, and corrosion of the cement paste ofconcrete (Alam, Ashraf, Shahzada , Afzal, & Khan, 2012).

When concretes are immediately visible to the chemically aggressive environment, the initial strength of concrete are retarded and low. Although there is small increment of strength during the curing process, concrete is suffering significant strength loss afterwards. The strength is initially retarded which follows by a gradual reduction in overall strength of concrete (Muhammad & Ismail, 2011).

There are diverse types of chemical attacks that effect the concrete structure. These include chlorides attacks, sulfate attacks, carbonation, Alkali-Silica Reaction (ASR) and acid attacks (Types of Chemical Attacks on Concrete Structure, 2017). Below is the graphical representation of precautions that should be taken in concrete structure to avoid deterioration from chemical attack mechanism.

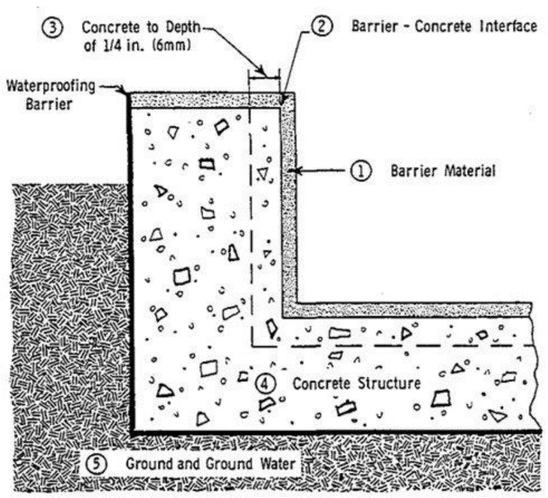


Figure 2. 1 - Chemical Attack Precautions In Concrete Structure (Types of Chemical Attacks on Concrete Structure, 2017)

2.4.1 Acid Attacks Mechanism (Sulphuric Acid)

Acids present in the environment (ground water or chemical waste water) can be harmful to concrete and affects its durability (Hobbs, et.al, 2009 cited in Nematzadeh & Fallah-Valukolaee, 2017). The hydration products of Portland cement concrete are alkaline and has a pH value ranging between 12 and 13.5 (Xiao, Qu, Li, & Zhu, 2016). It is inevitable from being attack by acid. Sulfuric acid is the most acid medium present in the environment. A better understanding of the deterioration mechanisms of concrete subjected to sulfuric acid attack is vital. In previous studies, mass loss and corrosion depth were indicators for evaluating the resistance of concrete to sulfuric acid attack. Typically, gypsum and ettringite are produced. The large amount of gypsum and ettringite produce cause the concrete to expand which then leads to deterioration such as cracking(Yang, Ji, Lin, Chen, & Yang, 2017)

The study (Mohseni, Tang, & Chui, 2017) explain the mass loss in concrete due to reaction of sulphuric acid.

a) Sulphuric acid responded with the calcium hydroxide and changed it to calcium sulfate

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4.2H_2O \text{ – (2)}$$

b) Calcium sulfate could leak out of concrete or reacted with calcium aluminate.

c) The calcium sulfate then reacted with calcium aluminate to form ettringite that could cause cracking and expansion.

$$3CaSO_4 + 3CaO\cdot Al_2O_3\cdot 6H_2O + 25H_2O \rightarrow 3CaO\cdot Al_2O_3 3CaSO_4 + 31H_2O \text{ – (3)}$$

d) The calcium silicate hydrate reacted with sulphuric acid and produce silica gel.

$$3CaO\cdot 2SiO_2\cdot 3H_2O + H_2SO_4 \rightarrow CaSO_4\cdot 2H_2O + Si(OH)_4 \text{ – (4)}$$

2.4.2 Sulfate Attack Mechanism (Sodium Sulfate)

Sulfate attack generally involves the formation of expansive product that cause deterioration in hardened concrete. Sulfate Attack indicates the deterioration by concrete structure from being attacked by salts or sulfate-bearing solutions (Soutsos, 2010). Chemical sulfate attack occur when sulfate penetrates concrete, and react with the hydration product of cement. It inhabits greater volume, causing expansion within the cement paste, which then produce internal and concentrated tensile stresses in hardened concrete(Soutsos, 2010)

Contact between sulfate and the cement cause sulfate attack. Sulfates may already present in cement, or exist during curing, can cause damage by expansion and cracking caused by deferred ettringite formation (Collepardi, 2003; Taylor et al., 2001 cited in Whittaker & Black, 2015). The deterioration in concrete appear in a form of spalling, expansion, and cracking of the member (Nie, Zhou, Shu, He, & Huang, 2014). It can be evaluated by length changes of mortar engrossed in a sulfate solution. A study found that addition of fly ash able to increase sulfate resistance as it reduces the amount of free lime and reactive aluminates for sulfate reaction (Lee, Moon & Swamy, 2005 cited in Nie, Zhou, Shu, He, & Huang, 2014).

Studies by Al-Amoudi (2002) have shown that adding pozzolanic minerals to concrete had expressively enhanced its durability when being subjected to sulfate attack. This statement is supported by Hooton (1993), Al-Akhras (2006), and Nehdi and Hayek (2005). Indeed, pozzolanic minerals reduce the porosity in concrete and consume calcium hydroxide (Suleiman A. R., 2014). Moreover, reducing the water to cement ratio improves the resistance to sulfate exposure. Reduction in volume of voids in the concrete matrix limits sulfates penetration (Mehta and Monteiro, 2006).

2.4.3 Efflorescence

Efflorescence is a crystalline deposition of salts that is recognized from its white appearance. It usually forms near or on the surface of concrete (Efflorescence Cause, Removal and Prevention, n.d.). It is considered as a surface defect which reduce the aesthetic value of the concrete. There are three types of efflorescence; primary efflorescence, secondary efflorescence and cryptoflorescence. Primary efflorescence appears first involving the water used, secondary efflorescence appears after due to an external water source while cryptoflorescence is crystallisation within the pore structure of the concrete (BASF, n.d.).

EN 1338:2003 Concrete Paving Blocks cited in BASF (n.d.) states that structures are not deteriorate by efflorescence, however, finishes deterioration or surface spalling may occur if efflorescence happen in large amount. A study (Kresse & Dow, 1989; cited in Sutan, Hamdan, Yakub & Talib, 2014) affirms that efflorescence can cause economical implication due to product rejection by customer and high remedial processes.

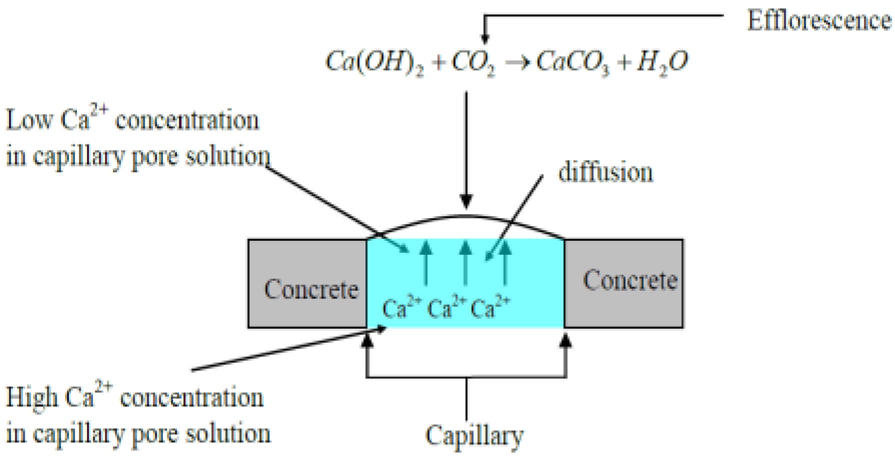


Figure 2. 2 - Schematic diagram of efflorescence from cross sectional view of concrete block

Carbonates are the main cause of efflorescence. It is formed from chemical reaction between carbon dioxide and calcium hydroxide during hydration process (BASF, n.d.).

$$Ca(OH)_2\ (dissolved) +\ CO_2\ (dissolved) \rightarrow CaCO_3\ (solid) +\ H_2O\ (liquid)$$

The physical processes of efflorescence involve transport of water and salts, evaporation, reaction with carbon dioxide and salt crystallisation (BASF, n.d.). Transport of water and salts; Liquid movement or ion transport through the concrete pore may be driven by hydrostatic pressure, capillary suction, or concentration gradient.

In conclusion, efflorescence will only occur if the three conditions stated above exist. Efflorescence can be control by reducing soluble alkali sulfates, enhanced detailing in structure design to prevent water from entering masonry and mitigate the path for moisture to attack the structure (Efflorescence Cause, Removal and Prevention, n.d.). Unfortunately, even after all the efforts, efflorescence may still occur. The remedial process of efflorescence may involve dry brush, rinsing with water, natural weathering process, hand washing with mild detergent as well as sandblasting (Efflorescence Cause, Removal and Prevention, n.d.)

CHAPTER 3

METHODOLOGY

3.1. FLOWCHART

A comprehensive flowchart is outlined to show the process taken in this study.

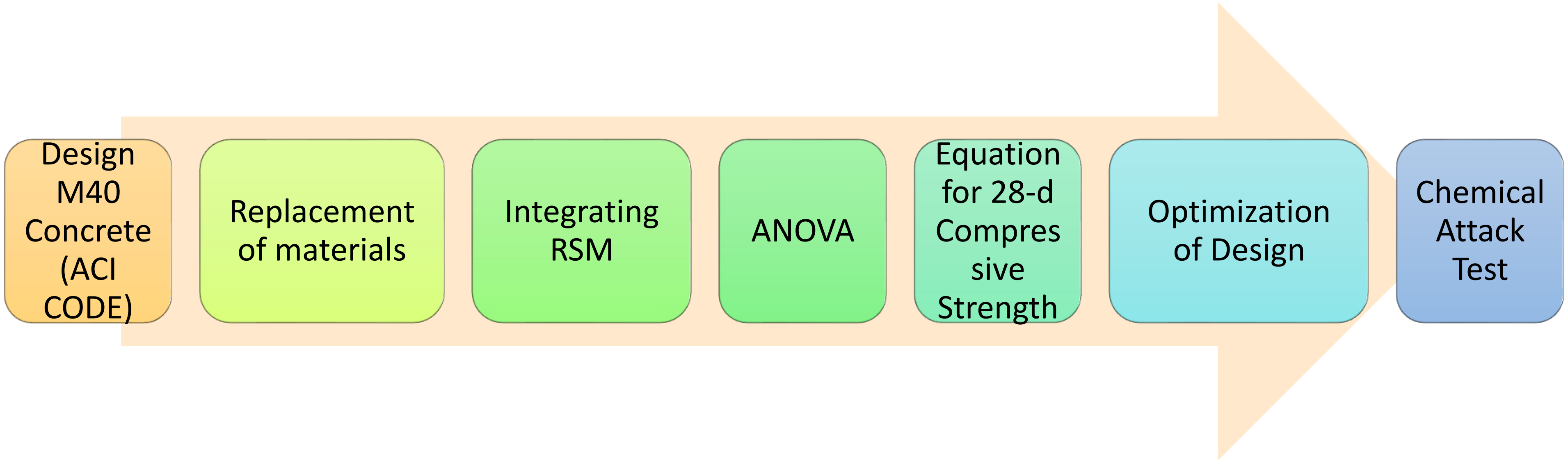


Figure 3. 1 - Flowchart of Project

3.2.KEY MILESTONE

Refer Attachment A for Gantt Chart.

