Tensile and Flexural Behaviour of Concrete Containing Crumb Rubber as Partial Replacement of Fine Aggregate

By

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19205

Dissertation submitted in Partial Fulfillment of
The Requirements for The
Bachelor of Engineering (Hons) Civil

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Ehsan Nikbakht Jarghouyeh)

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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.

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(NURUL AMEERA BINTI SAPARUDDIN)

ABSTRACT

The use of rubber crumb has been introduced in the production of concrete. This alternative is found out to be a great choice in order to significantly reduce the amount of scrap tire disposed in a landfill area. This is because the production of concrete annually could reach up to 500 million tonnes. However, crumb rubber considerably reduced the mechanical strength of concrete, which are compressive, tensile, and flexural strength. Thus, several materials are inserted in the design mix to improve its strength, such as, nano silica, fly ash, and superplastisizer. In this study, firstly, 30 trial mixes of Grade 40 are developed through Respond (RSM) software. Each mix consists of 6 cube samples with the size of 100 x 100 mm. Compressive strength test is done on the samples at 14^{th} day and 28^{th} day. Then, the results are analyzed to come up with the optimum mix design of the rubbercrete. Next, by using the optimum mix design, five mixes of different grade is used for direct tensile test and flexural test. Six samples of each mix design would be produced in the shape of dog-bone and tested for tensile strength of the concrete. It would be subjected to pure tensile force by using Universal Testing Machine. The test is referred to ASTM D638-03 standard. While for flexural test, prisms with 100 x 100 x 500 mm size are used and subjected to four-point loading which will follow ASTM D6272 standard. This is to ensure that the sample experienced a pure bending stress. With the presence of nano silica, the compressive strength of Rubbercrete significantly increased. Other materials added into the mixture also help in governing the strength of the concrete. However, for the aspect of direct tensile and flexural strength, no significant effect can be observed.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Millions of scrap-tires are created every year which result in accumulation of the discarded materials in landfill. Its bulky nature occupies large space and has voids that encourage the breeding of mosquitoes and be home for various types of pests. Area for land disposal also consequently becomes alarmingly lesser since this material does not biodegradable. Not only that, it also has high risk in fire hazards. Once it caught fire, the surrounding area would envelop in thick hazardous smoke which is unsafe for human health.

Various studies are conducted to find innovative usage of scrap tire to solve its disposal issues. Some of the alternatives include the usage of tire rubber in asphatic concrete mixtures, burning of tires in production of steam, and recycle ground tire rubber to make plastic and rubber products. Scrap-tires also are exploited as fuel for cement kiln. However, it involves high capital investment, thus it is not cost effective.

Other option is recycling the waste tires into concrete production. The reason of why this is one of the best alternatives is the production of concrete is relatively high with almost 4000 billion cubic meter annually. Scrap-tire could be processed and grounded to become crumb rubber and then could be used as one of the materials in concrete mixture.

1.2 Problem Statement

Scrap tire has become a major concern especially for its disposal process. It is a non-biodegradable material, thus, results in increasing volume of discarded tire in the landfill. Many researches have been done to find out the effective way to reuse and recycle this component into different applications. One of the common topics involves the use of crumb rubber from scrap tire in the concrete mixtures.

The concrete containing the crumb rubber, also widely known as rubbercrete, does have various advantages including, light in weight, could absorb more noise, resistant to impact, and high in ductility. However, rubbercrete also has drawback. One of the main problems is the reduction of strength, which incorporates the strength in compressive, tension, and flexural. In the rubbercrete, there are many voids caused by the hydrophobic property of the crumb rubber. These voids lessen the surface contact between the particles in the mixture, which ultimately results in the reduction of strength. Thereby, several materials are introduced to improve the surface contact between the crumb rubber and the concrete mixture and overall strength of the concrete, such as nano silica and fly ash. This paper will be focusing on how these materials affect the mechanical properties of concrete containing crumb rubber.

1.3 Objective

1) To determine the compressive strength of the concrete which have different amount of crumb rubber, nano-silica and fly ash;
2) To study the resultant tensile strength of the concrete through direct tensile test, and;
3) To observe and analyze the flexural behavior of the rubbercrete by conducting flexural test.

1.4 Scope of Study

This project will be discussing the effects of the materials such as crumb rubber, nano silica, and fly ash towards the mechanical properties of the concrete. The mechanical properties of concrete include compressive strength, direct tensile and flexural behaviour. There are different combinations of the amount of aforementioned materials in the mix design of Rubbercrete which ultimately designed for concrete of Grade 40. The behaviour of the concrete will be observed and analyzed based on the materials. The table below describes the amount of materials used in the design mix.

Table 1.1: Range of Amount of Materials

Materials	Amount
Fly Ash	0-70% from the weight of cement
Nano Silica	0-5% from the weight of cement
Crumb Rubber	0-30% from the volume of fine aggregate (Used volume to calculate the amount of crumb rubber due to lower specific gravity of crumb rubber compared to fine aggregate)
Water/Cement Ratio	0.25-0.35

1.5 Project Relevancy

This project focuses on the improvement of the mechanical strength of Rubbercrete, which includes the compressive, tensile, and flexural strength. By using nano silica, fly ash, and superplastisizer, the strength of the concrete could be increased. This helps in maximizing the use of crumb rubber in the production of concrete. It does not only help in lessening the impact of scrap tire disposal towards the environment, but it also give high benefits to the construction industry as Rubbercrete posses many advantages and functions, such as it could be used as soundproofing material.

1.6 Project Feasibility

The materials that would be using in the mix are easily attainable in the laboratory and purchased at nearby hardware store. Furthermore, the machine and apparatus use to conduct the tests are also accessible at the concrete laboratory complete with the manual. The experimentation activities also are predicted to be able to finish in the duration of the final year semesters.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter discussed about past studies that use crumb rubber as one of concrete materials. Several researches highlighted on how the use of crumb rubber in the design mix significantly reduced the strength of the concrete. To improve its strength a few additives or materials are introduced, such as nano silica.

Most papers analyzed in this chapter are from published materials. This chapter also served as comparison on possible ways to improve the mechanical properties of concrete containing crumb rubber and results of such testing.

2.2 Composition of Rubbercrete

2.2.1 Type of Materials

Typical constituents of Rubbercrete used by previous studies are crumb rubber, fine aggregate, coarse aggregate, cement, fly ash, and superplasticizer. However, there are slight changes in the constituents, usually to enhance its strength.

Girskas and Nagrokiene (2017) used two different granules sized which are fraction 2/4 and 4/6, and found out that the granules with smaller size reduced the compressive strength of the concrete more than that of the larger size. Yu and Zhu (2017) argued that as the size of crumb rubber decreased the mechanical properties of a mix also decreases.

Girskas and Nagrokiene (2017) also stated that rubber particles tend to adhere to cement binder well. However, according to Youssf et. Al (2016), they had used pre-treated rubber to improve the mechanical properties of the concrete due to the hydrophobic nature of the material. The pre-treatment of rubber provide boost in the adhesion of the rubber and cement in the concrete matrix. Sodium hydroxide (NaOH) solution used to treat the rubber removes the zinc stearate layers on the material surface (Pacheco-Torgal, et. Al, 2016).

Youssf, et. Al (2016) also stated on how the silica fume helps in increase by affecting the concrete physically and chemically. Physically, SF filled in the micro voids in the concrete thus increase the contact between the materials and results in more durable concrete. SF also reacts wholly or partially with the calcium hydroxide promoted by the hydration processed of cement, and generated calcium silicate hydrate which could alleviate the compressive strength of the concrete. Yousff, et. Al (2016) in their study also used large contents of cement which are 300 kg/m^3, 350 kg/m^3, and 400 kg/m^3.

Water to cement ratio also has diverse affect on properties of concrete. To attain required workability of a concrete without compromising the water content, superplasticizer is added to the mixture. For example, Mendis, et. Al (2017) added ADVA 650, a high water reducing admixture to the mix design.

2.2.2 Mix Proportion

Several mix design of Rubbercrete were developed and used by researchers of previous studies. Some papers discussed on the samples of the mix proportion in order to find the possible and similar concrete mix design to find for the optimum. Mendis, et. Al (2017) chose six mixes, three with compressive strength of 40-46 MPa and another three with 30-35 MPa. These mixes are chosen after conducting large number of trial mixes due to the lack of any established method of mix design. Table 2.1 shows the constituents of their mixtures.

Table 2.1: Mix Proportion used in the study of Mendis et. Al. (2017)

Mix ID		40R1	40R2	40R3	30R1	30R2	30R3
Water/Cement		0.50	0.45	0.40	0.49	0.50	0.56
Cement/Total Aggregate		0.17	0.17	0.17	0.20	0.17	0.08
% of Rubber		5.33	10.63	21.11	16.22	13.26	5.40
Cement (kg/m^3)		388	388	388	424	388	300
Water (kg/m^3)		194.0	174.6	155.2	209.0	194.0	167.0
Coarse Aggregates (kg/m^3)	10 mm	465.6	465.6	465.6	1105.0	465.6	1107.2
	14 mm	737.2	737.2	737.2	0	737.2	0
Fine Aggregates (kg/m^3)		663.48	628.56	558.72	556.00	611.10	885.85
Rubber (kg/m^3)		14.73	29.47	58.95	42.44	36.84	20.00
Admixture (kg/m^3)		0	2.52	2.48	0	2.5	4.36

The crumb rubber used in the study has three different size ranges, 40% from #30 mesh, 35% is 1 mm to 3 mm in sizes, and size 2 mm to 4 mm rubber granules constitutes another 25% of the rubber mix. This is to maintain the size distribution of fine aggregates. The results showed that the compressive strengths of the mixes of each group (group of Grade 30 and Grade 40) were similar. Several modifications were done to achieve this, for example, alteration on the water per cement ratio, cement content, and cement to aggregate ratio of the mix. Mendis et. Al (2017) highlighted on how the reduction of water to cement ratio helps in tackling the strength reduction of the concrete caused by the addition of amount of crumb rubber in the mix.

Mohammed, et. Al (2016) developed twenty four mixtures with the addition of Nano silica. Four ranges of crumb rubber are used to replace the fine aggregates by volume, which are 0%, 10%, 25%, and 50%, and six ranges (0-5%) of nano silica is added to the mixture. The results underlined the role of nano silica in improving the contact between the crumb rubber and cementitious materials of the mix and consequently increase the strength of the concrete. The mix proportions of this study are described in Table 2.2 below.

Table 2.2: Mix Proportions used in the study of Mohammed, et. Al (2016)

Mixture Reference	Cementitious Materials			Aggregates		
	Cement	Fly Ash	Nano Silica	Fine Aggregate	Crumb Rubber	Coarse Aggregate
NS0 CR0	0.85	0.15	0	2.0	0	1
NS0 CR10	0.85	0.15	0	1.8	0.2	1
NS0 CR25	0.85	0.15	0	1.5	0.5	1
NS0 CR50	0.85	0.15	0	1.0	1.0	1
NS1 CR0	0.85	0.15	0.0085	2.0	0	1
NS1 CR10	0.85	0.15	0.0085	1.8	0.2	1
NS1 CR25	0.85	0.15	0.0085	1.5	0.5	1
NS1 CR50	0.85	0.15	0.0085	1.0	1.0	1
NS2 CR0	0.85	0.15	0.0170	2.0	0	1
NS2 CR10	0.85	0.15	0.0170	1.8	0.2	1
NS2 CR25	0.85	0.15	0.0170	1.5	0.5	1
NS2 CR50	0.85	0.15	0.0170	1.0	1.0	1
NS3 CR0	0.85	0.15	0.0255	2.0	0	1
NS3 CR10	0.85	0.15	0.0255	1.8	0.2	1
NS3 CR25	0.85	0.15	0.0255	1.5	0.5	1
NS3 CR50	0.85	0.15	0.0255	1.0	1.0	1
NS4 CR0	0.85	0.15	0.0340	2.0	0	1
NS4 CR10	0.85	0.15	0.0340	1.8	0.2	1
NS4 CR25	0.85	0.15	0.0340	1.5	0.5	1
NS4 CR50	0.85	0.15	0.0340	1.0	1.0	1
NS5 CR0	0.85	0.15	0.4250	2.0	0	1
NS5 CR10	0.85	0.15	0.4250	1.8	0.2	1
NS5 CR25	0.85	0.15	0.4250	1.5	0.5	1
NS5 CR50	0.85	0.15	0.4250	1.0	1.0	1

2.3 Mechanical Properties of Rubbercrete

2.3.1 Compressive Strength

Compressive strength is the most basic property of concrete. When crumb rubber is used as a partial replacement of fine aggregates in concrete mix, its compressive strength reduced considerably. Raffoul, et. Al (2016) came up with 40 Rubbercrete concrete mixes to study the optimum mix especially regarding the amount of binder material and water to binder ratio. They divided their experimental works into two parts; Part 1 involved the observation on the Rubbercrete compressive strength by using several different water-to-binder ratios, binder materials, method of samples preparation, and admixture at constant amount of crumb rubber (40% of fine aggregate volume), while in Part 2, optimum mix from Part 1 was selected to study how its compressive strength was affected by rubber contents and sizes. Raffoul, et. Al (2016) suggested to limit the water to binder ratio to 0.35 and replacing 20% of cement with silica fume and pozzolanic fly ash. According to Mohammed, et. Al (2010), partially replacing cement material with silica fume and fly ash also strengthen the concrete compressive property.

