Bond Strength of Concrete Containing Crumb Rubber as Partial Replacement to Fine Aggregate

By

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19096

Dissertation submitted in partial fulfilment of
Requirements for the
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CERTIFICATION OF APPROVAL

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A Project Dissertation submitted to the
Civil Engineering Programme
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Approved by,

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(Dr Ehsan Nikbakht Jarghouyeh)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
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.

(AQILAH BINTI MOHD AZMI)

ABSTRACT

Crumb rubber is a recycled rubber from the scrap tires. There are environmental problem associated with waste tires. This is because the tires are bulky and non-biodegradable. The smoke released by tires that caught fire are also extremely dangerous which is difficult to extinguish and release a lot of toxic gases. Rubbercrete is a concrete containing crumb rubber as the partial replacement of fine aggregate. It is a good idea to introduce crumb rubber in concrete as it can solve the problem of the abundance of waste tire to be disposed and lack of natural fine aggregate. The advantages of using rubbercrete such as lighter in weight, high impact of resistance and better electrical resistivity. Rubbercrete also is good in ductility compare to normal concrete which is known as brittle material. However, as the percentage of crumb rubber increase the strength of rubbercrete decrease. This research paper, study about the compressive strength and bonding strength of the rubberrcrete. Thirty trial mixtures with the different percentage of crumb rubber, nano silica and fly ash were prepared. The 0%, 15% and 30% of crumb rubber replacement to fine aggregate by volume. For nano silica, 0%, 2.5% and 5% will be added to concrete with respect to cementations material. Fly ash also will be replaced with cement by 0%, 35% and 70%. The range of water per cement ratio used is 0.25 to 0.35. The compressive strength test followed the BS EN12390-3:2002 for all the thirty trial mixtures. The pull-out test followed the ASTM C234 to test the bond strength between the rubbercrete and steel bar. Result shows the compressive strength of 30 trial mix and the analysis from Response Surface Methodology (RSM). Furthermore the bonding strength of five mixtures (Grade 20, 25, 30, 40 and 50) with different percentage of nano silica which is 0%, 0.81%, 1.8%, 3.71% and 5% were studied. The rubbercrete contain 0%, 0.81%, 1.8% and 3.71% of nano silica shows the increasing of bonding strength. However, 5% of nano silica shows less effect in improving the bonding strength. This might due to the limitation of the amount of nano silica and it might due to agglomeration of nano silica in the cement matrix.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

There are the environmental problems associated with waste tires. Tires are bulky, non-biodegradable waste and also tires fires are extremely dangerous. In Malaysia waste tires are disposed in many ways legally and illegally, through physical reuse, open burning, landfills and illegal dumping or stockpiling. The alternative of waste management option to solve the waste tires problems is by recycling the waste tires for useful use. The annual global production of concrete is about 3820 billion cubic meters which is about 5 billion cubic yards. So the best solution is by use the crumb rubber in the concrete.

Rubberized concrete or rubbrcrete is the inclusion of crumb rubber from scrap tires in concrete as partial replacement to fine aggregate. Rubbercrete have provided many valuable impacts to environmental and also concrete. There are many properties of rubbercrete improved compared to normal concrete. This paper presents the study of the compressive strength of the rubbercrete and also the bond strength between the rubbercrete and reinforcement bar. In reinforced constructions, the bond between the concrete and reinforcement is very important factor affecting the strength of the structure. Other than that, it is also important to the structural integrity and durability of the concrete member. Thus, the bond strength plays in important roles in stress transferring from concrete to steel bars.

1.2 PROBLEM STATEMENT

Rubbercrete is a concrete with crumb rubber as the replacement of the fine aggregate. The introducing of rubbercrete is the great idea as it can solve the problem of the abundance of waste tire to be disposed and lack of natural fine aggregate. Rubbercrete have many advantages such as lighter in weight, high air content, improved slump, high impact of resistance, better sound absorption with higher noise reduction and better electrical resistivity. The introduction of crumb rubber in the concrete also introduce the ductility behaviour which good for construction industry compare to the normal concrete which is brittle. However, rubbercrete strength decreased as the amount of crumb rubber increased. This is because of the attributed of crumb rubber which is hydrophobic. This mean the crumb rubber have non-polar layer which will repels the water and make the adhesion between cement and aggregate decreased. In order to further improvement, it will require the different addition of the material to the composite such as nano silica. Other materials also will affect the strength of the concrete such as fly ash, water per cement ratio and superplasticizer.

Normal reinforced concrete is used in construction industry and has stronger bonding strength between steel bars and concrete. Thereby, it is important to know the behaviour of the bonding strength between the steel bars and rubbercrete. Hence in this paper focus on the bonding behaviour between rubbercrete and reinforcement bar.

1.3 OBJECTIVE

The main aim of this research is to investigate the strength of properties of rubbercrete at different design mixtures. The main objective are:

1. To investigate the compressive strength behaviour of rubbercrete with different design mix
2. To determine and analyse the bond strength between the rubbercrete with the reinforcement

1.4 SCOPE OF STUDY

This research paper is to investigate the structural behaviour of crumb rubber in the concrete. The first step is to find the best mix design for rubbercrete from the 30 trial mix with different percentage of crumb rubber, nano silica, fly ash and water per cement ratio. From the result of 30 trial mix of compressive strength, the analysis will be done through the Response Surface Methodology (RSM) using Design Expert Software. Five different design mix with different compressive strength get from the RSM, and then the bonding strength between the rubbercrete and the reinforcement also were studied.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the works on various authors about the crumb rubber in the concrete has been discussed. The research is about the composition of the materials in the rubbercrete to increase the compressive strength. Other than that, in this research paper is focus on the bond strength between the steel bars and concrete containing crumb rubber. Hence in the literature review there also the works on various authors about the bonding strength in the concrete.