3.3. EXPERIMENT MATERIALS FOR RUBBERCRETE

Materials used in preparations of rubbercrete mixtures were Ordinary Portland Cement (OPC), fly ash (F), Nano silica (NS), river sand or fine aggregate (FA), coarse aggregates (CA) with the maximum nominal size of 10 mm, crumb rubber (CR), superplasticizer and water.

3.3.1. Cementitious Materials

Table 3. 1 Chemical Composition of Cementitious Materials

Chemical Composition/ Properties	**Cement (%)**	**Fly Ash (%)**	**Nano silica (%)**
SiO_2	25.21	64.69	99.8
Al_2O_3	4.59	18.89	-
Fe_2O_3	2.99	4.90	-
CaO	62.85	5.98	-
MgO	1.70	1.99	-
Na_2O	0.98	2.41	-
K_2O	1.68	1.14	-
Specific Gravity	3.15	2.3	-
Loss on Ignition (%)	2.02	1.87	6

3.3.1.1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) is commonly used in concrete construction. It is grey in colour which capable of bonding mineral fragments into a dense complete mix when added with water. In this experiment, the Ordinary Portland Cement (OPC) used is Type 1 conforming to the requirements of ASTM.

3.3.1.2. Fly Ash (FA)

Fly ash is a by-product from burning pulverized coal in electric generation power plant. It is a pozzolan material, containing aluminous and siliceous material. Since fly ash is consider as a waste material, the use of it as partial replacement to cement not only enhance the structural properties of the concrete but also environmental friendly. The fly ash was classified as class F with total amount of silicon oxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) of 88.48% and loss of ignition less than 6% according to the specification of ASTM C618 (American Society for Testing and Materials, 2005).

3.3.1.3. Nano Silica (NS)

Nano silica or silicon dioxide Nanoparticles is widely used as an addition for cementitious material in concrete mixture due to its pozzolan properties. Nano silica can influence cement composite properties, is seeding effect. Nano silica could provide extra sites for the precipitation of hydration products, leading to the acceleration of early stage hydration. It modified the rubberized concrete to gain higher compressive strength by refining pore system as well as densify the interfacial transition zone of the mixture.

3.3.2. Aggregates

The physical properties of aggregates are shown in Table 3.2.

Table 3. 2 Properties of Aggregates

Properties	Coarse Aggregate	River sand	Crumb rubber
Specific gravity	2.67	2.65	0.95
Water absorption (%)	1.10	2.10	-
Moisture Content (%)	0.30	1.30	-
Fineness modulus	-	2.20	0.92

3.3.2.1. River sand (Fine Aggregates)

River sand is a natural granular material that is obtained from the banks or beds of rivers. It is fine and is usually whitish grey in colour. Sand acts as one of the main constituent of concrete. The fine aggregate used in this experiment is ranging from 0.1mm to 0.3mm in size.

3.3.2.2. Crumb Rubber (Fine Aggregates)

Crumb rubber are utilized in concrete production due to the abundance of scrap tire in the environment. It is obtained by shredding and grinding of scrap tire. The use of crumb rubber as partial replacement to fine aggregate in concrete mix has many advantages. In this experiment, the quantity of crumb rubber replacing fine aggregate are ranging from 0% to 30% for optimum effects. However, the major problem when utilizing crumb rubber is it degrade the compressive strength of the concrete. Thus, other materials are to be included in the mix to counter the problem.

3.3.2.3. Coarse Aggregate

Chipped stone and gravel are the main constituent of coarse aggregate for this experiment ranging from 5mm to 10mm.

3.3.3. Water and Superplasticizer

The ratio of water to cementitious material is important in concrete mixtures. Having lower water to cement ratio produce a higher density of cement paste which result in an enhancing the compressive and flexural strength but with lower workability. Therefore, superplasticizers are admixtures added to allow reduction of water to cement ratio or to lower the settling rate of the concrete while maintaining the smooth flowable properties of the mix. It can also adjust the properties of concrete making them more appropriate to work without using much mechanical energy.

3.4.MIX DESIGN

Table 3. 3 Thirty Trial Mix Design for Rubbercrete Containing Fly Ash and Nano Silica

Run	w/c	Crumb Rubber		Fine aggregate kg/m^3	Course aggregate kg/m^3	Water kg/m^3	Fly Ash		Nano silica		Cement kg/m^3
		%	kg/m^3				%	kg/m^3	%	kg/m^3	
1	0.25	0	0	804.00	1008	162.90	0	0	0	0	651.60
2	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
3	0.3	15	44.07	683.40	1008	195.48	0	0	2.5	16.29	651.60
4	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
5	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
6	0.35	30	88.13	562.80	1008	228.06	70	456.12	5	32.58	195.48
7	0.3	15	44.07	683.40	1008	195.48	35	228.06	5	32.58	423.54
8	0.25	0	0	804.00	1008	162.90	70	456.12	5	32.58	195.48
9	0.35	30	88.13	562.80	1008	228.06	0	0	0	0	651.60
10	0.3	15	44.07	683.40	1008	195.48	35	228.06	0	0	423.54
11	0.35	0	0	804.00	1008	228.06	0	0	5	32.58	651.60
12	0.35	30	88.13	562.80	1008	228.06	0	0	5	32.58	651.60
13	0.25	0	0	804.00	1008	162.90	70	456.12	0	0	195.48
14	0.3	15	44.07	683.40	1008	195.48	70	456.12	2.5	16.29	195.48

15	0.25	30	88.13	562.80	1008	162.90	70	456.12	0	0	195.48
16	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
17	0.25	30	88.13	562.80	1008	162.90	0	0	5	32.58	651.60
18	0.25	15	44.07	683.40	1008	162.90	35	228.06	2.5	16.29	423.54
19	0.35	0	0	804.00	1008	228.06	70	456.12	5	32.58	195.48
20	0.35	0	0	804.00	1008	228.06	70	456.12	0	0	195.48
21	0.25	30	88.13	562.80	1008	162.90	70	456.12	5	32.58	195.48
22	0.3	0	0	804.00	1008	195.48	35	228.06	2.5	16.29	423.54
23	0.25	0	0	804.00	1008	162.90	0	0	5	32.58	651.60
24	0.35	0	0	804.00	1008	228.06	0	0	0	0	651.60
25	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
26	0.3	30	88.13	562.80	1008	195.48	35	228.06	2.5	16.29	423.54
27	0.35	15	44.07	683.40	1008	228.06	35	228.06	2.5	16.29	423.54
28	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
29	0.25	30	88.13	562.80	1008	162.90	0	0	0	0	651.60
30	0.35	30	88.13	562.80	1008	228.06	70	456.12	0	0	195.48

3.5.METHOD OF STATEMENT

The chapter summarize the main activities to be conducted in the laboratory to achieve the objective of this project.

3.5.1. Material Preparations

All materials are prepared. Sieve analysis are done for river sand, crumb rubber and coarse aggregate to get the gradation curves.

3.5.1.1. Sieve Analysis

Referring to AASHTO T 27 and ASTM C 136: Sieve Analysis of Fine and Coarse Aggregates, the procedure is as follow;

1. Sample is weighted to the nearest 0.1g. This weight will be used to check for any loss of material after the sample has been graded.
2. Select suitable sieve sizes in accordance with the specifications. Nest the sieves in order of decreasing size from top to bottom and begin agitating and shaking the sample for adequate amount of time.

These sieves are self-nesting and supported in an automated shaker. It requires shaking times of ranging from 6-12 minutes. This is to ensure the sample are adequately shaken and graded

3.5.2. Cube Samples Preparation (ASTM C192/C 192M -02)

Cube samples for trial mix and testing (each consist of 30 distinctive design mixtures) are prepared.

Apparatus/Materials:

a) Concrete Mixture
b) Concrete Moulds
c) Scale
d) Measuring Cylinder

Procedure:

1. 6 cubes of 100mm x 100mm x 100mm size. M40.
2. Mix the concrete in a laboratory batch mixer
   a) Prior to starting rotation of the mixer add the coarse aggregate, some of the mixing water, and the solution of admixture, when required.
   b) Disperse the admixture in the mixing water before addition.
   c) Start the mixer, then add the fine aggregate, cement, and water with the mixer running.
   d) Mix the concrete, after all ingredients are in the mixer, for 3 min followed by a 3-min rest, followed by a 2-min final mixing.
   e) Cover the open end or top of the mixer to prevent evaporation during the rest period.
   f) To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform.
3. For sampling
   a) Clean and apply oil to the mounds
   b) Fill the concrete in the moulds in layers.
   c) Compact each layer with not less than 25 strokes per layer using a tamping rod
   d) Level and smoothen the top surface with a trowel

4. For curing,
    a) The test samples are exposed to air for 24 hours
    b) Then, marked the samples, removed from the moulds and submerged in clear fresh water until taken out prior to test.
    c) The water for curing should be tested every 7 days and the temperature of water must be at 27+-2^{o}C.

3.5.3. Compressive Strength Test

Six cube samples (for all 30 trial mixes) produced in the lab is tested for compressive strength at 14-day and 28-day after curing.

Apparatus/Materials:

a) Crushing Machine

Procedure:

1. Remove the samples from water after specified curing time and wipe out excess water from the surface.
2. Dimension of the samples is taken to the nearest 0.2mm
3. Surface of machine is cleaned properly
4. Place the samples in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast.
5. Samples are aligned in centre.
6. Load is applied gradually without shocked
7. Data is recorded.
8. For precautions,
    a) Average of three sample should be test for accuracy
    b) Samples varies by more than 15 per cent of average strength should be rejected.