2.3.2 Tensile Strength

Concrete is a brittle material that is easily subjected to tensile failure or cracking due to many kinds of effects and applied loading. Tensile strength is an essential property of concrete. Compare to its compressive strength, tensile strength of concrete is very low. There were not many studies on tensile behaviour of Rubbercrete adopted the direct tensile test method. This is because to apply uniaxial tension to concrete samples are difficult. For example, Youssf, et. Al (2016) tested two 150 x 300 mm Rubbercrete cylinders to test for indirect tensile test. The pre-treated rubber used in the samples increased its tensile strength by 15% than that of non-treated rubber.

Ganjian, et. Al (2009) also used indirect tensile test to measure the tensile strength of the concrete. It was hypothesized that the replacement of fine aggregate with crumb rubber would significantly increase the concrete tensile strength as it acts as barrier against crack growth. However, the results showed that the tensile strength was reduced as the amount of crumb rubber replacing the fine aggregates decreased.

2.3.3 Flexural Strength

Ganjian et. Al (2009) also studied the tensile strength of concrete containing crumb rubber. The rubber, as expected, reduced the flexural strength of the concrete specimens. 37% reduction of flexural strength occurs. This lessening of strength is due to the poor bonding between rubber granules and cementitious materials (Ganjian, et. Al, 2009)

2.4 Testing on the Mechanical Properties of Rubbercrete

2.4.1 Compressive Strength Test

Mohammed, et. Al (2016) used BS EN 12390-3 as guideline to prepare and test the compressive strength. Three samples of cubes were prepared with the dimension of 100 x 100 x 100 mm, and one specimen of 20 x 20 x 5 mm dimension was also casted. Mechanical pressure of 2500 MPa was applied on the samples for 1 min. Rouffoul, et. Al (2016) used BS EN 12390-2 which instructed the concrete to be applied with uniaxial compression using a cube crusher of 3000kN at rate of 0.6 MPa which was later reduced to 0.1 MPa to avoid premature failure. The samples prepared are four cylinders and one cube.

2.4.2 Tensile Test

As previously mentioned, there are only a few researches have adapted the direct method of tensile test. Yousff, et al (2016) prepared two 150 x 300 mm cylinders to determine indirect tensile strength at 28 days. The test is performed by using AS 1012.10 as guideline. AS 1012.10 used constant loading rate on the specimens, which is 1.5 ± 0.15 MPa/min. the cylinder was placed horizontally on the Universal Testing Machine.

2.4.3 Flexural Test

Mendis et al (2017) followed an Australian Standard, which is AS 1012.11 to carry out flexural strength test. The test was done on each batch of Rubbercrete over time on 7^{th}, 14^{th}, 28^{th}, and 56^{th} day after casting. In this test, prisms with dimension of 100 x 100 x 350 mm were used.

2.5 Summary

A notable numbers of studies have been done on the concrete containing crumb rubber as partial replacement of fine aggregates. Several studies discussed on the type of materials and also the composition of the constituents in the mix design. In addition, the effects of the amount of materials on the compressive strength also were observed. A few papers also studied on the mechanical properties of the Rubbercrete such as compressive strength, tensile strength, and flexural strength. However, there are lack of research that discussed about the effects of nano silica, fly ash, and superplastisizers towards the mechanical properties of Rubbercrete.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter discusses the steps or procedure which would be used in order to achieve the aforementioned objectives. These planning and preparation stages are important in ensuring all activities done in according to the requirement, progress proceed in the correct timing and schedule, and goals targeted could be attained by the end of the project. General activities are showed in the Flow Chart section, followed by the discussion on mix design applied in the experiment together with the testing samples. Next, brief explanations are done on the materials and experimental apparatus. Details description on each experiment procedures is then discussed. By the end of this chapter, Gantt chart is attached for progress tracking.

3.2 Flow Chart

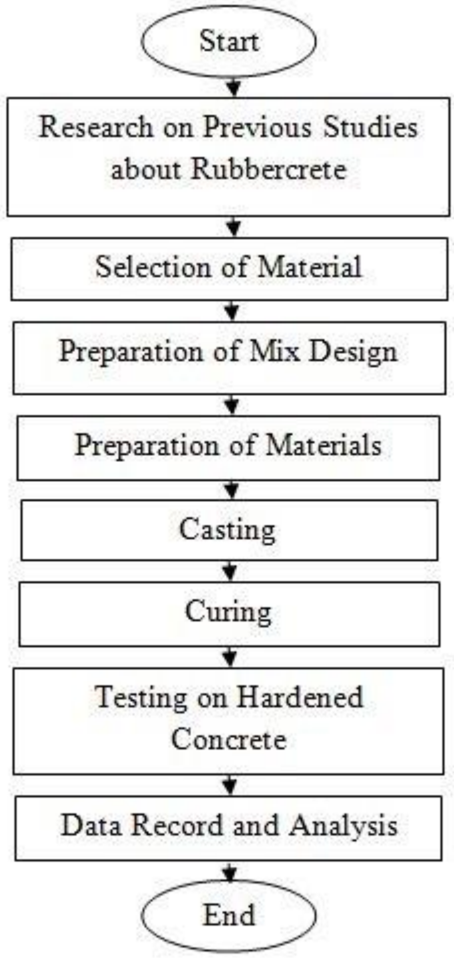


Figure 3.1: Methodology Flow Chart

3.3 Concrete Mix Design

Concrete mix design is prepared by selecting suitable concrete ingredients and dictating their relative quantity to produce a concrete with desired strength, durability, and workability as economically as possible.

For compressive strength test, there are 30 mix designs to be utilized as trial mix designs for Rubbercrete. These mix designs are obtained through software called Response Surface Methodology (RSM). All 30 mix designs are expected to achieve 40 MPa of the stipulated compressive strength. They are combinations of different amount of the materials of the mixture, such as, course aggregate, washed river sand, Ordinary Portland cement (OPC), crumb rubber, fly ash, nano silca, water, and superplastisizer, as describes in Table 3.1. These different combinations of material quantity will induce slight difference in the compressive strength value. Analysis will be done to observe the effect of each material towards the strength of the concrete. Then, next 5 mix designs will be determined for direct tensile and flexural test of the concrete. Table 3.1 shows all the mix proportions used for compressive strength test, followed by number of samples produced for each mix in Table 3.2.

Table 3.1: Mix Design for Compressive Strength Test

Run	Crumb Rubber (m^3)	Crum Rubber (kg)	Nano Silica (kg)	Fly Ash (kg)	Water-Cement Ratio	Cement (kg)	River Sand (m^3)	River Sand (kg)
1	0	0	0	0	1.14	4.56	2.17	5.63
2	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
3	0.32475	0.31	0.11	0	0.3	4.56	1.84	4.78
4	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
5	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
6	0.6495	0.62	0.23	3.19	0.35	1.37	1.52	3.94
7	0.32475	0.31	0.23	1.60	0.3	2.96	1.84	4.78
8	0	0	0.23	3.19	0.25	1.37	2.17	5.63
9	0.6495	0.62	0	0	0.35	4.56	1.52	3.94
10	0.32475	0.31	0	1.60	0.3	2.96	1.84	4.78
11	0	0	0.23	0	0.35	4.56	2.17	5.63
12	0.6495	0.62	0.23	0	0.35	4.56	1.52	3.94
13	0	0	0	3.19	0.25	1.37	2.17	5.63
14	0.32475	0.31	0.11	3.19	0.3	1.37	1.84	4.78
15	0.6495	0.62	0	3.19	0.25	1.37	1.52	3.94
16	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
17	0.6495	0.62	0.23	0	0.25	4.56	1.52	3.94
18	0.32475	0.31	0.11	1.60	0.25	2.96	1.84	4.78
19	0	0	0.23	3.19	0.35	1.37	2.17	5.63
20	0	0	0	3.19	0.35	1.37	2.17	5.63
21	0.6495	0.62	0.23	3.19	0.25	1.37	1.52	3.94
22	0	0	0.11	1.60	0.3	2.96	2.17	5.63
23	0	0	0.23	0	0.25	4.56	2.17	5.63
24	0	0	0	0	0.35	4.56	2.17	5.63
25	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
26	0.6495	0.62	0.11	1.60	0.3	2.96	1.52	3.94
27	0.32475	0.31	0.11	1.60	0.35	2.96	1.84	4.78
28	0.32475	0.31	0.11	1.60	0.3	2.96	1.84	4.78
29	0.6495	0.62	0	0	0.25	4.56	1.52	3.94
30	0.6495	0.62	0	3.19	0.35	1.37	1.52	3.94

Table 3.2: Number of Samples

Test	Mix Proportion
Compression Test (100 x 100 x 100 mm)	30 Mixtures - 6 Cubes each Every 3 for 14^{th} and 28^{th} days
Direct Tensile Test (Dog-bone Shaped Mould)	5 Mixtures - 3 Cubes each Every 3 for 28^{th} days
Flexural Test (Prism)	5 Mixtures - 3 Cubes each Every 3 for 28^{th} days

3.4 Experimental Materials

3.4.1 Coarse Aggregate

Figure 3.2: Coarse Aggregate

Course aggregate as shown in Figure 3.2 usually considered as inert materials in concrete mix, especially as it is cheaper in comparable to other components, such as cement. However, it is proven that aggregate largely affects the stability and durability of the concrete. This is why it is important to make sure the aggregate is not contaminated and thoroughly dried. The course aggregate used in the mixture is the chipping type. It has the size of 5mm. By using this chipping type of coarse aggregate, sieving process could be skipped.

3.4.2 Washed River Sand (Fine Aggregate)

Figure 3.3: Washed River Sand

The use of fine aggregate in concrete mixture helps in lessening the amount of cement as it helps in filling the voids. For concrete production, river sand with size of 0.3mm is mainly used (refer Figure 3.3). River sand could significantly reduce the amount of water or/and superplasticizer required which subsequently results in lower water and cement content in the mixture. The following table shows the sieve analysis done on the material. Total passing percentage is 100% for first two sieve trays, but decrease significantly at Sieve No. 30 with size of 0.6mm.

Table 3.3: Sieve Analysis for Fine Aggregate

Sieve size (mm)	Weight of Sieve (kg)	Sieve + Weight of Fine 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 (No.8)	0.443	0.443	0	0.00	0.00	100.00
1.18 (No.16)	0.337	0.337	0	0.00	0.00	100.00
0.6 (No.30)	0.384	2.244	1.86	92.95	92.95	7.05
0.3 (No. 50)	0.338	0.477	0.139	6.95	99.90	0.10
0.15 (No. 100)	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
Pan	0.365	0.365	0	0.00	100.00	0.00
Total	2.751	4.752	2.001	100.00		

3.4.3 Ordinary Portland Cement (OPC)

Figure 3.4: Ordinary Portland Cement (OPC)

Figure 3.4 shows the type of cement used in the concrete mix, which is Ordinary Portland Cement (OPC). OPC is the main cementitious material of the mixture. To follow environmental recommendation, the amount of OPC is reduced by introducing other materials to replace it.

3.4.4 Crumb Rubber

Figure 3.5: Crumb Rubber

Crumb rubber used in the mix design is the chipping type AS SHOWN IN Figure 3.5. It has the finest size compared to other types. The adoption of crumb rubber in the mixture helps in lessening the amount of aggregates. Since it is a waste material, reduction in overall cost could be observed.

However, the application of crumb rubber also results in diminution of the strength of the concrete. This is because crumb rubber possessed the hydrophobic property which causes the cementitious materials to repel from them. Voids between the materials form, and thus reduce the bonding between the materials. Table 3.4 describes the sieve analysis for crumb rubber. From the total passing percentage, it shows that the size of the crumb rubber is ranging from 1-3mm.

Table 3.4: Sieve Analysis for Crumb Rubber

Sieve size (mm)	Weight of Sieve (kg)	Sieve + Weight of Crumb Rubber (kg)	Weight Retained (kg)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Total Passing (%)
5	1.206	1.206	0	0.00	0.00	100.00
2.36 (No.8)	1.11	1.85	0.74	37.00	37.00	63.00
1.18 (No.16)	0.97	2.01	1.04	52.00	89.00	11.00
0.6 (No.30)	0.9	1.12	0.22	11.00	100.00	0.00
0.3 (No.50)	0.79	0.79	0	0.00	100.00	0.00
0.15 (No.100)	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		

3.4.5 Fly Ash

Figure 3.6: Fly Ash

In the mixture, fly ash (as shown in Figure 3.6) would partially replace the amount of OPC. It acts as a supplementary cementitious material (SCM). It is the most common pozzolonas, an artificial material containing silica in reactive form obtained from precipitation of ashes from coal-fired power stations. Its particles are low in carbon content, spherical in shape and high fineness, which is favourable as it reduces water demand in concrete.