2.2 COMPOSITION OF RUBBERCRETE

One of the compositions used in the rubbercrete is nano silica. The introducing of nano silica would improving the size of the pores and density of the interfacial transition zone (ITZ) between cement matrix and aggregate in rubbercrete (Mohammad et.al, 2016). The inclusion of nano silica in the rubbercrete resulted with increasing the compressive strength.

The benefits of rubbercrete are (Mohammad et.al, 2016):

i. Lower density
ii. Increased ductility
iii. Enhanced plastic capacity
iv. Higher toughness
v. Higher impact resistance
vi. Higher thermal conductivity
vii. Higher noise reduction factor
viii. Better electrical resistivity
ix. Better energy dissipation, durability and damping ratio.

The disadvantage of rubbercrete is reducing in strength especially for mechanical properties such as compressive, flexural, tensile and splitting as the number crumb increase in the concrete (Mohammad et.al, 2016).

The decreasing strength in rubbercrete is due to the attribute of the crumb rubber which is hydrophobic properties which causes the weak bond between cement matrix and the crumb rubber particles. The crumb rubber also have non-polar layers that will increasing the ITZ thickness between the crumb rubber and cement matrix (Mohammad et.al, 2016). This attribute of crumb rubber causes the development of microstructures that will lead to early failure. Other study shows that as the increasing amount of crumb rubber, the adhesion between the cement and coarse aggregate will decreased (Mohammad et.al, 2012). This is due to the surface of course aggregate was exposed with less cement paste coating then it causes weak bonding between coarse aggregate and cement paste formed in hardened concrete. The micro cracks also start to form a weak chemistry between cement paste and crumb rubber due to stress concentration and finally leads to failure (Mohammad et.al, 2012).

There are a of lot treatment methods that the researchers have tried to improve the strength of rubbercrete. Therefore, using nano silica is the best method for the demands of high performance material. This means that nano silica can improve the strength of the concrete. This is because nano silica act as physical filler in filling the nano voids between the aggregates and cement matrix. Other than that, nano silica also act as an activator to pozzolanic reaction, which will produces more C-S-H gel that enhance the microstructure of concrete (Mohammad et.al, 2016).

Other study shows that nano silica improves concrete mechanical properties, durability, lower setting time, reduces the overall cost of construction (Adamu, 2016). Nano Silica is highly reactive filler when used in concrete even at lower percentage. The reason is nano silica will densified the concrete micro structures, enhance rate of hydration, decrease the bleeding and improves premature strength development (Adamu, 2016).

When nano silica used in concrete, it create a high strength, durable and sustainable concrete. In figure 2.1 shows the pozzolanic reactivity by adding the nano silica which can increase the hydration cement and produces more C-S-H gel (Singh, 2013). Even though by adding smaller amount of nano silica, it will shows higher increasing in the mechanical properties due to its pozzolanic reaction (Adamu, 2016). Introducing of nano silica in concretes also enhance the permeability by making the paste denser, more uniform and the interfacial transition zone (ITZ) between the cement paste and aggregate become denser and stronger. However, when nano silica added in concrete its lower the workability because of it have larger surface area (Adamu, 2016)

Nano – Silica + $H_2O \rightarrow H_2SiO_4^{2-}$ (1)

$Ca(OH_2) + H_2O \rightarrow Ca^{2+} + OH-$ (2)

Then $H_2SiO_4^{2-} + Ca^{2+} \rightarrow C - S - H\ gel$ (3)

Figure 2.1: Pozzolanic Reactivity

Other than that, the addition of the fly ash in concrete not only reduces the amount of calcium hydroxide (lime), but in the process converts it into calcium silicate hydrate providing more cementing material and thereby can enhance the strength of the concrete mixture. When the proper amount of silica fume and fly ash were added to replace the cement, the compressive strength will be increase (Lam et.al, 1998)

2.3 BONDING STRENGTH IN CONCRETE

The bond behavior is the fundamental importance in bonded between concrete and reinforcing steel bars and the structural response of reinforced concrete members (Song et.al, 2015). The slip magnitude that correspond to bond strength also parameter that will determines the bond behavior between concrete and reinforcement bar (Shen et.al, 2016). Wu et.al, (2013), also stated that the bond slip relationship between reinforcing bars and concrete is important and critical for the design and analysis of RC structures.

The various factors affecting the concrete-reinforcement bond strength τ_{max} (Kim et.al, 2013):

i. Compressive strength of concrete f_c,
ii. Yield strength of steel,
iii. Diameter of steel reinforcement d_b,
iv. Surface geometry of reinforcement/rib ratio and shape,
v. Depth at which reinforcement is embedded into concrete,
vi. Thickness of concrete cover c surrounding the reinforcement and
vii. Types of aggregate phase on the surrounding concrete

According to Mo et.al, (2013), there are three main components that contribute to the bond between the reinforcing bar and the concrete. The components are the shear stress due to chemical adhesion between the reinforcing bar and the concrete, the mechanical anchorage or bearing of the rib against the concrete surface, and frictional forces between the reinforcing bar and the concrete at the rib interface. The chemical bonding between the reinforcement bar and the concrete causes the forces transferred by the adhesion on initial loading. The slip occurs because of chemical adhesion lost at low level of stress. When the slip occurs, frictional and bearing forces begin, thus lead to the bond between the reinforcing bar and the concrete. The research of Bompa et.al, (2017), stated that the friction between the rebars and rubberised concrete seems to be relatively low, fundamentally due to the weak interfacial bond between rubber particles and cement paste which allows premature cracking to develop. The bond behavior is not only governed by concrete properties, but also by reinforcement geometry. Surface properties and rib configuration may increase the bond strength (Bompa et.al, 2017).