3.5.4. Response Surface Method (RSM)

Response Surface Method (RSM) is a collection of mathematical techniques to obtain optimum response for experiment (Wikipedia, n.d). In this experiment, RSM is used to get the suitable mix design for concrete mixture of M40 consists of cement, crumb rubber, fine and course aggregate, Nano-silica, fly ash and superplasticizer. 30 different mix designs are obtained by using RSM for the trial mix. Once compressive test is done for all the mixes, the compressive test result will be input into the RSM to mathematically gain the suitable mix for the chemical attack resistance test.

3.5.5. Chemical Attack Resistance Test

Chemical attack on concrete by harsh chemicals threaten its durability and may cause deterioration in the structure. The environment is full of chemicals that may risk the life span of concrete structure. Thus, it is important to identify the behaviour of the new rubbercrete when facing chemical attack. In this experiment, rubberized concrete is tested for its ability to resist chemical attack; acid attack, sulfate attack and efflorescence.

3.5.5.1. Preparation of cube samples for Chemical Attack Testing

The procedure as per discussed in Item 3.3.2

3.5.5.2. Durability Test Resistance Against Acidic Attack (ASTM C642)

OPC in concrete is not acid resistant. Acid in the environment can come from many sources. Acids are formed by the dissolution in water of carbon dioxide from the atmosphere. They are also available from the industrial waste. A dense and lower permeable concrete is required to resist acid attack. Rubbercrete is tested for its durability against acid attack.

Apparatus/Materials:

a) Sulphuric acid
b) Weighing balance

Procedures:

a) Test concrete cube of size 100mm x 100mm x 100 mm are prepared.
b) The samples are cast and cured in molds for 24 hours, then, all the samples are de-molded and kept in curing tank for 7-days.
c) After 7-days all samples are kept in atmosphere for 2-days for constant weight. Next, the samples are weighed and immersed in 5% sulphuric acid (H_2SO_4) solution for 30-days.
d) The pH value of the acidic media was at 1.2. The pH value was periodically checked and maintained at 1.2.
e) After 30-days of immersing in acid solution, the samples are taken out and were washed in running water, kept in atmosphere for 2-day for constant weight.
f) Sample are weighed, loss in weight and percentage weight loss is calculated.

3.5.5.3. Concrete Length Change Exposed to Sulfate Solution (ASTM C1012)

Measurement of the expansion of the samples exposed to sulfate solution are taken as per the ASTM C1012 (ASTM 2012b) method.

Apparatus/Materials:

a) Lime Water
b) Sodium Sulfate Solution
c) Magnesium Sulfate Solution

Procedure:

a) The samples were cured in lime water along with cube samples after de-molding.
b) Initial length readings of the samples were taken using a standard comparator before immersing them in 5% sodium sulfate solutions to evaluate the sulfate resistance of the samples in each type of solution.
c) The length measurements were recorded at regular intervals of time until 30 days (~ 1 months) and the expansions were calculated using the formula specified in the test procedure.

3.5.5.4. Efflorescence (ASTM C67)

Apparatus:

a) Trays and Containers
b) Drying Room
c) Drying Oven

Procedure:

a) Set one samples partially immersed in distilled water to a depth of approximately 1 in. (25.4 mm) for 7 days in the drying room. When several samples are tested in the same container, separate the individual samples by a spacing of at least 2 in. (50.8 mm). and then dry both sets in the drying oven for 24 h.
b) Examination and Rating—After drying, examine, and compare each pair of samples, all four faces of each samples are observed from 3 m under an illumination of not less than538.2 lm/m^2 by an observer with normal vision.
c) The bricks shall then be examined for efflorescence. It is to be reported as "Nil", "Slight", "Moderate", "Heavy", or "Serious" in accordance with the following definitions.

Nil: No perceptible deposit of salt.

Slight: Not more than 10 percent of the area of the bricks covered with a thin deposit of salt.

Moderated: A heavier deposit than under "Slight" and covering up to 50 percent of the area of the bricks surface but unaccompanied by powdering of flaking of the surface.

Heavy: A heavy deposit of salt covering 50 percent or more of the bricks surface but unaccompanied by powdering or flaking of the surface.

Serious: A heavy deposit of salt accompanied by powdering and/or flaking of the surfaces

Precision and Bias—No information is presented about either the precision or bias of the test method for efflorescence because the test result is nonquantitative.

CHAPTER 4

RESULT AND DISCUSSION

4.1. SIEVE ANALYSIS

4.1.1. Fine Aggregates

The sieve analysis result for both river sand and crumb rubber are shown below.

Table 4. 1 Sieve Analysis for River Sand

Sieve size (mm)	Weight of sieve (kg)	sieve + weight of coarse aggregate (kg)	weight retained (kg)	percentage retained (%)	cumulative percentage retained (%)	Total Passing (%)
5	0.379	0.379	0	0.00	0.00	100.00
2.36	0.443	0.443	0	0.00	0.00	100.00
1.18	0.337	0.337	0	0.00	0.00	100.00
0.6	0.384	2.244	1.86	92.95	92.95	7.05
0.3	0.338	0.477	0.139	6.95	99.90	0.10
0.15	0.256	0.258	0.002	0.10	100.00	0.00
0.063	0.249	0.249	0	0.00	100.00	0.00
0	0.365	0.365	0	0.00	100.00	0.00
Total	2.751	4.752	2.001	100.00		

Table 4. 2 Sieve Analysis for Crumb Rubber

Sieve size (mm)	Weight of sieve (kg)	sieve + weight of coarse aggregate (kg)	weight retained (kg)	percentage retained (%)	cumulative percentage retained (%)	Total Passing (%)
5	1.206	1.206	0	0.00	0.00	100.00
No.8(2.36)	1.11	1.85	0.74	37.00	37.00	63.00
No.16(1.18)	0.97	2.01	1.04	52.00	89.00	11.00
No.30(0.6)	0.9	1.12	0.22	11.00	100.00	0.00
No.50(0.3)	0.79	0.79	0	0.00	100.00	0.00
No.100(0.15)	0.827	0.827	0	0.00	100.00	0.00
0.063	0.802	0.802	0	0.00	100.00	0.00
Pan	0.744	0.744	0	0.00	100.00	0.00
Total	7.349	9.349	2	100.00		

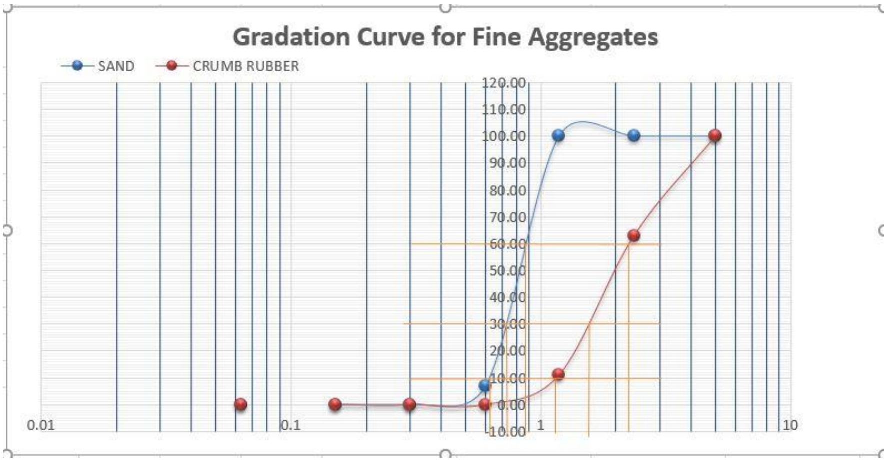


Figure 4. 1 Gradation Curve for Fine Aggregate

Gradation of aggregate can be determined by calculating the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, and comparing the calculated values with its limits

$$Cu = \frac{D_{60}}{D_{10}}$$

$$Cc = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

For crumb rubber;

$D_{60} = 2.25$

$D_{30} = 1.65$

$D_{10} = 1.25$

$Cu = \frac{2.25}{1.25} = 1.8$, $Cc = \frac{1.65^2}{2.25 \times 1.25} = 0.97$

For river sand

$D_{60} = 0.86$

$D_{30} = 0.73$

$D_{10} = 0.62$

$Cu = \frac{0.86}{0.62} = 1.39$, $Cc = \frac{0.73^2}{0.86 \times 0.62} = 1.0$

For sand and crumb rubber to be classified as well graded, Cc need to be within the range of 1.0-3.0 and Cu is greater than 4. Since, the results do not satisfy both conditions, sand and crumb rubber are to be classified as poorly graded. Therefore, having rubber crumb as partial replacement to river sand is acceptable.

4.1.2. Coarse Aggregates

Table 4. 3 Sieve Analysis for Coarse Aggregate

Sieve size (mm)	Weight of sieve (kg)	sieve + weight of coarse aggregate (kg)	weight retained (kg)	percentage retained (%)	cumulative percentage retained (%)	Total Passing (%)
13.2	1.077	1.077	0	0.00	0.00	100.00
9.5	1.079	1.083	0.004	0.13	0.13	99.87
4.75	1.172	3.097	1.925	64.17	64.30	35.70
2.36	1.085	2.015	0.93	31.00	95.30	4.70
1.18	0.951	1.077	0.126	4.20	99.50	0.50
0	0.735	0.75	0.015	0.50	100.00	0.00
Total	6.099	9.099	3	100.00		

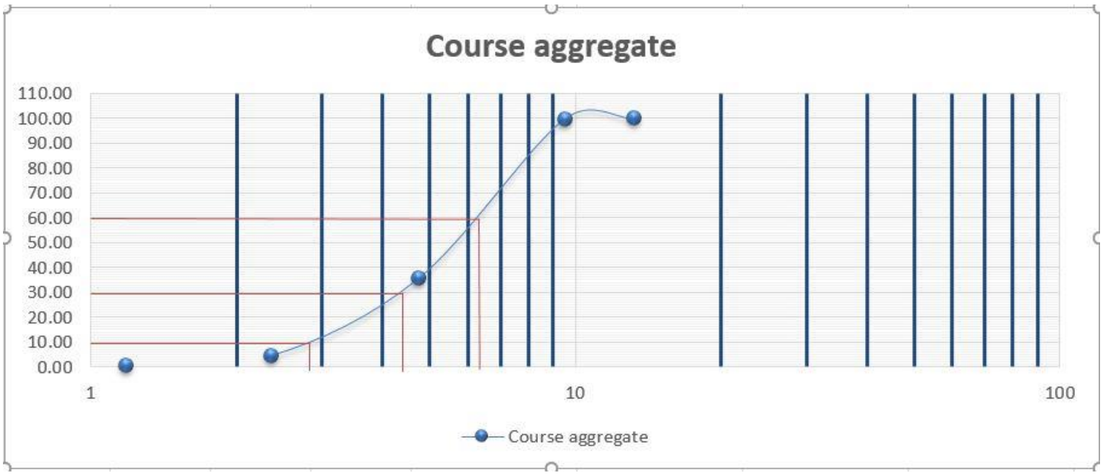


Figure 4. 2 Gradation Curve for Fine Aggregate

$D_{60} = 6.3$

$D_{30} = 4.4$

$D_{10} = 2.8$

$$Cu = \frac{6.3}{2.8} = 2.25, Cc = \frac{4.4^2}{6.3 \times 2.8} = 1.1$$

For coarse aggregate to be classified as well graded, Cc need to be within the range of 1.0-3.0 and Cu is greater than 6. Since, the results do not satisfy both conditions, coarse aggregate are to be classified as poorly graded.