3.4.6 Nano Silica

Figure 3.7: Nano Silica

The role of nano silica mainly is to fill in the voids formed due to the hydrophobic nature of crumb rubber. It helps strengthening the bond between all the materials present in the mixture. Nano silica reacts with the product of hydration, which has no strength, to form C-S-H gel that provide strength to the concrete.

3.4.5 Superplasticizer

Figure 3.8: Superplasticizer

Superplasticizer is an admixture that is water reducing. The concrete produced is substantially different than other concrete without superplasticizer as a very low water/cement ratio but with high workability can be obtained.

3.5 Experimental Apparatus

For compressive strength test, the mould used would be cube mould with dimension of 100mm X 100mm X 100mm, while direct tensile is dog bone shaped mould and prism (100mm X 100mm X 500mm) for flexural test. Other casting apparatus are concrete mixer, balance, and measuring cylinder. The test machine for compressive strength test is crushing machine, on the other hand, direct tensile and flexural test will use Universal Testing Machine

Figure 3.9: Cube Mould

Figure 3.10: Dog-bone Shaped Mould

Figure 3.11: Prism Mould

Figure 3.12: Concrete Mixer

Figure 3.13: Weighing Balance

Figure 3.14: Measuring Cylinder

Figure 3.15: Universal Testing Machine

3.6 Mixing and Casting

Mixing activities are done at Concrete Lab in building of Civil Engineering department, which is Block 13. Safety induction is conducted before any works could be conducted and apparatus could be used in order to make sure all safety precautions and rules are briefed and abided. The procedure of mixing Rubbercrete is as follows:

i) All materials are weighed according to the calculation of the amount of each material given by RSM;

ii) Coarse aggregate, river sand, cement, crumb rubber, fly ash, and nano silica are added into the mixer and left to dry mix for at most 5 minutes;

iii) Third quarter of amount of water is added into the mixture and further mix for several minutes while observing the consistency of the mixture at the same time;

iv) If the workability is not at the desired condition, superplasticizer is added gradually by mixing them with the remaining of the water;

v) Slump test is then been conducted. The slump value must be within the range of 75 to 100mm;

vii) If the slump falls in between the range, the amount of plasticizer used is recorded and samples are then being made.

3.7 Experimentation Tests

Three tests will be conducted on the samples, which are compressive strength test, direct tensile test, and flexural test. All these tests will describe the mechanical behaviour of the Rubbercrete.

3.7.1 Compressive Strength Test

Compressive strength test is the most basic and essential test conducted on concrete samples. It shows the overall idea on the characteristics of the concrete. Compressive strength is controlled by many factors such as water-cement ratio, quality of concrete material, and type of admixtures added.

The samples used to test the compressive strength can be in the shape of cube or cylinder. In this project, cube with dimension of 100mm X 100mm X 100mm is used. American Society for Testing Materials ASTM C39/C39M is referred for the standard test method for compressive strength.

The procedure for compressive strength test is as follows:

i) Cubes are casted and let cured for 14 days and 28 days;
ii) Cubes are taken out from the curing tank and any excess water is wiped off from the surface of the samples;
iii) Specimens are placed on the platform of the crushing machine where the load would be applied to the opposite sides of the cube;
iv) Load is applied gradually at the rate of 140 kg/cm^2 until the specimen fails;
v) The maximum load is recorded and any unusual features in the type of failure are noted;
vi) The compressive strength of the specimen is calculated by dividing the load at failure with the area of the specimen.

For each age (14 days and 28 days), three specimens would be tested.

3.6.2 Direct Tensile Test

Direct tensile test is one of the most common tensile strength test used by researchers. Direct tensile measures the strength of concrete under uniaxial tension. To know the tensile strength of concrete is important to study its resistance to cracking. In this test, sample with dog bone shape is used. ASTM D638-03 would be referred to conduct this experiment.

The procedure involves preparing the sample in the mould with desired shape which is dog bone shape and thickness of 50mm. The hardened specimen then is loaded into tensile grips on the Universal Testing Machine. In order to ensure uniaxial stresses are loaded and no end rotation occurs, the ends of the specimen are gripped within the test frame. The test starts by separating the tensile grips at a constant rate of speed, and ends right after the sample breaks. Targeted time taken for the test to take place is from 30 seconds up to 5 minutes.

3.6.3 Flexural Tensile Test

Flexural test applied upon the specimens will follow ASTM D6272 standard where the concrete experiences force needed to bend the beam under a four point loading system. This method is adopted especially for reinforced or unreinforced materials that do not fail within the limits of ASTM D790 (three point loading test). The location of the bending moment is what distinguished the two types of flexural tests. Uniform distribution between two loading noses occurs in four point bending method, while the stress takes place under the loading point in three point bending method. The four point loading system also could avoid premature failure of the concrete beam. Furthermore, four loading system allows pure bending moment to occur.

The specimen used has dimension of 100mm X 100mm X 500mm in the shape of prism. The specimen is lies on a span and stress is uniformly distributed between the loading noses. There are two procedures within the ASTM D6272 method, A with small deflections and for measuring modulus, and B with larger deflections and used for measuring strength. Load span to support span can be ratio of 1:2 or 1:3.

3.7 Key Milestone and Gantt Chart of The Project

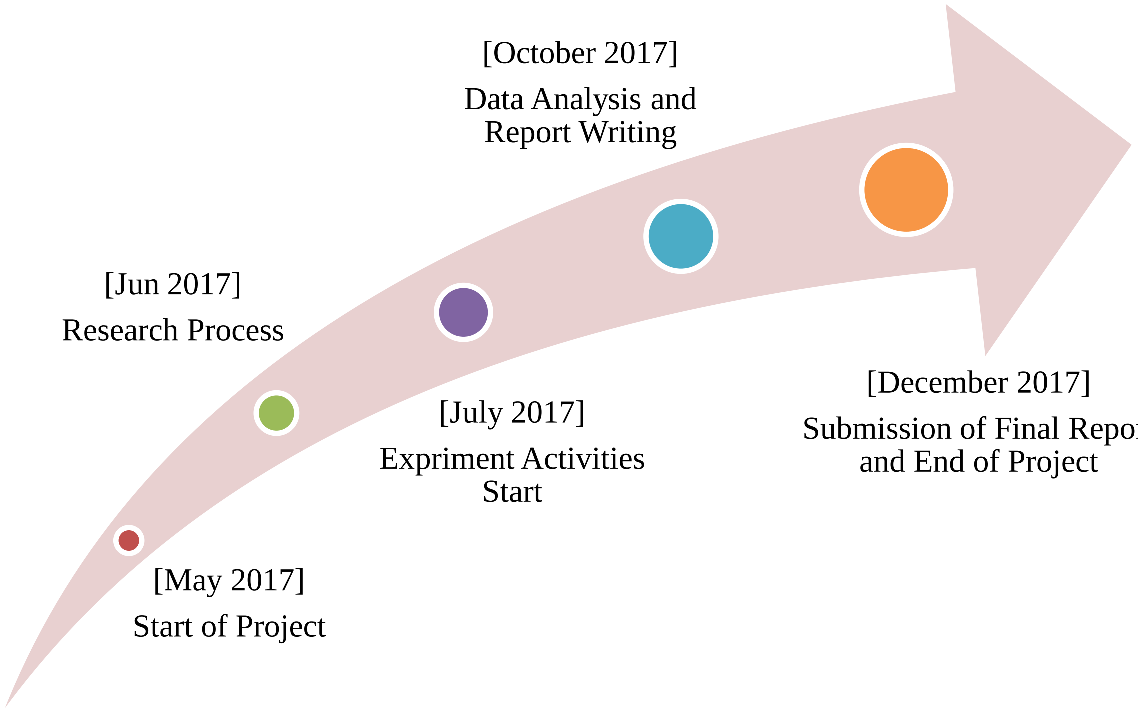


Figure 3.16: Key Milestone of the Project

Table 3.5: Gantt chart of the Project (FYP 1)

NO	ACTIVITIES	MAY			JUNE				JULY				AUGUST		
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Selection of Project Topic														
2	Brief Introduction and Explanation on Project Topic														
3	Research on Previous Studies														
4	Materials Preparation														
5	Preparing Extended Report Chapter 1 : Introduction														
	Chapter 2: Literature Review														
	Chapter 3: Methodology														
6	Submission of Extended Report														
7	Raya Holiday														
8	Proposal Defence														
9	Experimentation Activities														
10	Preparing Interim Report														
11	Submission of Draft of Interim Report														
12	Submission of Interim Report														

Table 3.6: Gantt chart of the Project (FYP 2)

NO	ACTIVITIES	SEPTEMBER			OCTOBER				NOVEMBER				DECEMBER		
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Experimentation Activities														
2	Data Analysis and Calculation														
3	Preparation of Reports and Presentation														
4	Submission Progress Report														
5	Pre-SEDEX														
6	Submission of Draft Final Report														
7	Submission of Dissertation (soft bound)														
8	Submission of Technical Paper														
9	Viva														
10	Submission of Project Dissertation (hard bound)														

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Compressive Strength Result

Total of 30 trial mix design were done. The trial mix were produced from RSM with combination of different amount of aforementioned materials used. Slump test were done on the mixture in order to make sure the workability is within the desired condition; slump measurement ranging from 75 mm to 100 mm. The table below recorded the data of the result of the trial mix design.

Table 4.1: Result of Trial Mix Design

Mixture			Compressive Strength (MPa)	
			14-day	28-day
1	SLUMP	100mm	71.84	89.73
	SP VALUE	2.52%		
2	SLUMP	90mm	47.84	51.04
	SP VALUE	1.10%		
3	SLUMP	100mm	53.25	39.00
	SP VALUE	0.94%		
4	SLUMP	95mm	40.73	48.08
	SP VALUE	1.25%		
5	SLUMP	89mm	42.99	53.19
	SP VALUE	1.12%		
6	SLUMP	82mm	27.47	42.88
	SP VALUE	0.88%		
7	SLUMP	93mm	33.58	40.44
	SP VALUE	2.85%		
8	SLUMP	100mm	39.15	64.64
	SP VALUE	2.63%		
9	SLUMP	85mm	31.36	33.25
	SP VALUE	0.28%		
10	SLUMP	85mm	46.10	46.56
	SP VALUE	0.39%		
11	SLUMP	80	25.89	34.08
	SP VALUE	1.64%		
12	SLUMP	100mm	33.63	20.96
	SP VALUE	1.21%		
13	SLUMP	90mm	62.95	39.41
	SP VALUE	0.31%		

14	SLUMP	77mm	32.53	42.95
	SP VALUE	0.48%		
15	SLUMP	100mm	30.90	32.22
	SP VALUE	0.22%		
16	SLUMP	100mm	47.12	49.16
	SP VALUE	1.53%		
17	SLUMP	100mm	46.18	36.42
	SP VALUE	2.78%		
18	SLUMP	85mm	55.57	36.91
	SP VALUE	0.66%		
19	SLUMP	82mm	38.57	43.11
	SP VALUE	1.10%		
20	SLUMP	75mm	27.86	24.55
	SP VALUE	0.11%		
21	SLUMP	80mm	32.43	54.97
	SP VALUE	1.12%		
22	SLUMP	100mm	41.19	43.64
	SP VALUE	0.61%		
23	SLUMP	100mm	43.69	75.64
	SP VALUE	1.82%		
24	SLUMP	100mm	63.04	66.99
	SP VALUE	0.26%		
25	SLUMP	90mm	43.66	50.03
	SP VALUE	1.12%		
26	SLUMP	81mm	34.93	29.43
	SP VALUE	0.66%		
27	SLUMP	80mm	33.22	40.69
	SP VALUE	0.64%		
28	SLUMP	85mm	42.68	48.74
	SP VALUE	0.57%		
29	SLUMP	100mm	37.26	42.09
	SP VALUE	0.75%		
30	SLUMP	75mm	18.76	18.88
	SP VALUE	0.20%		

Each of the mix is tested as per its compressive strength at 14th days and 28th days after curing. After all compressive strength of the mix have been recorded, analysis was done by using simple observation and research. From the result, it can be observed that by adding nano silica, the compressive strength can be improved a little. Then, the water to cement ratio also significantly affect the compressive strength of the sample. Mix with lower water to cement ratio exhibited higher compressive strength compared to mix with the same composition of aggregates and cementitious materials but with higher water to cement ratio.

4.1.1 Response Surface Method (RSM) Analysis of Compressive Strength

The result of the compressive strength of all mix were then inserted into Response Surface Methods (RSM) software to analyse and determine the optimum design mix in order to be used in the next part of the project. RSM uses statistical models to create precise process maps and graphs. It helps users optimizing their process and finding the point where all specifications are met at minimal costs.

The analysis tools used is Analysis of Variance (ANOVA), a tool in statistics that allows study of how several changing variables affect the dependent variable in a regression study. It determines the strength of the relationship between them.