One of the factors that affect the bond strength τ_{max} as mention earlier is compressive strength of concrete f_c which is considered as the most important factors that determined bond strength (Wu et.al, 2013). The bond strength τ_{max} is closely related to the square root of the concrete compressive strength f_c (equation [1]), it also defined as shear stress over the nominal area of the rebar (equation [2]) (Bompa et.al, 2017).

$$\tau_{max} = \gamma b\sqrt{f_c} \quad [1]$$

$$\tau = \frac{F}{\pi \; X \; D \; X \; L} \quad [2]$$

Where:

τ = Bond strength of the concrete

F= Breaking load applied

D= Diameter of rebar used (mm)

L= Depth of rebar penetration

The bond properties that stated by Bompa et.al, (2017), the replacement of mineral aggregates with rubber particles modifies the mechanical properties in terms of strengths, stiffness and stress-strain response. The averaged test results assessed in terms of bond coefficient γ_b, representing the ratio between τ_{max} and square root of f_c and indicates good bond conditions when $\gamma b > 2.5$ as defined by Model Code 2010. The observed that the presence of rubber produces some bond enhancement at rebar-rubberised concrete interface with bond coefficients ranging between γ_b of 3.9 and 5.1, while for normal concrete this was lower (γ_b =3.6-3.7) due to rebar yielding. This shows that the rubber-rebar interaction has a rather beneficial effect. Bond coefficients as high as γ_b=2.5 correspond to a good conditions. Bompa et.al, (2017) stated that the use of γ_b= 4.5 offers more accurate predictions including the failure mode.

Other than the effect of compressive strength of concrete, concrete cover *c* also give effect to the bond strength. Wu et.al, (2013), study that the increase in concrete cover c will cause an increase in bond strength but there is a limitation of the increasing of bonding strength.

According to Wu et.al, (2013), the effect of rebar diameter d_b usually referred as the size effect. Increasing diameter of the reinforcement bar lead to decrease in bond strength. However, the variation in d_b did not result in a consistent trend in the value of slip *s* corresponding to the peak bond strength. The bond strength was observed to increase as $\frac{c}{d_b}$ increase. Mo et.al, (2016), also stated that as the increasing of rebar diameter d_b and smaller size of concrete will lead to decreasing of bonding strength. This ratio was a key factor that affects bond strength.

According to the Shen et.al, (2016), the reinforcement is an effective way to reduce cracking width so the bond behavior has to be known. In the research of Shen et.al, (2016), the pull-out test on specimen at age of 2, 3, 4, 5, 6, 7, 10, 14 and 28 days are carry out. Besides, the significant parameter of bond behavior of High Strength Concrete (HSC) structures also determine by the corresponding of the slip to the bond strength. (Shen et.al, 2016). To obtain the cracking pattern and cracking width it is required to know the bond stress-slip relationship. It is also significant influence on the behavior of reinforced elements in cracked stage (Harajali et.al, 2008).

Shen et.al, (2016) stated that the relationship between bond strength and concrete age between steel bars and HSC increase rapidly with the slight slip value, and later decrease with high slip value once the maximum pull-out load reached. The strength of early age concrete increase with the forming of the cement hydration process, at the same time the bond strength between the reinforcing steel bars and the surrounding concrete also increase (Song et.al, 2015). The relationship between bond strength and concrete age was nonlinear. The slip corresponding to bond strength decreased with the increased of concrete strength. The studies also showed that the bond strength between steel bars and HSC increase with the increase of concrete strength (Shen et al, 2016).

Most cases, for reaching the maximum capacity of the bond strength between the reinforcing bar and the concrete the bond pull-out failure is preferable. However for bond-splitting failure, the use of bond properties obtained from well-confined specimens may grossly overestimate bond strengths and hence anchorage capacities and lead to underestimate of crack widths (Mo et al, 2016). The compaction level and concrete porosity can also have an influence on interface behavior. Bompa et.al, (2017), also stated that in normal concrete the bond behavior depends on the mechanical properties of the concrete, its microstructure, rebar configuration, concrete thickness and level of confinement. The presence of rubber particles in concrete modifies its microstructures, which directly influences the interlocking behavior between rebar ribs and concrete keys and consequently the splitting and crushing near the interface region.