4.2. COMPRESSIVE STRENGTH

Thirty trial mixtures have been done starting from May until August. All samples are tested for 14-day and 28-day of compressive strength.

Observing the result, the compressive strength of rubbercrete declines with time as proportion of crumb rubber as partial replacement to fine aggregate is increased (Alam, et al. 2015). This is due to the hydrophobic attributes of crumb rubber, result in a frail bonding among cement and crumb rubber particles. When stress is applied, it will lead to premature failure.

On the other hand, the compressive strength of rubbercrete increases with the adding of Nano silica into the rubbercrete. Nano silica reacting with $Ca(OH)_2$ to yield C-S-H gel which fill up the voids and densify the rubbercrete (Mohammed, B. S., et al. 2016). In addition, using Nano silica give aid to fly ash by preserving early strength of rubbercrete.

The 28-day strength recorded a slight decrease in strength relative to the 14-day strength. This can be ascribed to the total consumption of overall mix water in the samples which ceased the cement hydration process (Raheem, et al. 2013)

Table 4. 4 Trial Mix Design

Run	w/c	Crumb Rubber		Fine aggregate kg/m³	Course aggregate kg/m³	Water kg/m³	Fly Ash		Nano silica		Cement kg/m³
		%	kg/m³				%	kg/m³	%	kg/m³	
1	0.25	0	0	804.00	1008	162.90	0	0	0	0	651.60
2	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
3	0.3	15	44.07	683.40	1008	195.48	0	0	2.5	16.29	651.60
4	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
5	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
6	0.35	30	88.13	562.80	1008	228.06	70	456.12	5	32.58	195.48
7	0.3	15	44.07	683.40	1008	195.48	35	228.06	5	32.58	423.54
8	0.25	0	0	804.00	1008	162.90	70	456.12	5	32.58	195.48
9	0.35	30	88.13	562.80	1008	228.06	0	0	0	0	651.60
10	0.3	15	44.07	683.40	1008	195.48	35	228.06	0	0	423.54
11	0.35	0	0	804.00	1008	228.06	0	0	5	32.58	651.60
12	0.35	30	88.13	562.80	1008	228.06	0	0	5	32.58	651.60
13	0.25	0	0	804.00	1008	162.90	70	456.12	0	0	195.48
14	0.3	15	44.07	683.40	1008	195.48	70	456.12	2.5	16.29	195.48

15	0.25	30	88.13	562.80	1008	162.90	70	456.12	0	0	195.48
16	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
17	0.25	30	88.13	562.80	1008	162.90	0	0	5	32.58	651.60
18	0.25	15	44.07	683.40	1008	162.90	35	228.06	2.5	16.29	423.54
19	0.35	0	0	804.00	1008	228.06	70	456.12	5	32.58	195.48
20	0.35	0	0	804.00	1008	228.06	70	456.12	0	0	195.48
21	0.25	30	88.13	562.80	1008	162.90	70	456.12	5	32.58	195.48
22	0.3	0	0	804.00	1008	195.48	35	228.06	2.5	16.29	423.54
23	0.25	0	0	804.00	1008	162.90	0	0	5	32.58	651.60
24	0.35	0	0	804.00	1008	228.06	0	0	0	0	651.60
25	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
26	0.3	30	88.13	562.80	1008	195.48	35	228.06	2.5	16.29	423.54
27	0.35	15	44.07	683.40	1008	228.06	35	228.06	2.5	16.29	423.54
28	0.3	15	44.07	683.40	1008	195.48	35	228.06	2.5	16.29	423.54
29	0.25	30	88.13	562.80	1008	162.90	0	0	0	0	651.60
30	0.35	30	88.13	562.80	1008	228.06	70	456.12	0	0	195.48

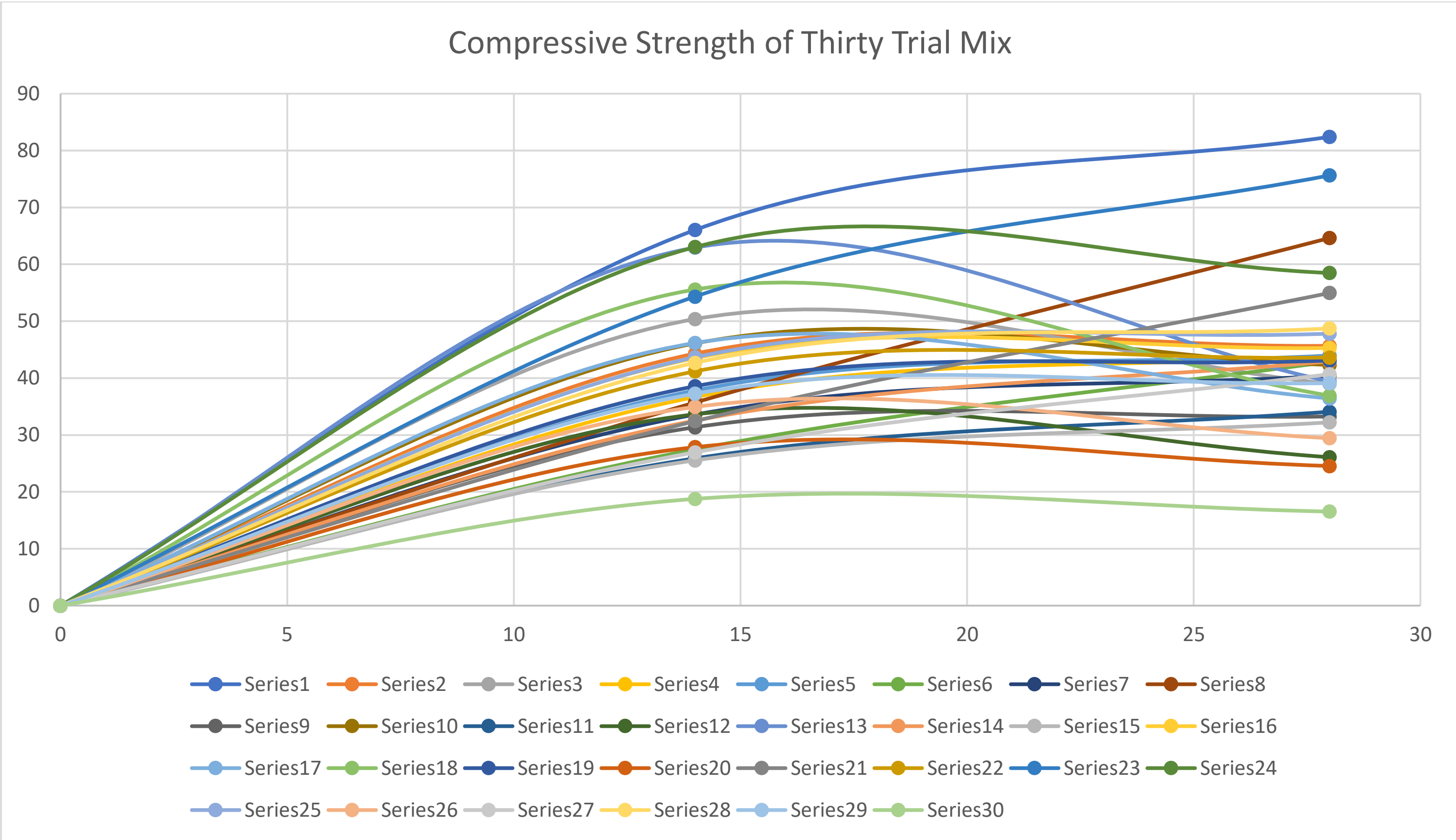


Figure 4. 3 Compressive Strength of Thirty Trial Mix

4.3.RESPONSE SURFACE METHOD (RSM)

Response Surface Method (RSM) use statistical approaches to design an experiment by processing interaction between variables. The objective of RSM is optimization. In this experiment, RSM is used to find the best set of mix design for the designated rubberized concrete. Variables such as Nano silica, fly ash, rubber crumb, water-cement ratio, superplasticizer and aggregates are considered for the RSM analysis.

ANOVA for Response Surface 2FI model

Analysis of variance table [Partial sum of squares - Type III]

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	5879.69	10	587.97	19.40	< 0.0001	significant
A-Crumb rubber	*1601.59*	*1*	*1601.59*	*52.84*	*< 0.0001*	
B-Nano-silica	*143.24*	*1*	*143.24*	*4.73*	*0.0426*	
C-Fly ash	*523.08*	*1*	*523.08*	*17.26*	*0.0005*	
D-w/c	*1099.39*	*1*	*1099.39*	*36.27*	*< 0.0001*	
AB	*163.07*	*1*	*163.07*	*5.38*	*0.0317*	
AC	*506.48*	*1*	*506.48*	*16.71*	*0.0006*	
AD	*352.63*	*1*	*352.63*	*11.63*	*0.0029*	
BC	*1381.24*	*1*	*1381.24*	*45.57*	*< 0.0001*	
BD	*70.08*	*1*	*70.08*	*2.31*	*0.1448*	
CD	*38.90*	*1*	*38.90*	*1.28*	*0.2714*	
Residual	575.95	19	30.31			
Lack of Fit	*551.54*	*14*	*39.40*	*8.07*	*0.0154*	*significant*
Pure Error	*24.41*	*5*	*4.88*			
Cor Total	6455.64	29				

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D, AB, AC, AD, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 8.07 implies the Lack of Fit is significant.

Std. Dev.	5.51	R-Squared	0.9108
Mean	44.68	Adj R-Squared	0.8638
C.V. %	12.32	Pred R-Squared	0.7473
PRESS	1631.07	Adeq Precision	20.133
-2 Log Likelihood	173.78	BIC	211.19
		AICc	210.45

The "Pred R-Squared" of 0.7473 is in reasonable agreement with the "Adj R-Squared" of 0.8638; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 20.133 indicates an adequate signal.