The following table describes the RSM analysis of Compressive Strength of all the mix after 14 days curing.

Table 4.2: Response 1 - 14-day Compressive Strength ANOVA for Response Surface Linear Model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3112.58	4	778.15	11.51	< 0.0001	significant
A - Crumb rubber	*1103.04*	*1*	*1103.04*	*16.32*	*0.0004*	*significant*
B - Nano-silica	*182.96*	*1*	*182.96*	*2.71*	*0.1124*	
C - Fly ash	*733.23*	*1*	*733.23*	*10.85*	*0.0029*	*significant*
D - w/c	*1093.35*	*1*	*1093.35*	*16.18*	*0.0005*	*significant*
Residual	1689.58	25	67.58			
Lack of Fit	*1531.21*	*20*	*76.56*	*2.42*	*0.1664*	*not significant*
Pure Error	*158.37*	*5*	*31.67*			
Cor Total	4802.16	29				

Std. Dev.	8.22	R^2	0.6482
Mean	41.21	Adj R^2	0.5919
C.V. %	19.95	Pred R^2	0.4225
PRESS	2773.07	Adeq Precision	15.013
-2 Log Likelihood	206.07	BIC	223.07
		AICc	218.57

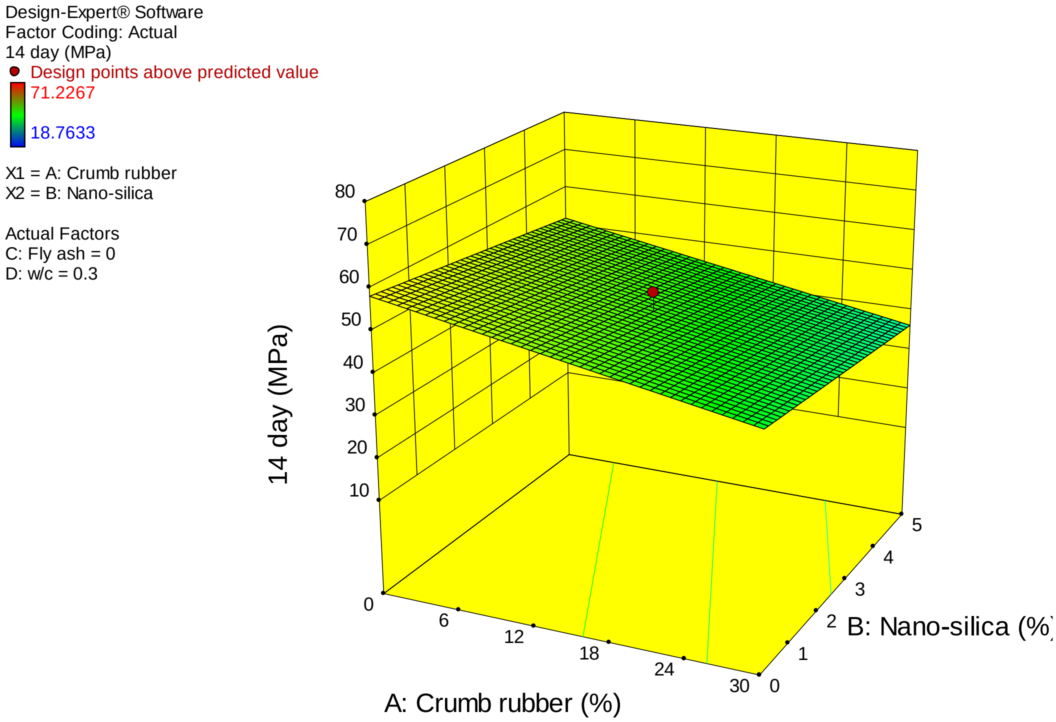
The p-value suggests the significant of each coefficient, at the same time denotes the strength of the interaction between the independent variables. From Table 4.2, it can be noted that the F-value of 11.51 insinuates that the model is significant as the chance for an F-value this big to take place is only 0.01% due to noise. The coefficient determination (R^2) of this analysis is 0.6482, implied the model can explain 64.82% of the variability with lower than 36% of the variations were not explained. The significance of the model also is described by the value of adjusted coefficient determination (Adj R^2) which is 0.5919. The Adjusted R^2 value is in the acceptable agreement with the Predicted R^2 of 0.4225. The difference between the values is less than 0.2 and this suggested that the model is significant. Adeq Precision, which measures the noise ratio signal, has ratio higher than 4. Thus, the model can be utilized to navigate the design space.

As for the model terms, ones with p-value less than 0.0500 are significant. It shows that the model term has high interaction strength. In this response, Crumb Rubber, Fly Ash, and Water-per-Cement Ratio are the significant model terms.

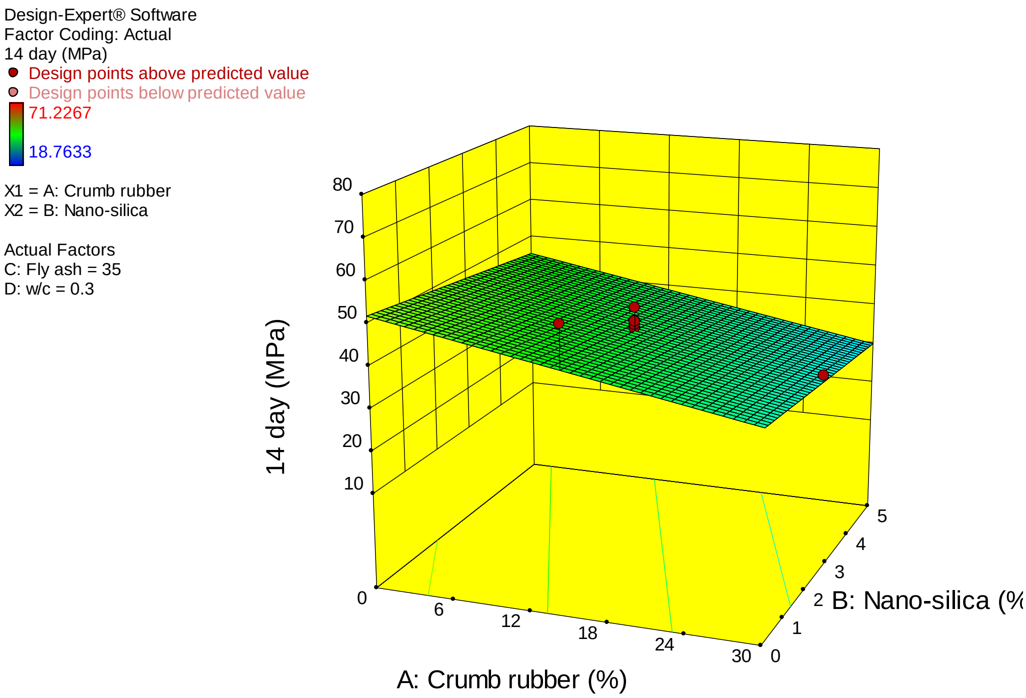
The model in terms of actual variables of 14-day compressive strength of rubbercrete is expressed by Eq. 4.1.

$$\begin{aligned} 14-day\ Compressive\ Strength &= 105.36626 - 0.52188(Crumb\ Rubber) \\ &- 1.27526(Nano-silica) - 0.18235(Fly\ Ash) \\ &- 155.87407(Water-per-cement\ ratio) \end{aligned} \quad (4.1)$$

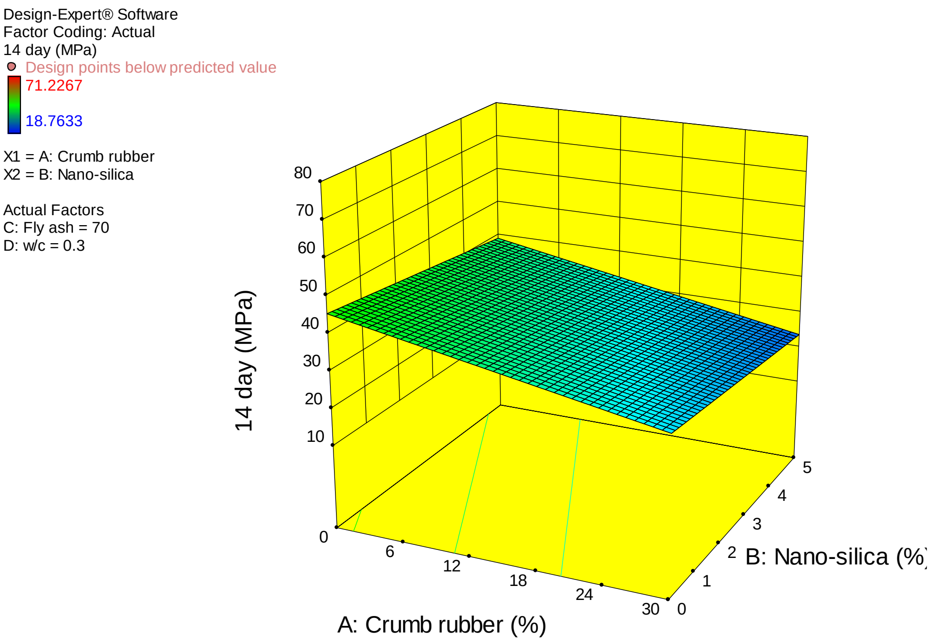
Figure 4.1 below decribes the three dimensional plots (3D) of the combined effect of Crumb Rubber, Nano-silica, Fly Ash, and Water-per-Cement Ratio on the 14-day Compressive Strength of the Rubbercrete samples. On each plot, two factors are made constant; percentage of Fly Ash replacing Cement and Water-per-Cement Ratio. Other two factors, Crumb Rubber and Nano-silica are varying at experimental range.



(a)



(b)



(c)

Figure 4.1: Response Surface Curve (3D Plot) of 14-Day Compressive Strength of Rubbercrete showing Crumb Rubber and Nano-silica Percentage with 0.3 Water-per-Cement Ratio and (a) 0% Fly Ash, (b) 35% Fly Ash, (c) 70% Fly Ash.

Figure 4.2.1(a), (b) and (c) showed similar distribution. The compressive strength after 14 days is the highest when 0% of Crumb Rubber and Nano-silica used. Whereas, the samples have the lowest strength when 30% Crumb Rubber and 5% Nano-silica are added to the mix.

Furthermore, it also can be seen that between the three plots, compressive strength of mix with 0% of Fly Ash, Crumb Rubber and Nano-silica are the greatest. With zero amounts of the three materials, normal mix of concrete is produced. This explains greatly on why the compressive strength is the highest as normal concrete normally exhibits greater strength than concrete mix with addition of crumb rubber. The reason for this is, as mentioned by Youssf et al (2016), due to the poor adhesion property of the crumb rubber.

This problem is tried to be solved by adding Nano-silica. However, from the graphs, the introduction of the said material could not help improve the sample's strength. It should aid in strengthening the bond between all the materials present in the mixture by reacting with the product of hydration, which has no strength, to form C-S-H gel that provide strength to the concrete. This C-S-H gel acts as cementitious materials for the mix. At 14^{th} day, the amount of gel produced from the reaction might not be sufficient. It needs longer time to maximizing the process and produce enough gel to help enhancing the bonding between the rubber crumb and other materials.

The following table describes the RSM analysis of Compressive Strength of all the mix after 28 days curing.