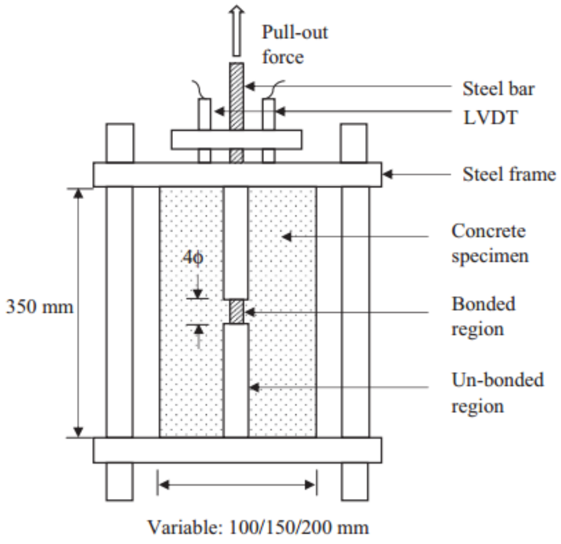


Figure 2.2: Bond test specimen

Figure 2.2 shows that the bond stress-slip relationship of oil palm shell lightweight concrete was carried out using the pull-out test (Mo et.al, 2016). There are the area of the bonded region and the un-bonded region between the concrete and reinforcement bar. The bonded length was maintained at four timed diameter of reinforcement bar (*4d*) at mid–height of the specimen to ensure uniform slip distribution, while the reminder of the reinforcing bar was enclosed using a polyvinyl chloride (PVC) tube to act as a bond breaker (Mo et.al, 2016). During the testing, the linear voltage displacement transducers (LVDT) was used to measure the loaded-end slip of the reinforcement bar from the concrete block. Lee et.al, (2016) stated that from the machine it will measured the applied load and axial displacement. Then, the bond strength will be calculated by the applied load given from the machine divided by the contact area of reinforcement bar by assuming constant bond stress distribution along the embedment length.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this research paper, there were 30 trial mixtures with different design mixtures. The compressive strength for all the 30 mixtures were tested and analysed using RSM. From the RSM, five mix design were chosen with different compressive strength to carry out the bonding strength test between the rubbercrete and steel bar. The types of materials and equipment used are also discussed in this chapter. Project Gantt charts and key milestone are also discussed for progress tracking.

3.2 FLOW CHART

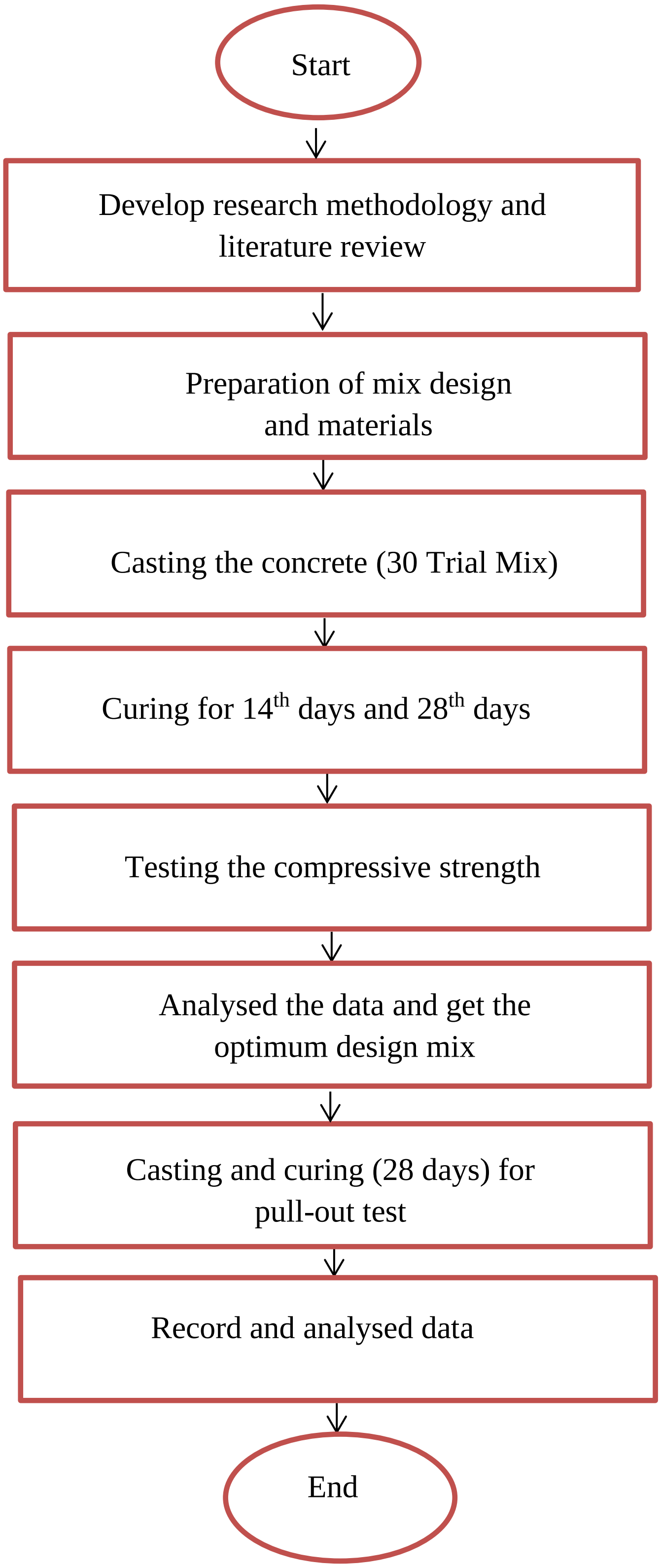


Figure 3.1: Flow Chart

3.3 CONCRETE MIX DESIGN

Concrete mix design is the process of selecting the optimum amount of materials of concrete to determine the concrete strength, durability and workability.

The compressive strength of 30 trial mix design were tested and analyses using the Response Surface Methodology (RSM). The Response Surface Methodology is the graph that explores the relationship between several variables and the main idea is to use a sequence of designed experiments to obtain an optimal mix design. The RSM also is a statistical approach that can occupy to maximize the production of special substances by optimization of operational factors. The range of the mix design used in this research is in the Table 3.1.