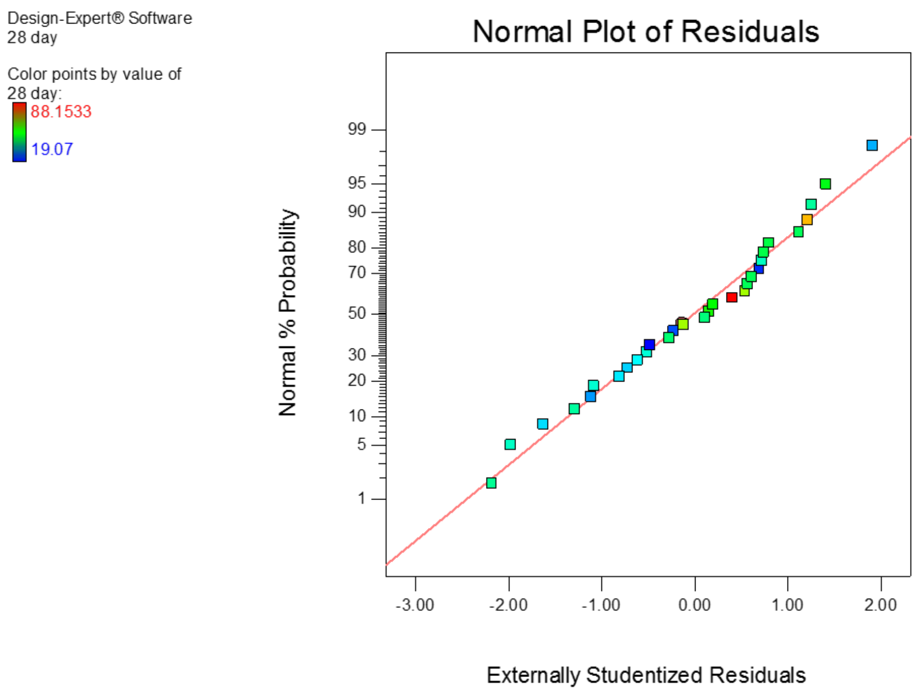


Figure 4. 4 Normal Plot of Residual for 28 days analysis

Residuals are estimates of experimental error obtained by subtracting the observed responses from the predicted responses. Small departures from the straight line in the normal probability plot are common. Breaks near the middle of this graph are also indications of abnormalities in the residual distribution

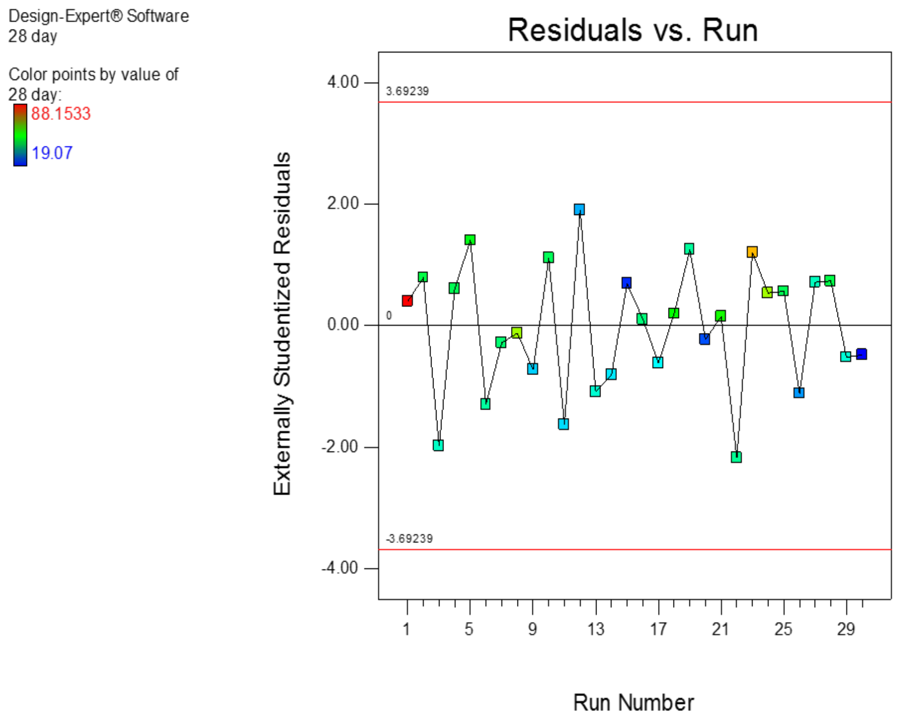


Figure 4. 5 Residual vs Run for 28 days analysis

The residuals suggest a time trend. Figure suggests that the system was drifting slowly to lower values as the investigation continued. If the investigation includes centre points, then plotting them in time order may produce a clearer indication of a time trend if one exists. Plotting the residual vs run responses in time sequence can also sometimes detect trend changes in a process that residual plots might not detect.

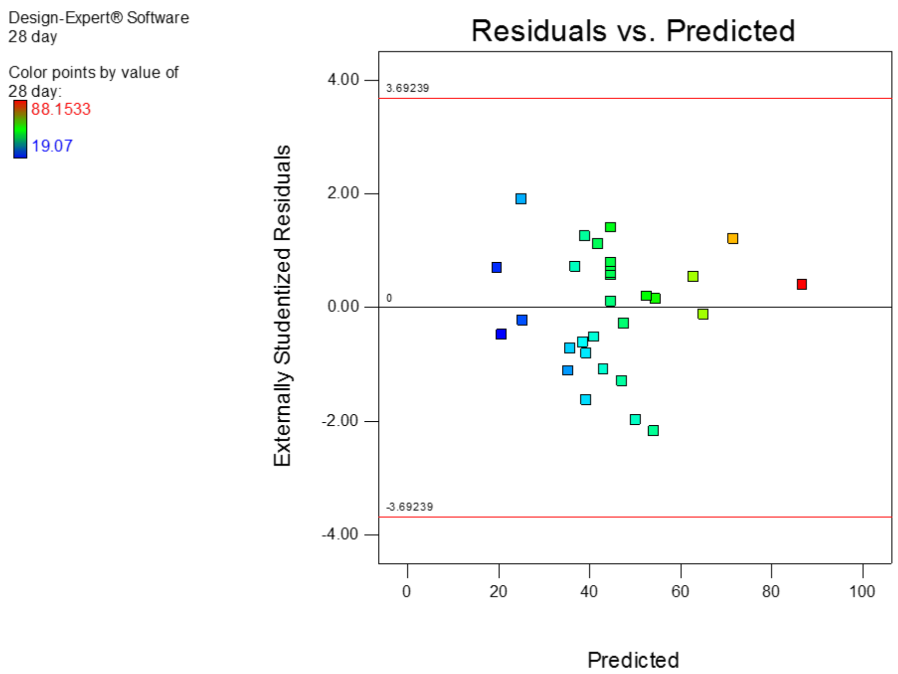


Figure 4. 6 Residual vs Predicted for 28 days analysis

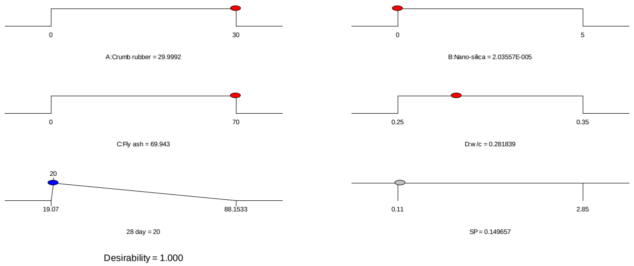
Plotting residuals versus predicted should produce a distribution of points scattered randomly about 0 and within the limits, regardless of the size of the fitted value.

The equation in terms of actual factors is determined and can be used to make predictions about the response for a given levels of each factor.

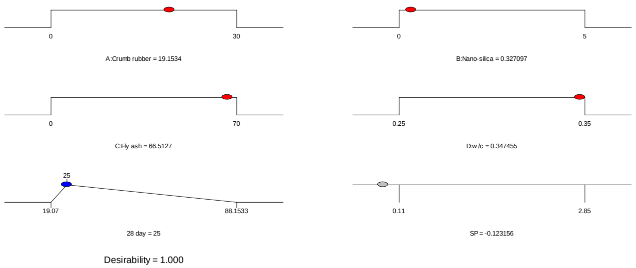
Final Equation in Terms of Actual Factors:

$$28\ day = +146.647 - 3.095CR + 1.158NS - 0.848FA - 239.52wc + 0.085CR.NS + 0.011CR.FA + 6.259CR.wc + 0.106NS.FA - 16.74NS.wc + 0.891FA.wc$$

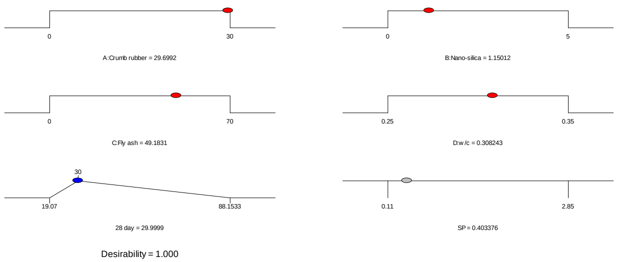
M20



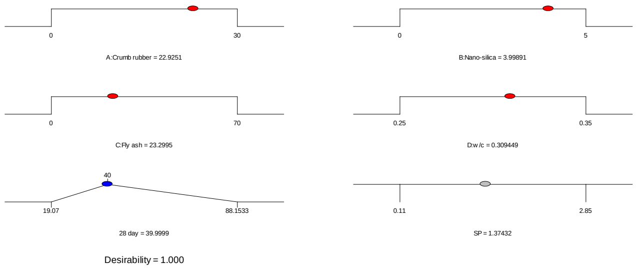
M25



M30



M40



M50

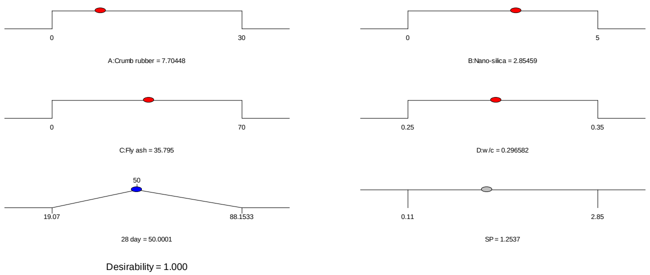


Figure 4. 7 Graphical Ramp View for Optimized Medium Slump Rubbercrete of Different Grades