Table 4.3: Response 2 - 28-day Compressive Strength ANOVA for Response Surface Linear Model

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*	*significant*
B - Nano-silica	*143.24*	*1*	*143.24*	*4.73*	*0.0426*	*significant*
C - Fly ash	*523.08*	*1*	*523.08*	*17.26*	*0.0005*	*significant*
D - w/c	*1099.39*	*1*	*1099.39*	*36.27*	*< 0.0001*	*significant*
AB	*163.07*	*1*	*163.07*	*5.38*	*0.0317*	*significant*
AC	*506.48*	*1*	*506.48*	*16.71*	*0.0006*	*significant*
AD	*352.63*	*1*	*352.63*	*11.63*	*0.0029*	*significant*
BC	*1381.24*	*1*	*1381.24*	*45.57*	*< 0.0001*	*significant*
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				

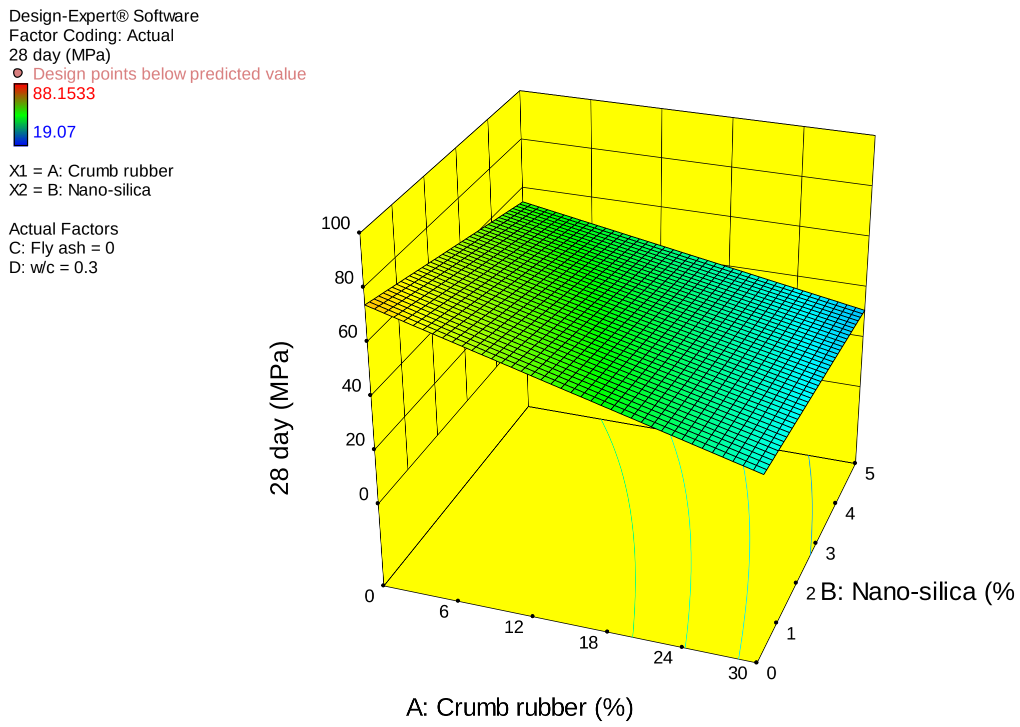
Std. Dev.	5.51	R^2	0.9108
Mean	44.68	Adj R^2	0.8638
C.V. %	12.32	Pred R^2	0.7473
PRESS	1631.07	Adeq Precision	20.133
-2 Log Likelihood	173.78	BIC	211.19
		AICc	210.45

Table 4.3 describes the ANOVA for Response 2; 28-day Compressive Strength of Rubbercrete. The model developed is greatly significant with p-value of 0.0001 and R^2 of 0.9108. This denotes that 91.08% of the variability could be explained and less than 9% are not. The Adjusted R^2 with the value of 0.8638 is within the acceptable agreement with the Predicted R^2 which equals to 0.7473. The difference between them is also lower than 0.2 thus implies that the model is significant. The model also possessed F-value equals to 19.40 with p-value of less than 0.0001. This makes the model as significant as there is only 0.01% probability for the value to occur due to statistical noise. The model also can be used to navigate the design space as its Adeq Precision (=20.133) is higher than 4.

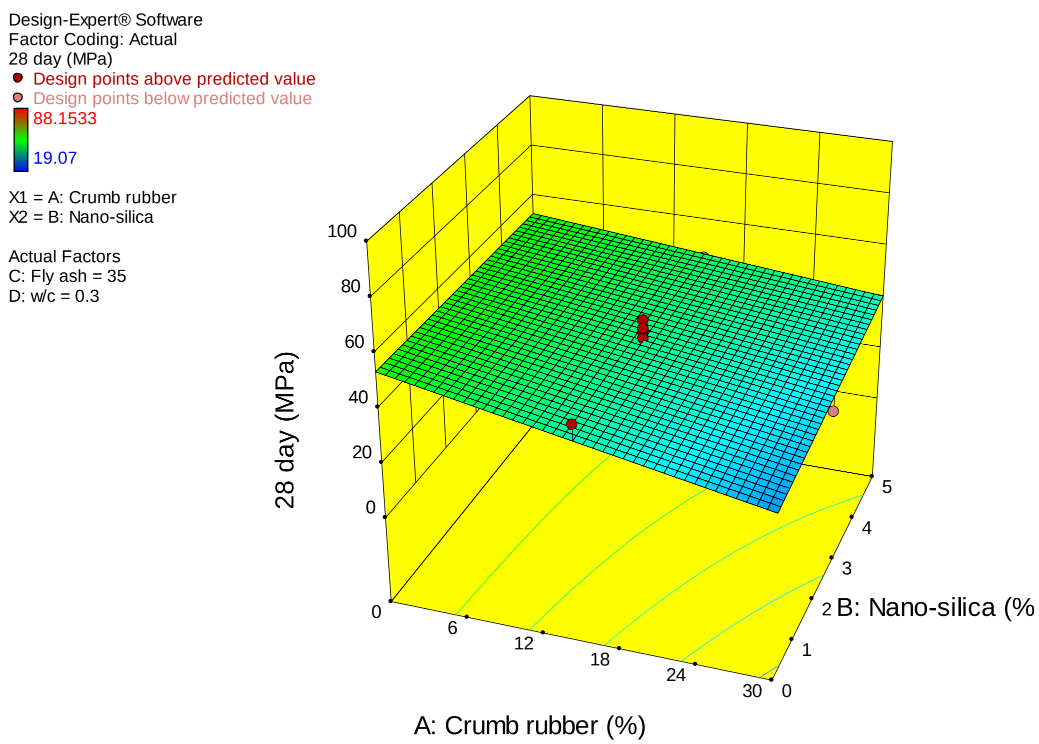
The model shows that Crumb Rubber (A) and Water-per-Cement Ratio (D) exhibited the greatest effect on the Compressive Strength of Rubbercrete after 28 days with p-value < 0.0001. Quadratic terms of Nano-silica and Fly Ash also has significance effect (p<0.0001) on the Compressive Strength. Other terms such as Nano-silica (B) and Fly Ash (C) also are significant as values of “Prob > F” are less than 0.0500.

The final equation of in terms of actual factors for this response is described in Eq. 4.2.

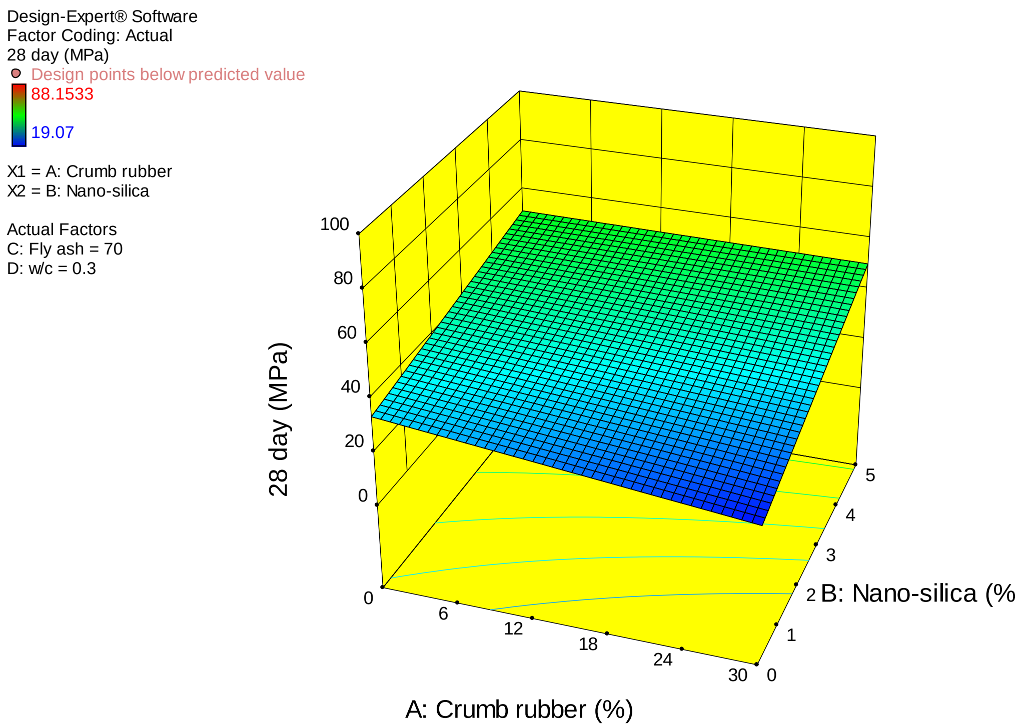
$$
\begin{aligned}
28 - day\ Compressive\ Strength \\
&= 146.64748 - 3.09460(Crumb\ Rubber) + 1.15787(Fly\ Ash) \\
&- 239.52037(Water - per - Cement\ Ratio) \\
&+ 0.085133(Crumb\ Rubber)(Nano - silica) \\
&+ 0.010717(Crumb\ Rubber)(Fly\ Ash) \\
&+ 6.25944(Nano - silica)(Fly\ Ash) \\
&- 16.74333(Nano - silica)(Water - per - Cement\ Ratio) \\
&+ 0.89095\ (Fly\ Ash)(Water - per \\
&- Cement\ Ratio) \qquad (4.2)
\end{aligned}
$$


Design-Expert® Software
Factor Coding: Actual
28 day (MPa)
Design points below predicted value
88.1533
19.07
X1 = A: Crumb rubber
X2 = B: Nano-silica
Actual Factors
C: Fly ash = 0
D: w/c = 0.3
28 day (MPa)
A: Crumb rubber (%)
B: Nano-silica (%

(a)


Design-Expert® Software
Factor Coding: Actual
28 day (MPa)
Design points above predicted value
Design points below predicted value
88.1533
19.07
X1 = A: Crumb rubber
X2 = B: Nano-silica
Actual Factors
C: Fly ash = 35
D: w/c = 0.3
28 day (MPa)
A: Crumb rubber (%)
B: Nano-silica (%

(b)



(c)

Figure 4.2: Response Surface Curve (3D Plot) of 28-Day Compressive Strength of Rubbercrete showing Crumb Rubber and Nano-silica Percentage with 0.3 Water-per-Cement Ratio and (a) 0% Fly Ash, (b) 35% Fly Ash, (c) 70% Fly Ash.

As previously stated, it also can be observed that sample with 0% Fly Ash, Crumb Rubber, and Nano-silica, has the highest compressive strength after 28 days as shown in Figure 4.2.2(a). Generally, the strength of normal concrete is higher than concrete with Crumb Rubber as there are many voids caused by the hydrophobic nature of the Crumb Rubber. This particular property of Crumb Rubber lessens the surface contact between particles in the sample which consequently results in reduction of the strength.

As the percentage of Fly Ash used in replacement of Cement is increased, the strength of the concrete with highest content of Crumb Rubber but zero Nano-silica is decreased. Simultaneously, when 5% of Nano-silica added to the mix, the strength slowly increased, as the amount of Fly Ash used increased.

This might due to the pozzolonic reaction in the mix. When Cement reacts with water (hydration), the products are C-S-H gel which acts as binder for the mix and much less important by-product, calcium Hydroxide (CaOH). Due to the presence of silica in the Fly Ash constituent, pozzolonic reaction then occurs between the CaOH and silica to produce more C-S-H gel.

By introducing Nano-silica in the mix, the pozzolonic reaction is enhanced and thus produces more of this desired cementitious material. As this amount of cementitious material increased, ultimately the Compressive Strength of the Rubbercrete also increased. The surface contact between the Rubber Crumb and other materials is improved by the presence of more C-S-H gel.

After analysis of RSM is done, optimize mix for concrete of Grade 20, Grade 25, Grade 30, Grade 35, Grade 40, and Grade 50 are developed. The combination of constituents of the mix and the amount required are based on the ANOVA as shown in Table 4.4 below.

Table 4.4: Mix Design for Flexural and Tensile Strength Test

Run	Crumb Rubber, %	Nano-silica, %	Fly Ash, %	Water-per-Cement Ratio	Superplasticizer, %
M20	30	0	70	0.35	0
M25	30	0.81	70	0.35	0
M30	30	1.8	70	0.35	0.08
M40	30	3.71	68.3	0.35	0.6
M50	30	5	70	0.33	1

The weight of each constituent is calculated according to the volume of the mould used. For tensile and flexural test, prism of 100mm X 100mm X 500mm dimension and dog-bone shaped mould with thickness of 50mm is used respectively. Three samples for each test are prepared for each run. The samples are then left for curing after 28 days before testing is done.

4.2 Direct Tensile Strength Result

As stated in previously, three dog-bone shaped samples for each grade of Rubbercrete are prepared for this test. Curing is done for 28 days before testing is executed on the samples. The test is done by following the procedure recommended by ASTM D638-03. Each sample from each mix design is tested on the Universal Testing Machine. Raw data are obtained after test is done and is analysed.

Figure 4.3: Direct Tensile Test Configuration

Figure 4.3.1 shows how the sample is positioned on the machine. Maximum load is recorded when the sample fails. Failure line mostly occurred along the smallest width of the sample.

Raw data obtained from the machine tabulated the load applied on the sample and the deflection occurred together with the time taken before it failed. From the raw data, stress and strain values are calculated. Had the raw data been calculated, stress versus strain graph is plotted for each mix design as shown in the following figure 4.4.