Table 3.1: Range of mix design

Material	Mix Proportion
Crumb Rubber	0%, 15% and 30%
Nano Silica	0%, 2.5% and 5%
Fly Ash	0%, 35 % and 70 %
Water/cement ratio	0.25-0.35

The weight of the cement is 543 kg/m^3, coarse aggregate is 840 kg/m^3 and fine aggregate (river sand) is 670 kg/m^3. The specific gravity of the sand is 2.6 while crumb rubber is 0.95. Thus, the specific gravity of the crumb rubber is lower than sand so it must calculate using a volume. In the calculation also we assume the wastage about 40%. Table 3.2 shows the percentage of the materials while the Table 3.3 shows the weight for the materials

Table 3.2: Percentage of Materials

Run	Crumb Rubber (%)	Nano Silica (%)	Fly Ash (%)	w/c
1	0	0	0	0.25
2	15	2.5	35	0.3
3	15	2.5	0	0.3
4	15	2.5	35	0.3
5	15	2.5	35	0.3
6	30	5	70	0.35
7	15	5	35	0.3
8	0	5	70	0.25
9	30	0	0	0.35
10	15	0	35	0.3
11	0	5	0	0.35
12	30	5	0	0.35
13	0	0	70	0.25
14	15	2.5	70	0.3
15	30	0	70	0.25
16	15	2.5	35	0.3
17	30	5	0	0.25
18	15	2.5	35	0.25
19	0	5	70	0.35
20	0	0	70	0.35
21	30	5	70	0.25
22	0	2.5	35	0.3
23	0	5	0	0.25
24	0	0	0	0.35
25	15	2.5	35	0.3
26	30	2.5	35	0.3
27	15	2.5	35	0.35
28	15	2.5	35	0.3
29	30	0	0	0.25
30	30	0	70	0.35

Table 3.2 shows that the percentage of the Crumb Rubber (0%,15% & 30%), nano silica (0%,2.5% & 5%) , fly ash (0%,35% & 70 %) and water per cement ratio (0.25,0.30 & 0.35). The design mixtures get from the Response Surface Methodology (RSM).

Table 2.3: The Weight of the Materials

Mix No.	Crumb Rubber (kg)	Nano Silica (kg)	Fly Ash (kg)	w/c	Cement (kg)	sand (kg)	Course Aggregate (kg)
1	0	0	0	1.14	4.56	5.63	7.056
2	0.31	0.11	1.60	1.37	2.96	4.78	7.056
3	0.31	0.11	0	1.37	4.56	4.78	7.056
4	0.31	0.11	1.60	1.37	2.96	4.78	7.056
5	0.31	0.11	1.60	1.37	2.96	4.78	7.056
6	0.62	0.23	3.19	1.60	1.37	3.94	7.056
7	0.31	0.23	1.60	1.37	2.96	4.78	7.056
8	0	0.23	3.19	1.14	1.37	5.63	7.056
9	0.62	0	0	1.60	4.56	3.94	7.056
10	0.31	0	1.60	1.37	2.96	4.78	7.056
11	0	0.23	0	1.60	4.56	5.63	7.056
12	0.62	0.23	0	1.60	4.56	3.94	7.056
13	0	0	3.19	1.14	1.37	5.63	7.056
14	0.31	0.11	3.19	1.37	1.37	4.78	7.056
15	0.62	0	3.19	1.14	1.37	3.94	7.056
16	0.31	0.11	1.60	1.37	2.96	4.78	7.056
17	0.62	0.23	0	1.14	4.56	3.94	7.056
18	0.31	0.11	1.60	1.14	2.96	4.78	7.056
19	0	0.23	3.19	1.60	1.37	5.63	7.056
20	0	0	3.19	1.60	1.37	5.63	7.056
21	0.62	0.23	3.19	1.14	1.37	3.94	7.056
22	0	0.11	1.60	1.37	2.96	5.63	7.056
23	0	0.23	0	1.14	4.56	5.63	7.056
24	0	0	0	1.60	4.56	5.63	7.056
25	0.31	0.11	1.60	1.37	2.96	4.78	7.056
26	0.62	0.11	1.60	1.37	2.96	3.94	7.056
27	0.31	0.11	1.60	1.60	2.96	4.78	7.056
28	0.31	0.11	1.60	1.37	2.96	4.78	7.056
29	0.62	0	0	1.14	4.56	3.94	7.056
30	0.62	0	3.19	1.60	1.37	3.94	7.056

Table 3.3 shows the weight crumb rubber, nano silica, fly Ash, cement, sand and course aggregate in kilogram.

3.4 EXPERIMENT SET UP

3.4.1 Materials

3.4.1.1 Ordinary Portland Cement (OPC)

Portland cement is the basic ingredient that will be used in a construction industry to make a concrete. In this research it will be used normal OPC that have in UTP laboratory at block 13. This cement is 840 kg/m^3. As there are 30 mixtures in this research experiment, so some mixtures the cement will replace by a fly ash.

Figure 3.2: Ordinary Portland Cement (OPC)

3.4.1.2 Fly Ash

The fly ash used in this research paper is class F. Class F of fly ash has constant fineness and constant carbon content. The main requirement of ASTM C618-08a is a minimum content of 70% of silica, alumina and ferric oxide taken all together. Fly ash in the mix will replace the Portland cement will give a big savings in concrete material costs as the concrete is expensive. The shape of fly ash particles is spherical that give the advantages in the water requirement point of view. Thus, a reduction of the amount of water/superplasticizer needed for mixing and placing concrete can be obtained. Next, the use of fly ash can show a better workability and also durability.

Figure 3.3: Fly Ash

3.4.1.3 Nano Silica

Inclusion of nano silica would reduce the size of the pores and improve the density the interfacial transition zone (ITZ) between cement matrix and aggregate. Nano silica help in improving the microstructures of the concrete because it acts as activator pozzolanic reaction that produce C-SH gel and it can fill the voids that creates by the crumb rubber. The amount of nano silica use in this research is 0%, 2.5% and 5% of cement

Figure 3.4: Nano Silica

Table 3.4: Chemical composition of Ordinary Portland Cement (OPC), Fly Ash and Nano silica

Chemical composition (%)	**Portland 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	4.9	-
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 in Ignition	2.02	1.87	-

Table 3.4 shows the composition of Portland cement, fly ash and also nano silica. Nano silica only consist of Silicon Oxide which is 99.8% of chemical composition.