Table 4. 5 Mix Design of M20, M25, M30, M40, M50

Mix No	w/c	Crumb Rubber		Cement kg/m³	Fine aggregate kg/m³	Course aggregate kg/m³	Water kg/m³	Fly Ash		Nano silica		SP kg/m³
		%	**kg/m³**					**%**	**kg/m³**	**%**	**kg/m³**	
M20	0.35	30	88.13	195.48	562.80	1008	228.06	70	456.12	0	0	0
M25	0.35	30	88.13	195.48	562.80	1008	228.06	70	456.12	0.81	5.28	0
M30	0.35	30	88.13	195.48	562.80	1008	228.06	70	456.12	1.8	11.73	0.52
M40	0.35	30	88.13	206.56	562.80	1008	228.06	68.3	445.04	3.71	24.17	3.91
M50	0.35	30	88.13	195.48	562.80	1008	215.03	70	456.12	5	32.58	6.52

4.4.CHEMICAL ATTACK TESTING

Table 4. 6 Compressive Strength for Different Exposure

		Normal		Acid Attack			Sulfate Attack			Efflorescence	
Mix	sample	Comp Strength	Average	Comp Strength	Average	Deterioration factor	Comp Strength	Average	Deterioration factor	Comp Strength	Average
M20	1.00	18.91	21.01	19.31	18.37	12.58	19.80	18.38	12.52	22.34	23.48
	2.00	24.64		18.60			19.16			26.27	
	3.00	19.48		17.19			16.18			21.84	
M25	1.00	22.14	22.13	18.24	16.48	25.53	24.00	22.87	-3.34	23.75	20.07
	2.00	19.72		13.99			21.31			21.41	
	3.00	24.52		17.20			23.29			15.04	
M30	1.00	26.70	27.75	14.75	17.64	36.44	31.90	27.05	2.55	23.58	26.45
	2.00	24.56		18.54			28.80			27.02	
	3.00	32.00		19.63			20.44			28.74	
M40	1.00	28.81	28.75	11.19	7.36	74.41	39.70	34.37	-19.52	14.79	12.19
	2.00	22.77		7.95			30.20			13.25	
	3.00	34.68		2.93			33.20			8.53	
M50	1.00	11.94	10.87	16.86	16.05	-47.65	20.40	16.01	-47.32	12.52	11.24
	2.00	10.85		19.70			15.38			11.71	
	3.00	9.82		11.59			12.26			9.49	

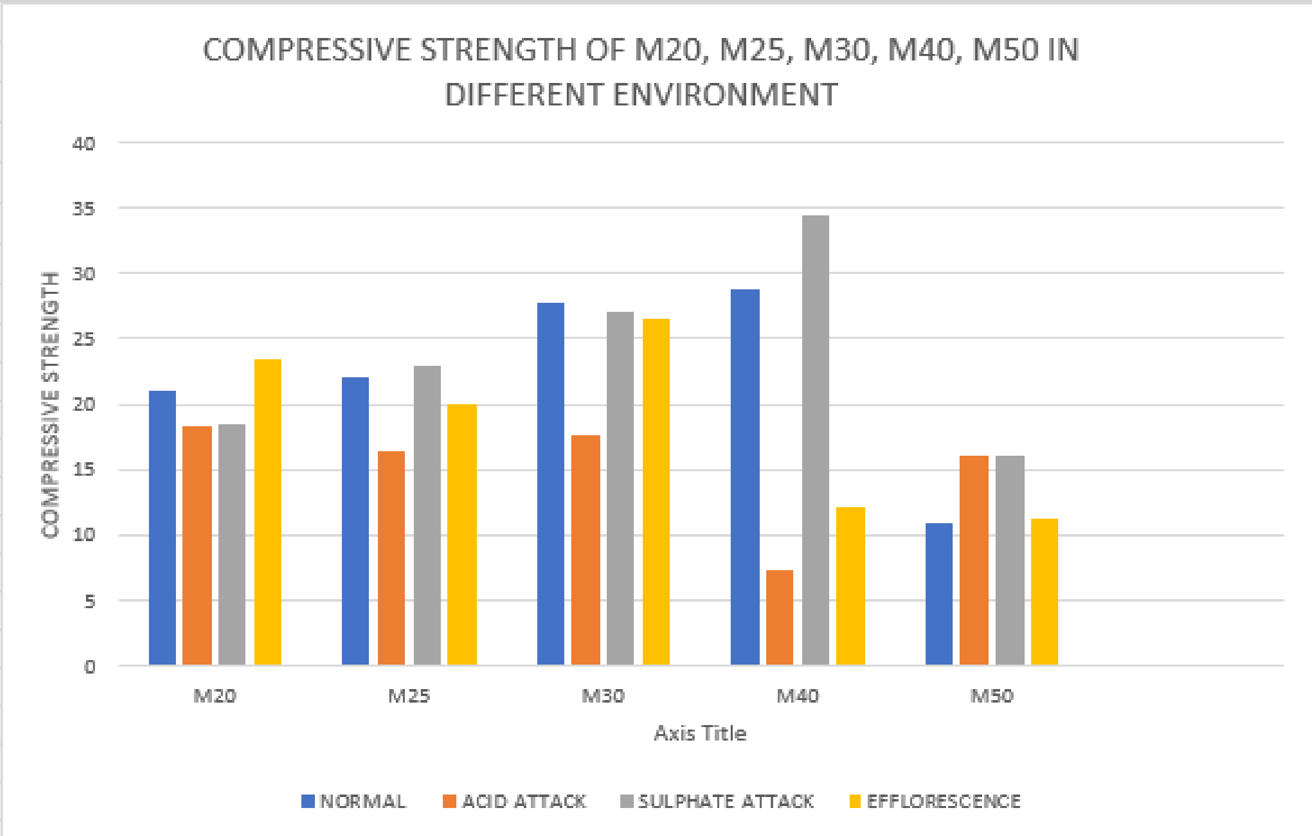


Figure 4. 8 Compressive Strength of M20, M25, M30, M40 and M50 in Different Exposure

Acid attack

The Strength Deterioration Factor (SDF) measures of the reduction in compressive strength when subjected to acid attack (Bai et al., 2003).

$$SDF = [(f_{c128} - f_{ca}) / (f_{c128})] \times 100$$

Where;
f_{c128} = average compressive strength of moistened concrete cubes at first 28 days
f_{ca} = average compressive strength of concrete cubes immersed in the acid solutions.

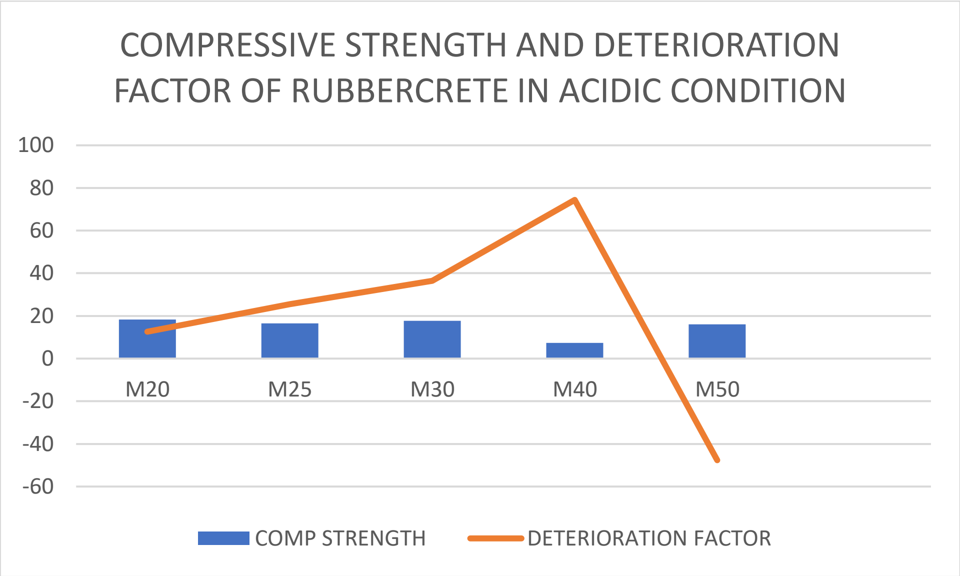


Figure 4. 9 Compressive Strength And Deterioration Factor in Acid Condition

For acid attack, all samples experience reduction in compressive strength. When curing in sulphuric acid solution, the progressive reduction in mass is due to formation of gypsum during neutralization between H2SO4 and Ca(OH)2, consequently leading to lowering of the compressive strength.

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4.2H_2O \text{ (gypsum)}$$

Sulfate attack

For Sulfate attack, M20, M30 experience reduction in comp strength, while M25, M40, and M50 increase in compressive strength.

Loss in strength is due to cracking due to ettringite and gypsum formation which causing expansion and the loss of C-S-H gel. Some cements may continue experiencing hydration reaction in the sulfate solution thus, result in strength and durability increment. Vulnerability to sulfate attack only be quantify through strength loss while increases in strength do not provide any evidence about the ability to resis sulfate attack.

Efflorescence

The samples did not show any visible sign of deterioration but rather show continuous enhancement in compressive strength. The addition of superplasticizer enhanced the compressive strength of concrete may due to the larger degree of hydration caused by the addition of superplasticizer.

With evaporation of water, efflorescence appears on the of the concrete. Efflorescence caused by Thenardite crystals expand by absorbing water and may cause flaking. However, efflorescence with the use of superplasticizer is different as the crystals formed on the surface are centralized and patterned. Aakman and cavdar 1999 reported that the crystals do not affect the concrete compressive strength and can be cleaned.

4.4.1. Acid Attack

Table 4. 7 Rubbercrete Weight Difference in Acid

		Weight (kg)				Average Weight Loss (%)
Mix	Sample	0		1		
M20	1	1.937	1.99	1.974	2.03	-1.89
	2	2.016		2.052		
	3	2.029		2.069		
M25	1	2.03	1.99	1.976	2.03	-2.13
	2	1.941		2.03		
	3	1.984		2.076		
M30	1	1.969	1.99	2.015	2.03	-2.17
	2	2.025		2.067		
	3	1.961		2.002		
M40	1	1.707	1.86	1.726	1.91	-2.24
	2	1.926		1.986		
	3	1.958		2.004		
M50	1	1.958	1.96	2.001	2.00	-2.25
	2	1.991		2.034		
	3	1.92		1.966		

Mix M50 experience the highest weight gain (has higher cement content compare to other mixes), compare to other mixes.

Concrete is susceptible to acid attack because of its alkaline nature. Calcareous aggregates (containing calcium) readily reacts with acids. The reaction between acid and the calcium compounds will form soluble calcium salts. These salts when leached can cause loss of density and cohesion of the cement paste. Calcium silicate hydrates when reacts with sulphuric acid will form fragile silica gel, thus reducing it strength. A visual inspection of concrete that experience acid attack proves the corrosion of the cement paste.