The formulas for stress and strain are as shown below.

$$stress, \sigma = \frac{\text{maximum load}}{\text{cross sectional area}} \quad (4.3)$$

$$strain, \varepsilon = \frac{\text{change in length}}{\text{total length}} \quad (4.4)$$

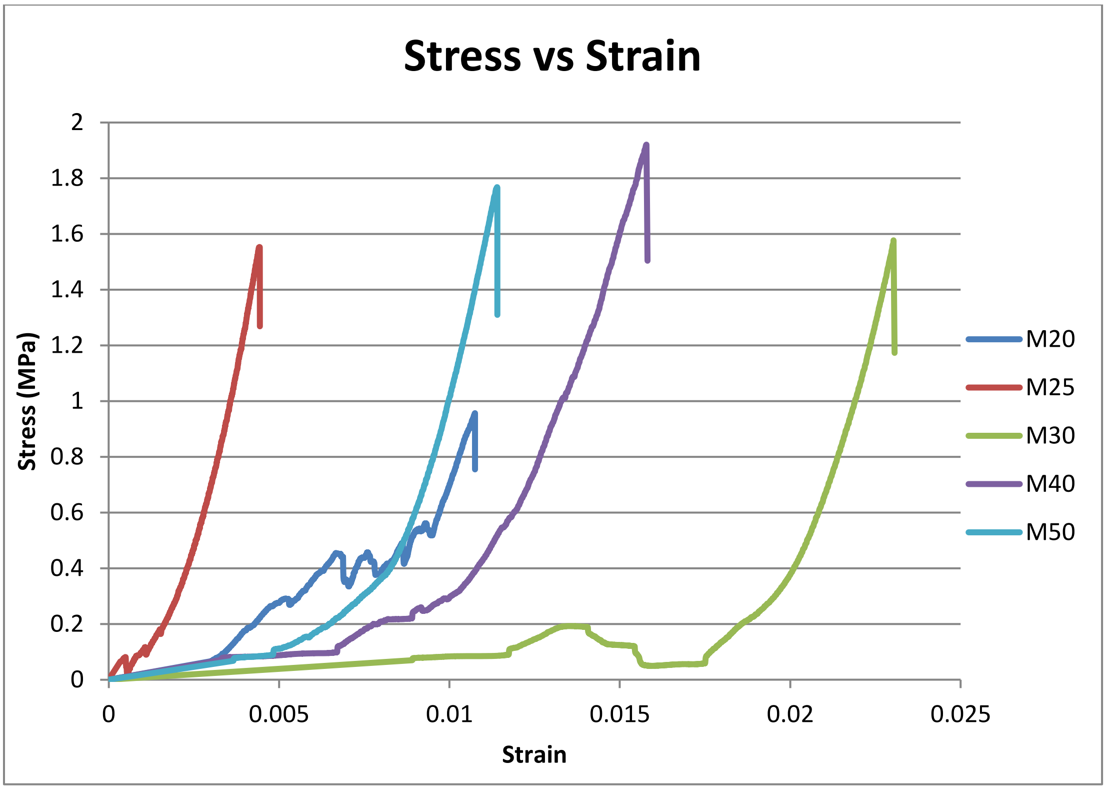


Figure 4.4: Stress versus Strain Graph

From Figure 4.4 it can be observed the lowest tensile stress is form Rubbercrete Grade 20 with values of 0.957 MPa and the highest is Grade 40, reaching up to 1.91 MPa. To visualize the trend of the tensile stress across the different grade of Rubbercrete, a table and graph of Tensile Strength against Compressive Strength of each grade is tabulated and plotted as shown in table 4.5 and figure 4.5.

Table 4.5: Tensile Stress of each grade of Rubbercrete

Compressive Strength (MPa)	Tensile Stress (MPa)
20	0.957
25	1.54
30	1.562
40	1.906
50	1.756

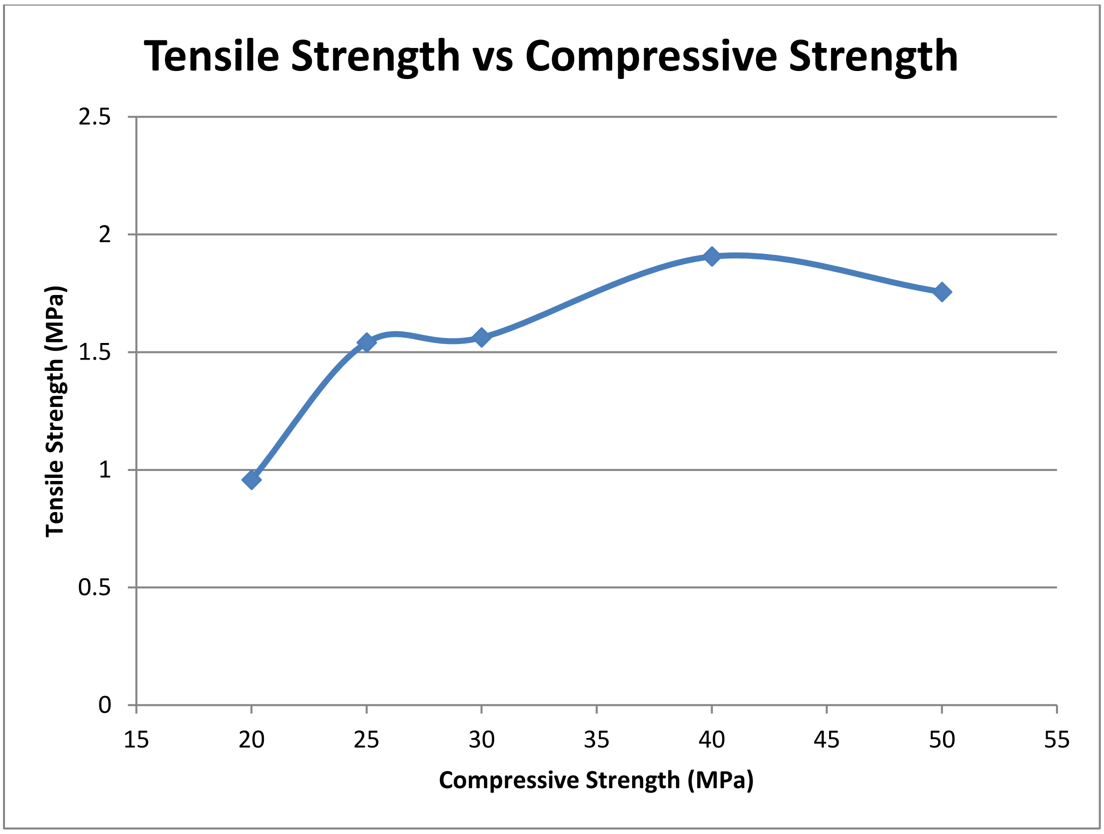


Figure 4.5: Tensile Strength versus Compressive Strength Graph

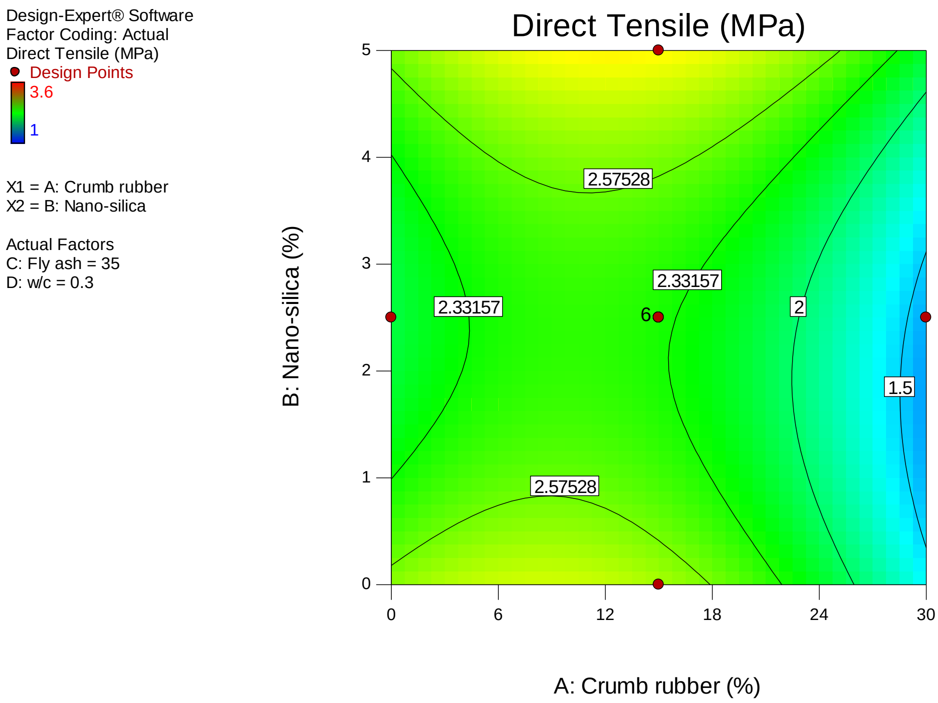
From the graph, it can be noted clearly how the trend goes. As compressive strength of the Rubbercrete increased, the tensile strength also gradually increased even the increments is not that significant as the difference of the strength values is only in range of 0.02 MPa to 0.4 MPa.

These improvements of tensile strength are due to the increasing amount of nano silica added to the mixture as shown in table 4.3. As more nano silica is used, the concrete became more densified as more C-S-H gel is produced to fill in the voids caused by the hydrophobic nature of crumb rubber. These facts also result in the enhancement of the compressive strength of the Rubbercrete.

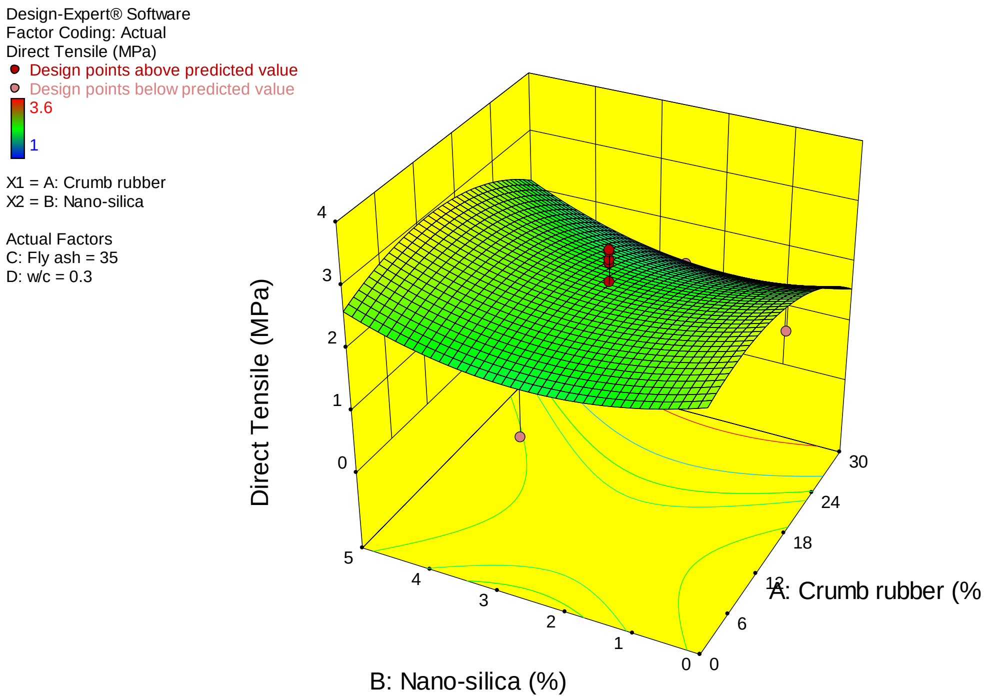
However, as for Rubbercrete of Grade 50, its tensile strength decreased slightly. From strength of 1.906 MPa, it dropped to 1.756 MPa. The reduction of the tensile strength is not significant but is worth to be discussed. The decrease of the strength might be due to the volume of nano silica. For Rubbercrete Grade 50, 5% nano silica is added in order to achieve the intended compressive strength. However, with the amount of 30% crumb rubber replacing fine aggregates, 5% nano silica is exceeding the optimum amount of the said material required. Nano silica here did not act as the filler for the voids but instead it became nano aggregate which then results in slight depletion of the Rubbercrete's tensile strength.

4.2.1 Response Surface Method (RSM) Analysis of Tensile Strength

The results attained from the direct tensile test are then inserted into Design Expert^{TM} to help plotting the Response Surface Methodology (RSM) in order to analyse the interaction between all the materials mentioned before.