3.4.1.4 Coarse Aggregate

The coarse aggregate used as a main ingredient in the rubbercrete. The weight of the coarse aggregate is 840 kg/m^3. Table 3.5 shows the sieve analysis test for course aggregate follow the ASTM C33.

Figure 3.5: Coarse aggregate

Table 3.5: Sieve Analysis of course aggregate

Sieve Size (mm)	Total Passing (%)
13.2	100
9.5	99.87
4.75	35.70
2.36	4.70
1.18	0.50

3.4.1.5 River Sand

River sand is natural sand that available on river banks. In term of shape it has smoother texture with better shape. Moisture content in river sand is trapped in between the particles which good for concrete purposes. It is very fine in quality and have white-grey colour. River sand weight is 670 kg/m^3 and the specific gravity is 2.6. In this research paper, the river sand will be replaced with the crumb rubber. The table 3.6 shows the sieve analysis test for river sand follow the ASTM C33.

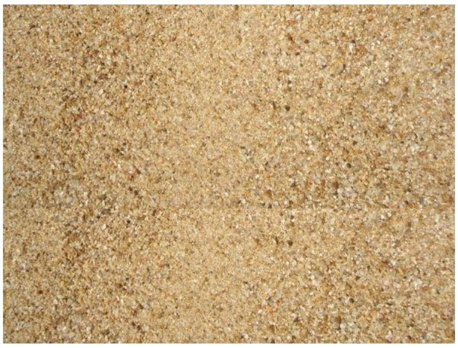


Figure 3.6: River sand

Table 3.6: Sieve analysis of river sand

Sieve Size (mm)	Total Passing (%)
1.18	100
0.60	7.05
0.3	0.10

3.4.1.6 Crumb Rubber

Crumb rubber is recycled rubber from automotive and truck scrap tires. Scrap tires are non-biodegradable waste due to the material of the tire which is difficult to break down. Scrap tires is made up from rubber, steel wire, fiber and also the newer materials like Kevlar. During the recycling process, steel and tire cord are removed, leaving only the tire rubber with a granular consistency. Then it will continue with the process of granulator or cracker mill to reduce the size of the particles. The Specific gravity of crumb rubber is 0.95 which is lower than sand. The amount of crumb rubber use in this research is 0%, 15 % and 30% of the amount of fine aggregates (river sand). The table 3.7 shows the sieve analysis test for crumb rubber follow the ASTM C33. Table 3.8 also shows differentiate properties of course aggregate, fine aggregate and also crumb rubber.

Figure 3.7: Crumb Rubber

Table 3.7: Sieve Analysis of crumb rubber

Sieve Size(mm)	Total Passing (%)
5.0	100
2.36	63
1.18	11

Table 3.8: Properties of coarse aggregate, fine aggregate and crumb rubber

Properties	Coarse aggregate	Fine aggregate	Crumb rubber
Water absorption (%)	1.13	4.48	-
Specific Gravity	2.65	2.6	0.95
Moisture Content (%)	0.94	16.7	1.15
Fineness modulus	-	2.32	0.92

3.4.1.7 Water and Superplasticizer (SPL)

Superplasticizers (SPL) are chemical admixtures which also known as high range water reducers. The addition of SPL allows reducing the amount of water per cement ratio, and also can improve the workability of the mix design. The SPL used in the rubbercrete is depends on the workability of the design mix. The percentage of SPL is calculated from the cementitous of the material.

Figure 3.8: Superplasticizer

3.4.1.8 Reinforcement Bar

The reinforcement bar with 16 mm diameter size is used in the pull-out test.

Figure 3.9: Reinforcement Bar

3.4.2 Experimental Apparatus

3.4.2.1 Concrete cube mould

The 100 mm x100 mm concrete cube moulds use for compressive strength test in this research. Every mix design will have 6 cubes to test for 14 days and 28 days.

Figure 3.10: Concrete cube mould

3.4.2.2 Concrete cylindrical mould

The size of 100 mm diameter, 200mm height of cylindrical mould used for the pull-out test.

Figure 3.11: Concrete cylindrical mould

3.4.2.3 Concrete mixer

Concrete mixer is used for mixing all the material together until homogeneous.

Figure 3.12: Concrete mixer

3.4.2.4 Measuring cylinder

To measure the amount of superplasticizer to be used.

Figure 3.13: Measuring cylinder

3.4.2.5 Balance Weight

To weight the mass of each materials.

Figure 3.14: Balance Weight

3.4.2.6 Abrams Cone

Abrams cone with top diameter of 100 mm, base diameter of 200 mm and height of 300 mm is used for the slump test. The slump test required to achieve medium slump which is from 75mm to 100mm. Medium slump is for beams and slabs.

Figure 3.15: Abrams Cone

3.4.3 Preparation of Test Specimen

The mix procedures take places at the civil engineering laboratory at block 13, Universiti Teknologi PETRONAS. There are 30 design mixtures with different percentage of cement, fine aggregate, course aggregate, fly ash, nano silica and crumb rubber. The test specimens were prepared and curing follow the ASTM C192. The six cube mould size 100 mm x 100 mm dimension were prepared for every mix as in figure 3.16. Then slump test were carried out follow the ASTM C143. The slump test is to checking the correct amount of water/superplasticizer that has been added to the mix design. This test will be done using Abrams cone with top diameter of 100 mm, base diameter of 200 mm and height of 300 mm. The square plate is used and the dimension is 1000 mm x 1000 mm. The slump test need to achieve is average range which is 75 mm-100 mm as in figure 3.19.