Concrete deterioration by sulfuric acid happens when sulphuric acid reacts with calcium hydroxide of cement hydrates and produces gypsum. The volume of gypsum increases largely causing expansion which eventually result in erosion. Similarly, the disintegration of hardened cement paste causes a reduction in the compressive strength of concrete.

The weight gain cannot be attributed to saturation of the samples since it was dried prior to weighing. The development of calcium sulfate cause reduce the density of the rubbercrete. Since volume and density are greatly affecting weight, the initial weight gain of the samples is due to the relative increase in volume being greater comparing to the relative decrease in density.

The chemical reaction involves in sulphuric acid attack on OPC can be given as:

$$Ca(OH)_2 + H_2SO_4 = CaSO_4.2H_2O$$

$$3CaO.2SiO_2.3H_2O + H_2SO_4 = CaSO_4.2H_2O + Si(OH)_4$$

$$3CaSO_4 + 3CaO.Al_2O_3.6H_2O + 25H_2O = 3CaO.Al_2O_33CaSO_4 + 31H_2O$$

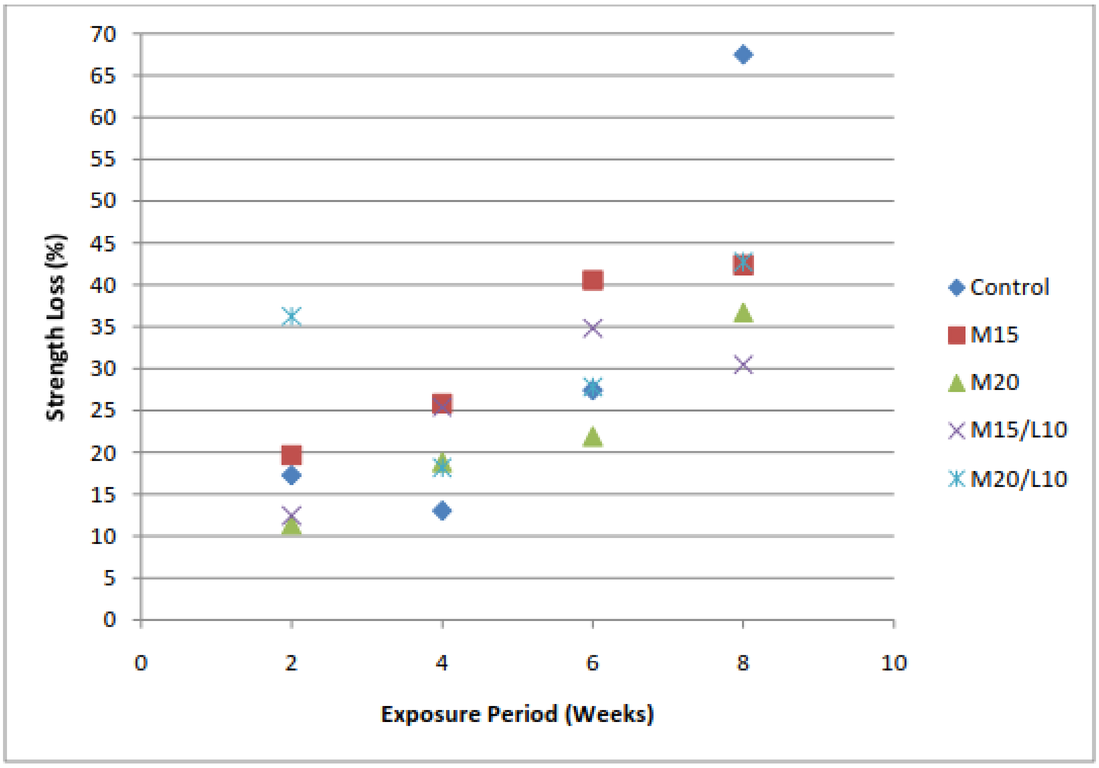


Figure 4. 10 Strength Loss of Concrete Samples after Exposure to a 5% Sulphuric Acid Solution

To test whether rubbercrete have a better acid attack resistance comparing to conventional concrete, research is made based on previous literature. Joorabchian (2010) stated in his report that Concrete M20 experience about 18% of strength loss after one month of being exposed to 5% sulphuric acid (refer to Graph 4.9).

Rubbercrete on the other hand shows a better resistance to acid attack as the strength loss is only about 12% after one month being exposed to the same solution. This could be the result of a better and densified porosity of rubbercrete which retard the ingress of sulphuric acid thus making it more acid resistance.

4.4.2. Sulfate Attack

Table 4. 8 Expansion of Samples in Sulfate Condition

	Length (mm)			Expansion (%)	
Mix	Before	Week 2	Week 4	Week 2	Week 4
M20	297.04	297.08	297.26	0.013	0.074
M25	292.01	292.08	292.17	0.024	0.055
M30	300.65	300.89	301.1	0.080	0.150
M40	298.88	299.06	299.7	0.060	0.274
M50	303.53	303.76	303.98	0.076	0.148

$$\triangle L = \frac{L_x - L_i}{L_g} x100$$

Where
$\triangle L$ = change in length at *x* age, %
L_x = comparator reading of samples at *x* age – reference bar comparator reading at *x* age, and
L_i = initial comparator reading of samples-reference bar comparator reading, at the same time
L_g = nominal gage length, or 250mm (in.) as applicable. (See C 490)

Samples undergoes volume expansion because of the sulfate solution. There are three chemical reactions that take place between sulfate and hardened cement pastes. These reactions are; recrystallisation of ettringite, formation of gypsum and decalcification of the main cementitious phase (C-S-H).

Calcium hydroxide formation in cement paste helps contributing to the conversion of alumina containing hydrates to ettringite which in times will increased by mechanisms. The formation of gypsum because of cation exchange reactions can cause expansion, however, it is typically relating to loss of mass and strength (Cao, Bucea, & Ferguson, 1997). Gypsum cause local expansion or cracking when formed in large amount. The decalcification of the C-S-H can be important when the sulfate solution is lower in pH value. Here, more gypsum formation will result to both strength loss and expansion.

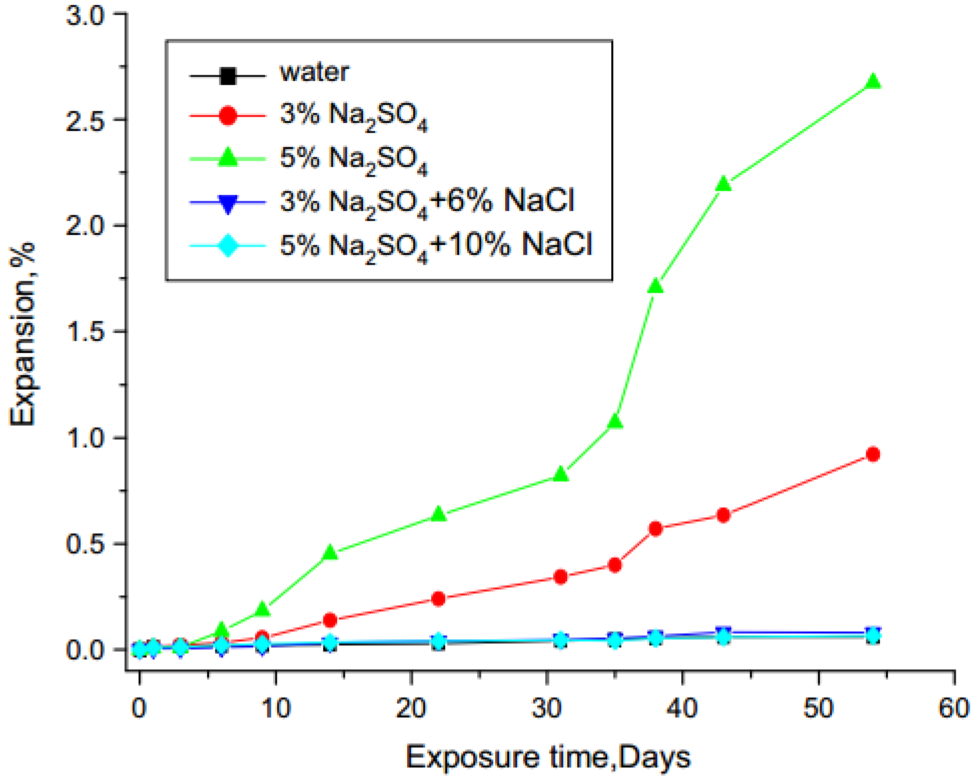


Figure 4. 11 Axial Expansion of Samples Being Immersed in Different Solutions

Based on Graph 4.11, immersion in 5% of sodium sulfate result in about 0.8% expansion in volume of the conventional concrete samples (Zhang, Chen, Lv, Wang,, & Ye,, 2013). Alternatively, rubbercrete only shows the expansion of less than 0.3% after the immersion period. This shows that the property of rubbercrete which have lower water-cement ratio and more densified pores have result in a better sulfate attack resistance.

4.4.3. Efflorescence

Table 4. 9 Result for Efflorescence

	Report
M20	Slight
M25	Slight
M30	Moderate
M40	Heavy
M50	Heavy

Nil: No perceptible deposit of salt.

Slight: Not more than 10 percent of the area of the bricks covered with a thin deposit of salt.

Moderated: A heavier deposit than under "Slight" and covering up to 50 percent of the area of the bricks surface but unaccompanied by powdering of flaking of the surface.

Heavy: A heavy deposit of salt covering 50 percent or more of the bricks surface but unaccompanied by powdering or flaking of the surface.

Serious: A heavy deposit of salt accompanied by powdering and/or flaking of the surfaces

Presence of soluble salts, water to carry the salts in solution, and a pathway to the surface for the salt's migration is the three conditions that need to be fulfil for efflorescence to happen. Cement content, mix water, water/cement ratio, admixtures, curing conditions, and permeability are some of the factors affecting the intensity of efflorescence.

Efflorescence occurs when salts are dissolved in moisture inside the concrete. The water serves as carrying agent of the salt to the surface of the wall. When water evaporates it leaves the salt as a small crystals deposit. Efflorescence only occurs when there is a significant movement of water within the wall to the surface, thus, there is no specific time to be recognize for it to appear.