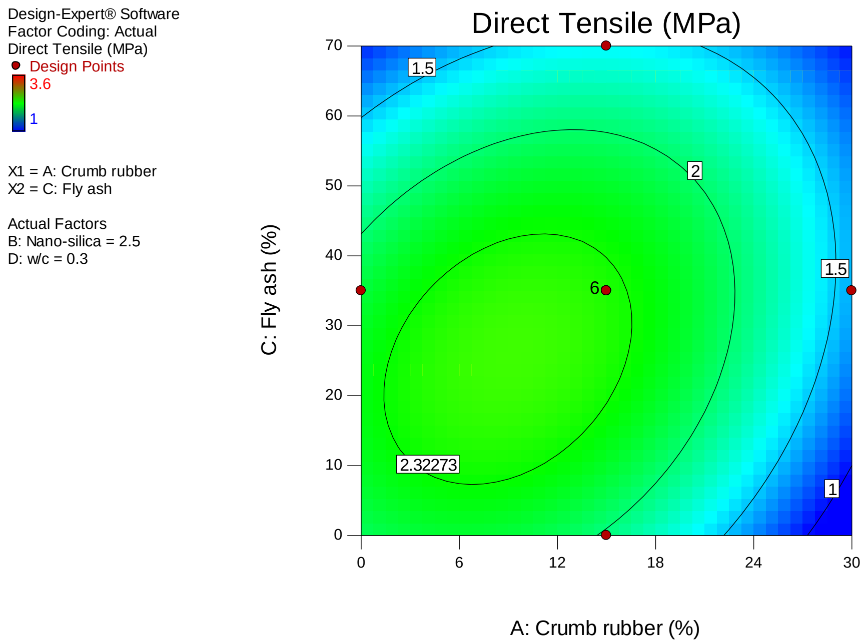
(a)



(b)

Figure 4.6: (a) Plan or 2D view, and (b) 3D view of RSM Graph of Crumb Rubber (%) and Nano-silica (%) against Direct Tensile Strength (MPa)

From figure 4.6 it can be observed distinctly how the materials affect the direct tensile strength of the Rubbercrete. As shown, highest tensile strength can be obtained with 18% of fine aggregates are replaced by crumb rubber and 5% nano silica is added and might achieved up to 3 MPa. The C-S-H gel formed through the reaction of calcium hydroxide and nano silica micro-filled the voids and boosted the microstructure of the concrete.



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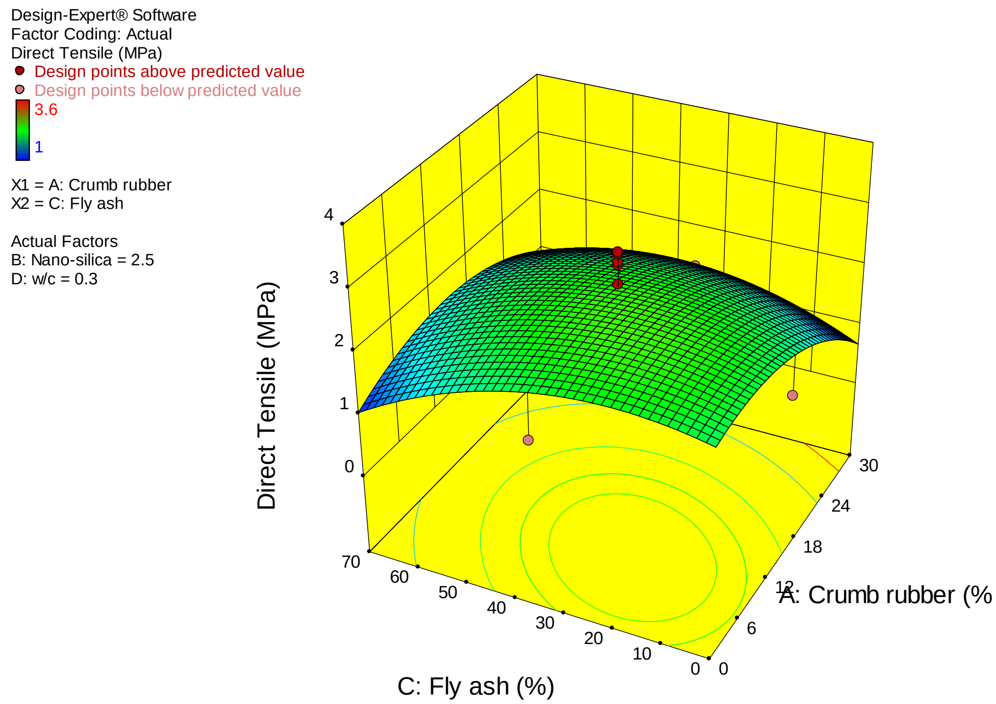


(b)

Figure 4.7: (a) Plan or 2D view, and (b) 3D view of RSM Graph of Crumb Rubber (%) and Fly Ash (%) against Direct Tensile Strength (MPa)

From figure 4.7 (a) and (b), it can be observed that the optimum amount of crumb rubber and fly ash used in the concrete mixture should exceeding 18% and 50% respectively when 2.5% of nano silica and water-per-cement ratio of 0.3 are utilized. The direct tensile strength dropped up to 25% if such combinations are used. Such results happened is caused by the nature of crumb rubber which repels water. On the other hand, the particles of fly ash are even and round which help decreasing the water requirements of the mixture. With the constant water-per-cement ratio, the reaction between the two materials can be deduced. The concrete reaches better direct tensile strength when the amount of crumb rubber and fly ash are less than 18% and 50% respectively. The water repels by the crumb rubber are taken by the fly ash which then improves the workability of the mix. However, as more crumb rubber is added, the direct tensile decreases as more voids are formed as more crumb rubber repel the water which ultimately reduced the contact surface between the particles.

4.3 Flexural Strength Result

Three prism-shaped samples are prepared for each design mix for flexural testing. After casting, the samples are cured for 28 days and then testing would be done on them. Four-point load flexural test is utilized as referred to ASTM D6272 as shown in figure 4.8 below.

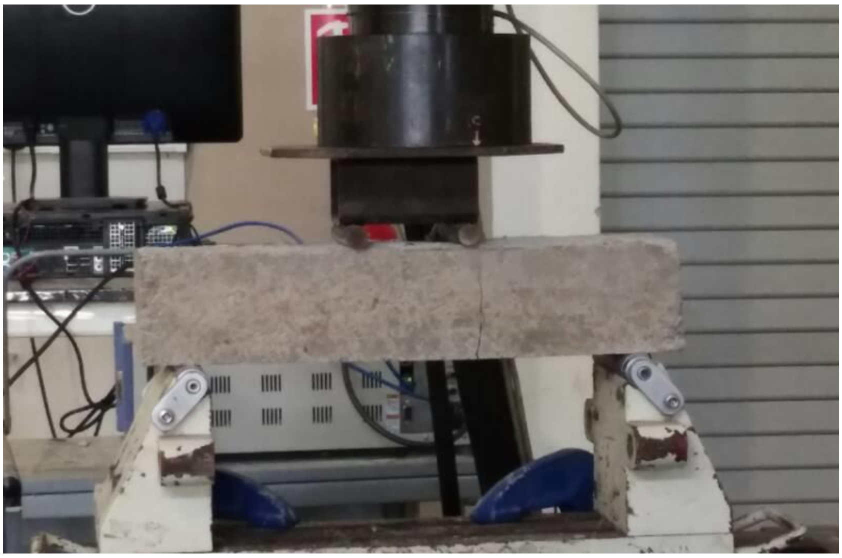


Figure 4.8: Four-point loading Flexural Test Configuration

Raw data obtained from the test is tabulated and calculated to plot the graph of Load against Deflection as being demonstrated in figure 4.9.

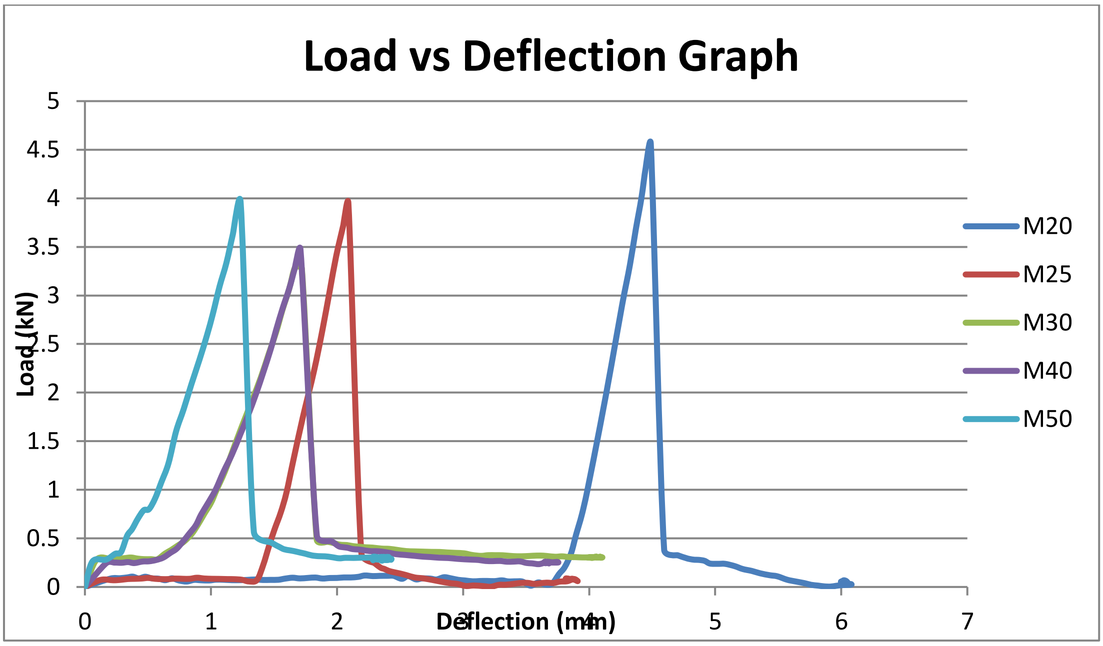


Figure 4.9: Load versus Deflection Graph

From this graph, maximum load which the samples failed are recorded. The values then are used to calculate the modulus of rupture, also known as flexural strength, of every grade by using the following equation:

$$Modulus\ of\ Rupture, S = \frac{PL}{bd^2} \quad (4.5)$$

Where,

P - Maximum load;

L - Span length between the support;

b - The width of the cross-sectioned of the sample, and;

d - The depth of the sample.

Table 4.6: Modulus of Rupture of Different Rubbercrete Grade

Compressive Strength (MPa)	Modulus of Rupture (MPa)
20	1.8164
25	1.5244
30	1.3132
40	1.324
50	1.4876

The calculations that are tabulated as shown in table 4.6. Next, moduli of rupture of normal concrete are also calculated. These moduli of rupture are calculated by using the equations provided by several codes of practice from different countries including India, United States of America, New Zealand, Europe, and Britain.

Table 4.7: Recommended Empirical Relationships between Flexural Strength and Compressive Strength of Plain Concrete (Beeby and Naranayan, 1995)

Code	Country	Relationship
IS:456-2000	India	$f_r = 0.7\sqrt{f_c}$
ACI	USA	$f_r = 0.62\sqrt{f'_c}$
NZS-3101	New Zealand	$f_r = 0.60\sqrt{f'_c}$
EC-02	Europe	$f_r = 0.201 f_c$
BS-8110	Britain	$f_r = 0.60\sqrt{f'_c}$

From equation stated it Table 4.7, the modulus of rupture for different concrete grade are calculated, tabulated (on table 4.8) and plotted on a graph (figure 4.10). The modulus of rupture for Rubbercrete also is plotted on the same graph so that comparisons and analysis can be done.

Table 4.8: Calculated Values of Modulus of Rupture of Plain Concrete according to Different Codes

Compressive Strength (MPa)	Modulus of Rupture (MPa)					
	Rubbercrete	IS:456-2000	ACI	NZS-3101	EC-02	BS-8110
20	1.816	3.130	2.773	2.683	4.02	2.683
25	1.524	3.5	3.1	3.0	5.025	3.0
30	1.313	3.834	3.396	3.286	6.03	3.286
40	1.324	4.427	3.921	3.795	8.04	3.795
50	1.488	4.950	4.384	4.243	10.05	4.243