The mould need to be prepared and grease before placing the concrete as shown in figure 3.16. During the placing of the concrete, the compaction need to be done three times with equal depth using a rod. The test specimen were removed from the mould after 24 hours and curing for 14 days and 28 days as shown in figure 3.18.

Figure 3.16: Preparation of mould

Figure 3.17: The specimen

Figure 3.18: Curing of the specimen

Figure 3.19: Slump test

The pullout test or bond strength test specimen is prepared as shown in figure 3.20. The steel rebar size is 16 mm diameter and 61 cm length. The vertical steel bar was positioned vertically at its center and inserted into the specimen. The bonded region was maintained in the middle of specimen is 4d which is 4 multiply the diameter of rebar. Thus, the length of bonded region is 64 mm, while un-bonded region length is 68 mm for upper part and 68 mm for lower part. This bonded region is to make sure the uniform slip distribution, while the reminder of the reinforcing bar was enclosed using a PVC tube to act as a bond breaker (Mo et al, 2016). After pouring the concrete mix, the compaction was carried out three times with equal depth using a rod. The test specimen were removed from the mould after 24 hours and curing for 28 days. Figure 3.21, 3.22 and 3.23 shows the process of fix the steel bar in the mould and casting. Figure 3.24 shows the specimen that will be curing for 28th days.

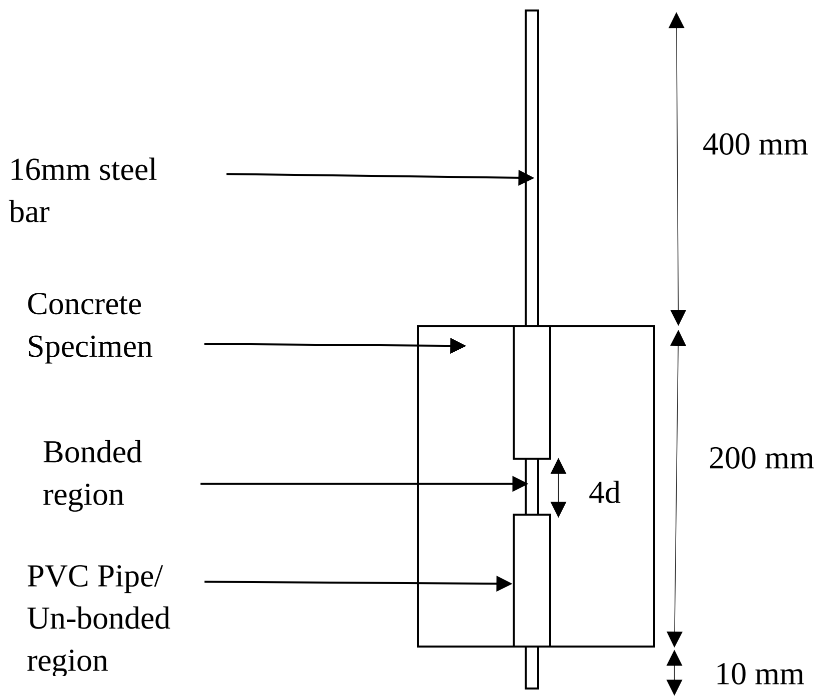


Figure 3.20: Dimension of the specimen for pullout test

Figure 3.21: Steel bar

Figure 3.22: Mould for pullout test

Figure 3.23: Concreting for pullout test

Figure 3.24: The specimen for pull-out test

3.5 EXPERIMENTATION TEST

In this research, two main tests will be run which is compressive strength and pull-out test.

3.5.1 Compressive Strength Test

Compressive strength is the most main test that will give an idea about the characteristics of the concrete. Test for compressive strength is carried out with the 100 mm x 100 mm of the cube. Compressive strength will be test on 14^{th} days and 28^{th} days of curing for three cubes each. The cubes will be placed into the Compression Testing Machine for strength testing. The test will be carried out follow the BS EN 12390-3:2002.

Figure 3.25: Compression Testing Machine

3.5.1.1 Procedure of Compressive Strength

1. Remove the concrete cube from water after specified curing time and wipe out excess water from the surface
2. The bearing of the testing machine need to be clean
3. Place the concrete cube in the machine
4. Align the center of concrete cube on the base plate of the machine.
5. Applied the load until the concrete cube fail.
6. Record the maximum load.

3.5.2 Pull-Out Test

In this study, the rebar-concrete interface properties were investigated by conducting the single pull-out test. The pull-out test is to test the bond strength between the rebar and the concrete. The major factor in affecting the mechanical behavior of this composition material is the bond between the rebar and the matrix in a rebar-reinforced brittle the matrix material. The reinforcement bar will be used is 16 mm diameter.

The test procedure used in this basically followed the specification of ASTM C234. The pull-out test will be performing using a Universal Testing Machine (UTM). The speed of loading used in this research is 0.367kN/s. During the test, the loading and the displacement values were recorded using data acquisition system. From the machine the breaking load or the maximum loading applied to pull out the steel rebar from the concrete will be given. From the result given, the bond strength of the concrete will be calculated using equation [2].