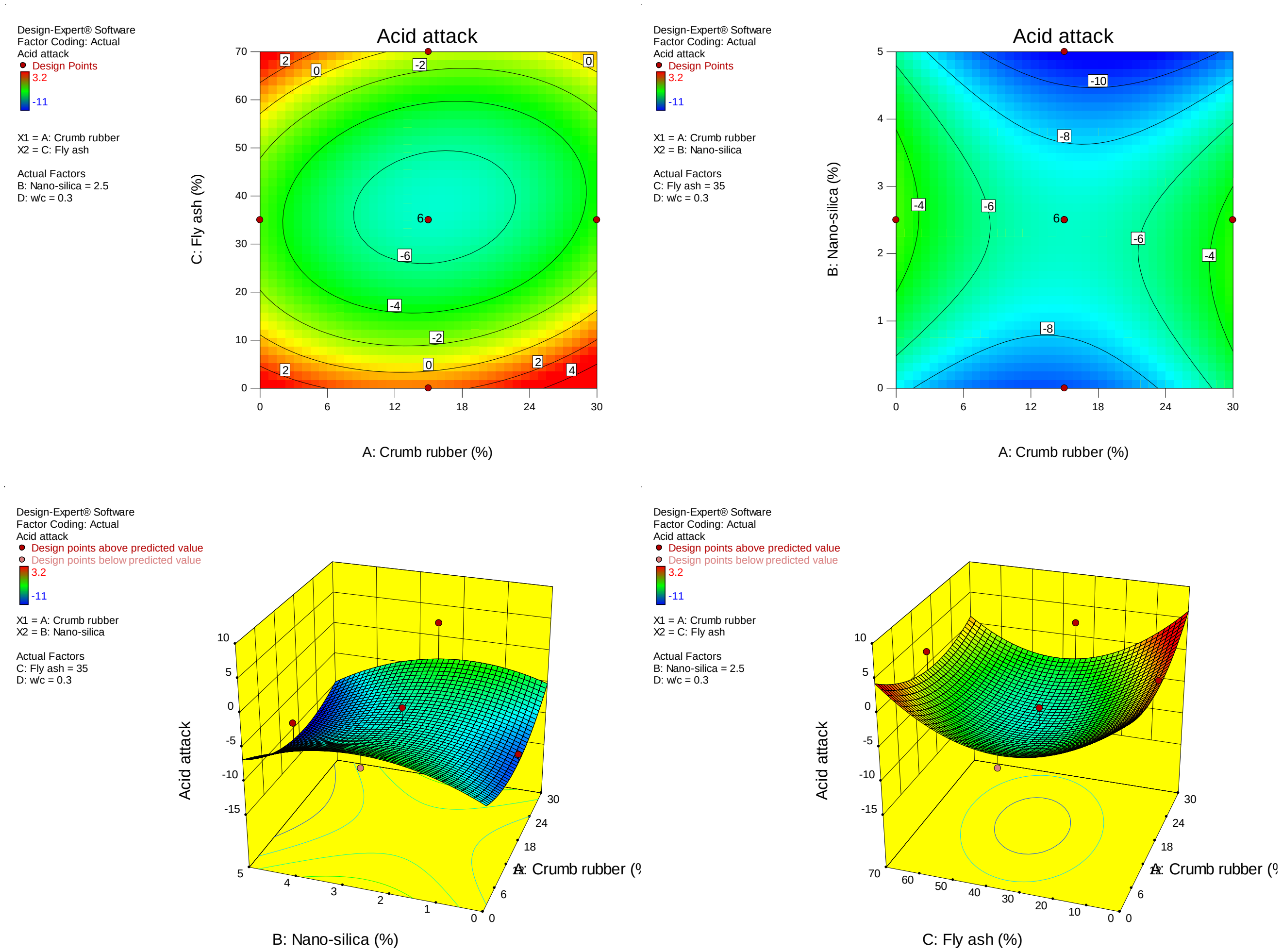


Figure 4. 12 Countor Graph and 3D Graph for Acid Attack Responses

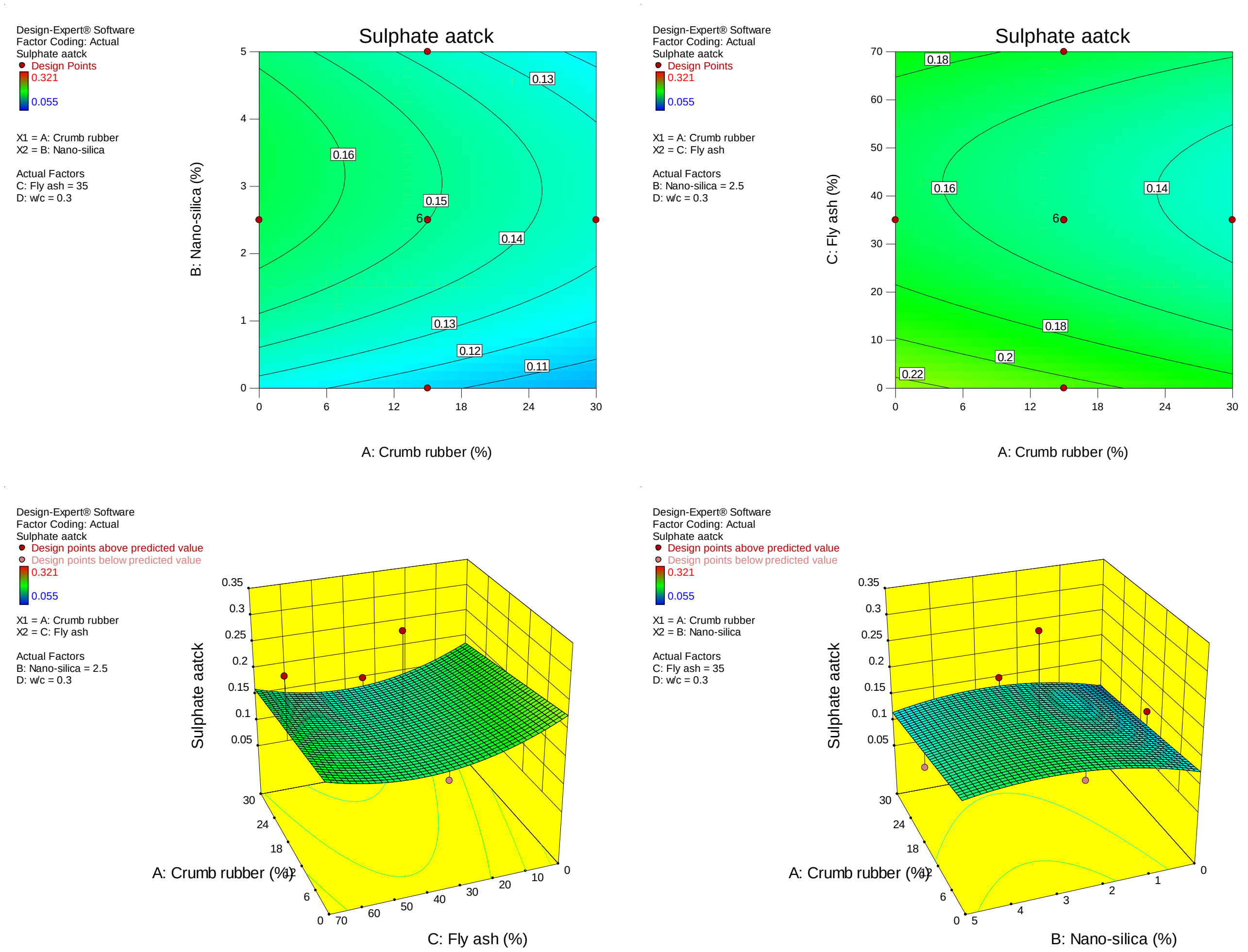


Figure 4. 13 Countor Graph and 3D Graph for Sulfate Attack Responses

CHAPTER 5

CONCLUSION

In conclusion, utilizing crumb rubber from scrap tires as alternative to fine aggregate in concrete production gives many benefits especially to the environment. Two major environmental problem that can be reduced from this practice are the depletion of natural resources (in this case fine aggregates) and abundance of scrap tires that is hard to dispose. The production of rubberized concrete which integrate the partial replacement of cement with fly ash also promotes sustainability value as the waste material such as fly ash gives lower carbon dioxide emission.

Rubberized concrete also known as rubbercrete, although result in a lower compressive strength compare to the conventional concrete has more advantages when used in the construction company. The limitation of rubberized concrete which gives the lower compressive strength can be counter by adding Nano Silica into the mixture. Study by Mohammed, Awang , Wong, & Nhavene (2016) shows that the addition of Nanosilica up to 5% improves the microstructure of the rubbercrete due to its physico-chemical attributes.

The performance of rubberized concrete within a chemical-contained environment is tested. The rubberized concrete is tested in three conditions; when subjected to acid attack, sulfate attack and efflorescence. The innovated rubbercrete has the property to retard the ingress and movement of water transporting the chemical. Nano Silica is known to densify the interfacial transition zone (ITZ) between the crumb rubber particles and the cement paste and refining pore system in the rubbercrete (Belkowitz J, Armentrout DL. (2009) cited in Said, Zeidan, Bassuoni, & Tian, (2012)). Since the rubberized concrete has a densified porosity, less chemical can seep into the concrete to attack it. Comparison between rubbercrete and normal concrete are made based on Jaroobchian (2010) report where normal concrete M20 experience about 18% strength loss after one month of exposure to sulphuric acid while rubbercrete shows only 12%

of strength loss in the same environment. Another comparison is made based on Zhang, Chen, Lv, Wang, & Ye (2013) where normal concrete is immersed in 5% of sodium sulfate in a period of one month gives expansion rate of about 0.8%. On the other hand, experimental result for rubbercrete only gives less than 0.3% expansion rate. Therefore, it proves that rubbercrete has a higher resistance to chemical attack.

RECOMMENDATIONS

A stronger acid solution gives significant increase in the volume of the concrete in comparison to the reduction of the density. Therefore, weight loss is not a consistent measure when comparing the effect of sulfuric acid on concrete. For testing of rubbercrete against sulphuric acid, the expansion of samples may be a more consistent measure than the weight loss as sulfuric acid-cement paste reaction will result in increase of volume. The use of samples with large surface area-to-volume ratios is preferable. Future study to evaluate samples expansion and weight loss as measures of concrete deterioration due to acid with different are needed.

For testing of rubbercrete against sulfate attack, past studies had recommended that poor sulfate resistance can be recognize when there is a 25-30% reduction in original strength of samples. For samples that is being tested he first time, strength reduction at 4 and 9 weeks of sulfate exposure is to be determined.

The study has exclusively focused on acid attack, sulfate attack and efflorescence to determine the chemical attack resistance of rubbercrete. There is a need for future studies to investigate on other chemical deterioration mechanisms that pose threat to rubbercrete such as the alkali-aggregate reaction (AAR), chloride attack and carbonation. There is also a need for future studies on rubbercrete attributes in protecting reinforcing steel from corrosion. By understanding its behaviour with reinforcing steel, the usage of rubbercrete will be widen and not limited.

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APPENDICES

Attachment A – Gantt Chart