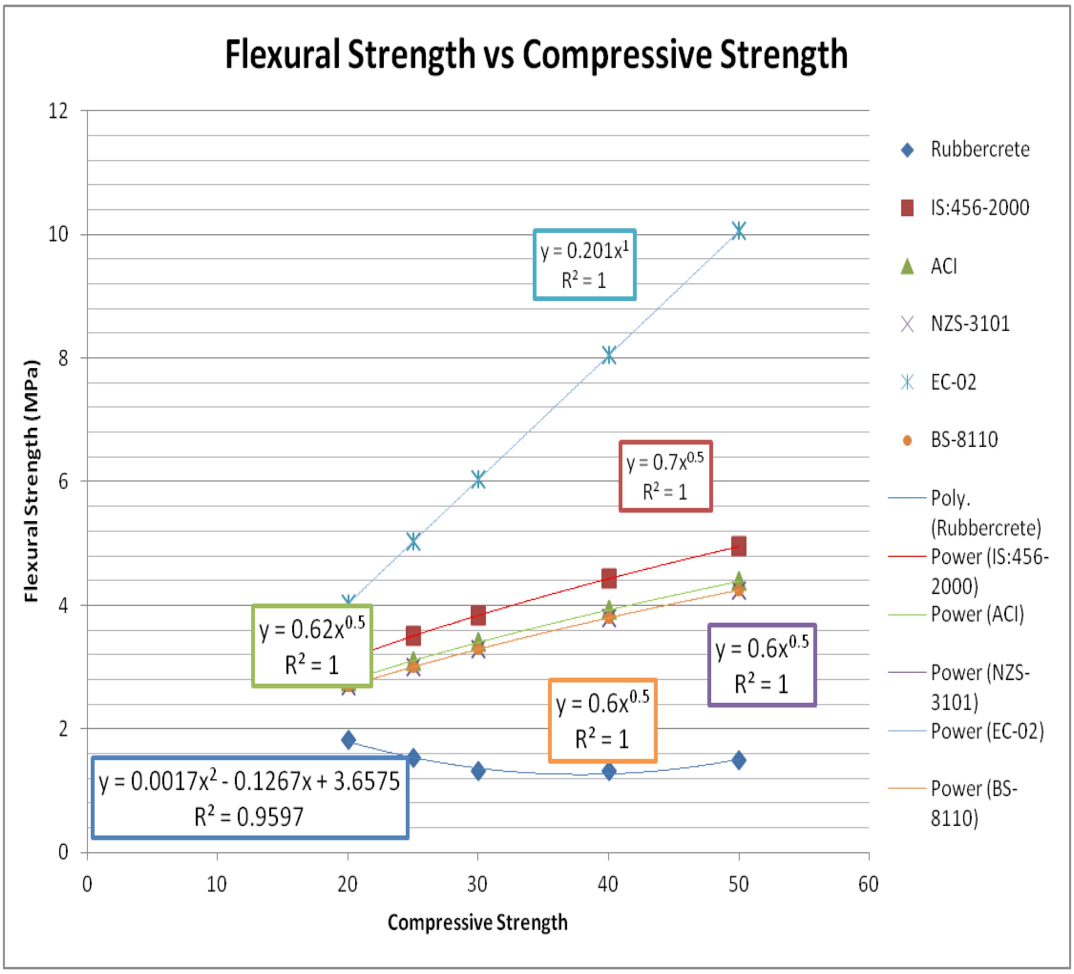


Figure 4.10: Graph of Modulus of Rupture a.k.a Flexural Strength versus Compressive Strength

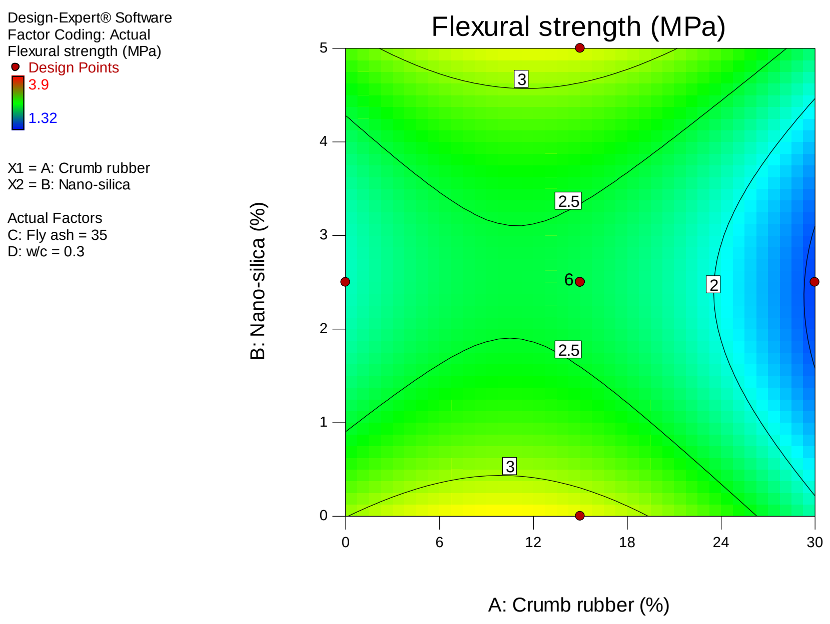
As the Flexural strength of the Rubbercrete has been plotted, the equation which shows the relationship between its compressive strength and flexural strength can be determined. With R^2 value of 0.9597, the equation for the relationship would be;

$$f_r = 0.0017x^2 - 0.1276x + 3.6575 \quad (4.6)$$

Figure 4.10 describes markedly on how the modulus of rupture or the flexural strength of Rubbercrete is lower than that of the normal concrete regardless of the code of practice used. The addition of nano silica helps in enhancing the compressive strength of Rubbercrete, but does not significantly affects the flexural strength of it. Nano silica helps in filling the micro voids, increasing the contact surface between the particles and densifying the concrete, however, it does not work as efficient as cement paste in binding the particles together and helps resisting the bending failure.

4.2.1 Response Surface Method (RSM) Analysis of Flexural Strength

The raw data also are input into Design Expert^{TM} to produce RSM graph in order to analyse clearly how each of the materials affect the flexural strength of Rubbecrete.



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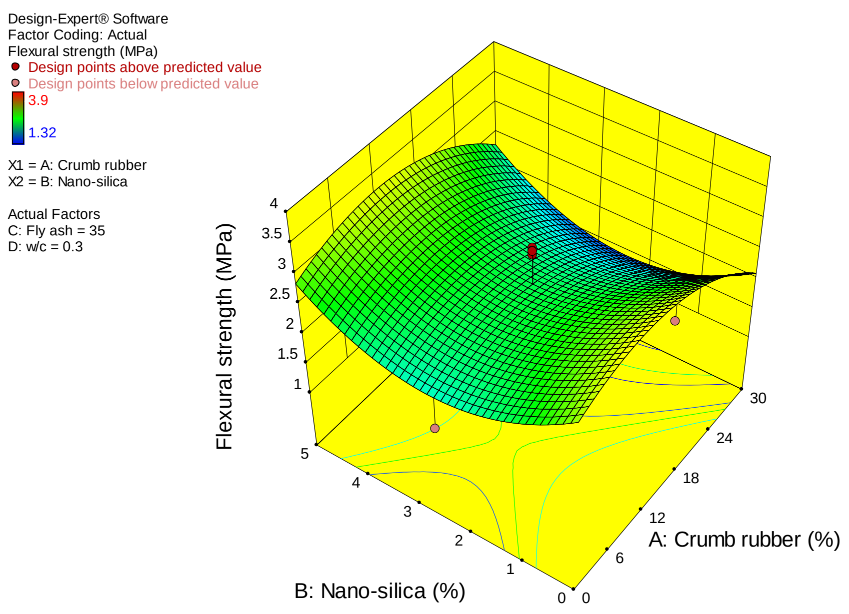
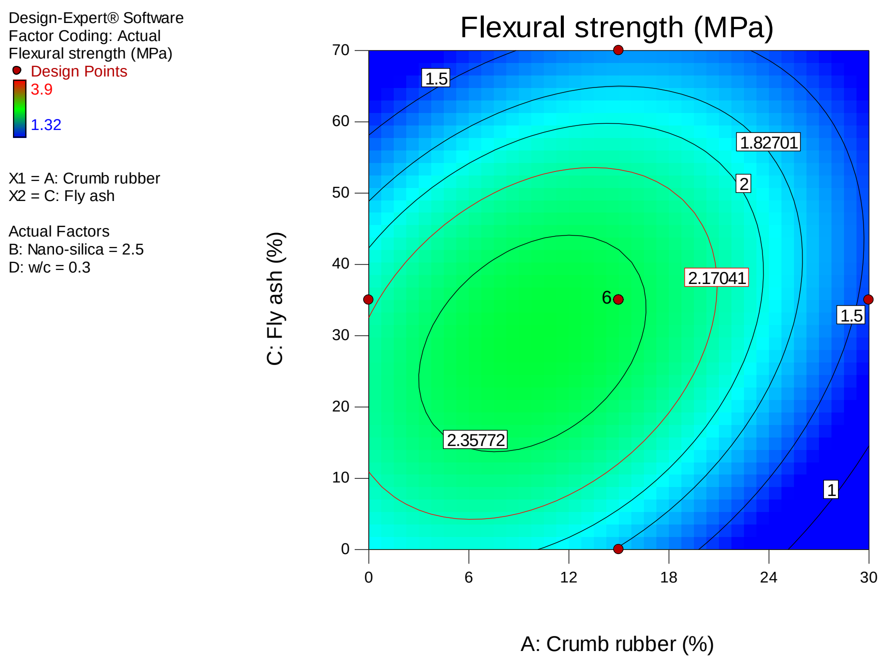


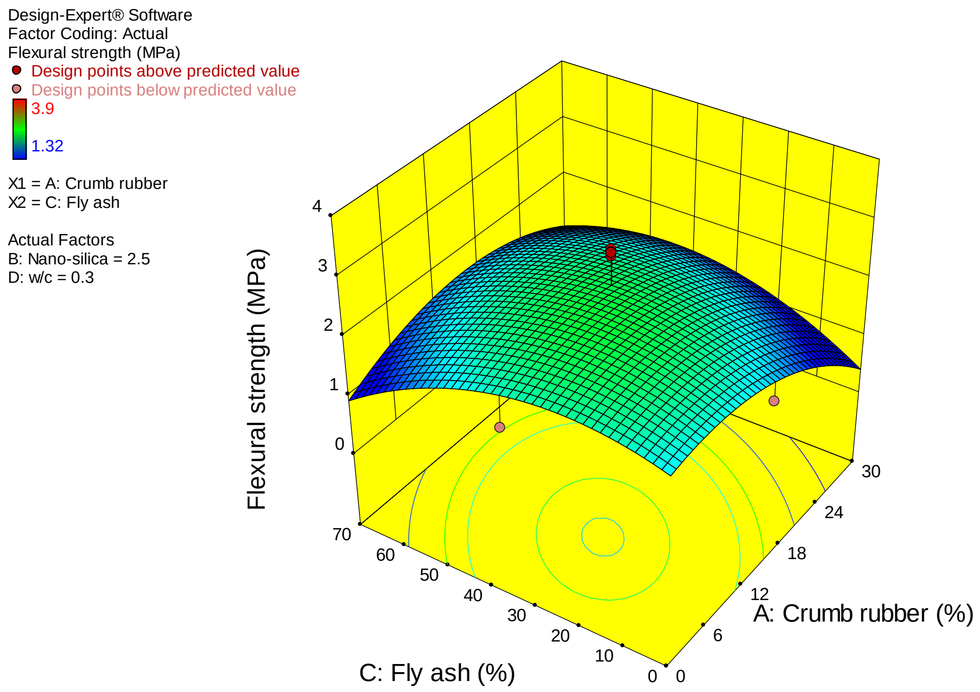
(b)

Figure 4.11: (a) Plan or 2D view, and (b) 3D view of RSM Graph of Crumb Rubber (%) and Nano-silica (%) against Flexural Strength (MPa)

The interaction between amount of crumb rubber and nano silica used in the mix can be further observed through figure 4.11. Highest flexural strength can be achieved, up to 3.2 MPa if 18% of fine aggregates are replaced by crumb rubber with addition of 5% of nano silica. The amount of nano silica is at the optimum amount to densified and bound the particles of the concrete mixture together.



(a)



(b)

Figure 4.12: (a) Plan or 2D view, and (b) 3D view of RSM Graph of Crumb Rubber (%) and Fly Ash (%) against Flexural Strength (MPa)

For direct tensile strength and flexural strength, the interaction of crumb rubber and fly ash towards their strength is similar. However, as for flexural strength, the range of the combinations of the materials is smaller. The amount of crumb rubber should be in between 3-18% and fly ash is 10-15% in order to get better flexural strength of the Rubbercrete.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The objectives of this project are to investigate the effects of each constituent of the mix design on mechanical properties of Rubbercrete, such as compressive strength, tensile strength, and flexural strength. The constituents involved in the study are crumb rubber, nano silica, fly ash, coarse aggregate, fine aggregate, and superplasticizer. Different combinations of mix proportions are developed by using RSM.

By using nano-silica, the compressive strength of Rubbercrete notably increased. This is due to the reaction of nano-silica with the product of hydration process, calcium hydroxide to produce more C-S-H gel. This gel helps in micro filling the voids that presents caused by the hydrophobic nature of the crumb rubber. Thus, the microstructure of the concrete is improved and densified, and the contact surface between the particles increased.

Other selected materials, such as the amount of fly ash, superplasticizer, and water-per-cement ratio also governed the strength of the concrete. This is especially crucial because as mentioned previously, crumb rubber repels water. By replacing Ordinary Portland Cement (OPC) with fly ash, the demand of the mixture for water could be reduced (which ultimately could reduce the water-per-cement ratio) as the fly ash particles are in smooth and spherical shapes which helps elevate the workability of the mixture. Superplasticizer also can be used to increase the flow and workability of the concrete without compromising the amount of water needed for the concrete. This consequently leads to higher strength of the concrete.

With this addition of several materials, compressive strength of Rubbercrete is improved, however, on the other hands; they did not significantly affects the direct tensile and flexural strength of the Rubbercrete. For future works, testing is recommended to be done at the later ages of the samples such as at 56 days and 84 days of curing in order to inspect further on how the materials react to each other in a long run. The increment of the mechanical strength can be observed and improvements might be seen as the materials take time to react and improve the concrete strength.

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