Figure 3.26: Universal Testing Machine (UTM) for pullout test

3.6 KEY MILESTONE

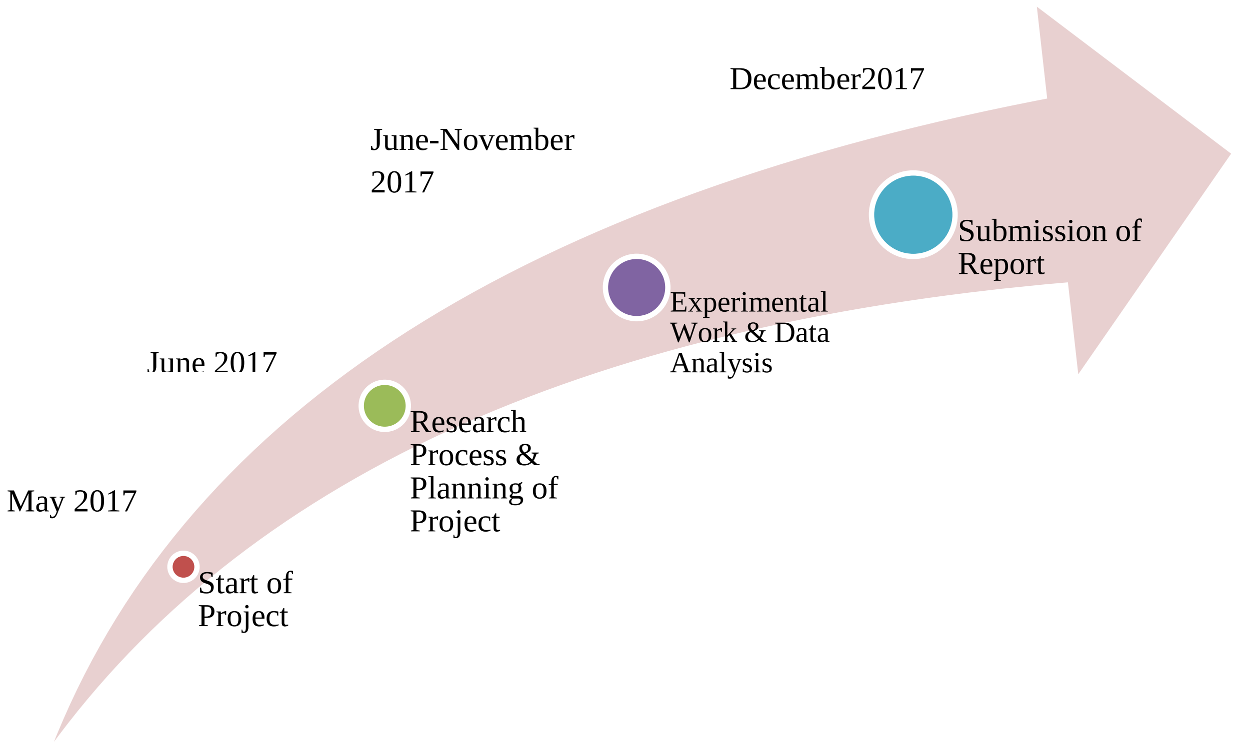


Figure 3.27: Key milestone

3.7 PROJECT PLANNING (GANTT CHART)

Final Year Project 1 (FYP1)

ACTIVITIES	MAY 17			JUNE 17				JULY 17				AUGUST 17		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Selection of Project Topic														
Brief Explanation of Project Topic														
Materials Preparation														
Experimental Work														
Submission of Extended Proposal														
Raya Holiday														
Proposal Defense														
Experimental Work														
Submission of Interim Draft Proposal														
Submission of Interim Report														

Figure 3.28: Gantt Chart FYP1

Final Year Project 2 (FYP2)

ACTIVITIES	SEPTEMBER 17			OCTOBER 17				NOVEMBER 17					DECEMBER 17	
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Experimental Work														
Preparation of Reports and Presentation														
Submission of Progress Report														
Pre-SEDEX														
Submission of Draft Final Report														
Submission of Dissertation (soft bound)														
Submission of Technical Paper														
Viva														
Submission of Project Dissertation (Hard bound)														

Figure 3.29: Gantt Chart FYP 2

CHAPTER 4

RESULT AND DISCUSSION

4.1 COMPRESSIVE STRENGTH RESULT

Table 4.1: Result of compressive strength

Mix No.	CR %	NS %	FA %	w/c	Compressive Strength (14 days) (N/mm^2)	Compressive Strength (28 days) (N/mm^2)
1	0	0	0	0.25	66.04	82.41
2	15	2.5	35	0.30	44.31	45.68
3	15	2.5	0	0.30	53.25	39.00
4	15	2.5	35	0.30	36.67	48.08
5	15	2.5	35	0.30	37.83	53.19
6	30	5	70	0.35	27.47	42.88
7	15	5	35	0.30	33.58	40.44
8	0	5	70	0.25	39.15	64.64
9	30	0	0	0.35	31.36	33.25
10	15	0	35	0.30	46.10	42.31
11	0	5	0	0.35	23.13	36.53
12	30	5	0	0.35	33.63	31.44
13	0	0	70	0.25	62.95	39.41
14	15	2.5	70	0.30	32.53	42.95
15	30	0	70	0.25	25.54	32.22
16	15	2.5	35	0.30	43.50	45.30
17	30	5	0	0.25	46.18	36.42
18	15	2.5	35	0.25	55.57	36.91
19	0	5	70	0.35	38.57	43.11
20	0	0	70	0.35	27.86	24.55
21	30	5	70	0.25	32.43	54.97
22	0	2.5	35	0.30	41.19	43.64
23	0	5	0	0.25	54.33	75.64
24	0	0	0	0.35	63.04	66.99
25	15	2.5	35	0.30	43.66	47.82
26	30	2.5	35	0.30	34.93	29.43
27	15	2.5	35	0.35	33.22	40.69
28	15	2.5	35	0.30	42.68	48.74
29	30	0	0	0.25	37.26	39.11
30	30	0	70	0.35	18.76	18.61

The 30 trial mixes in the table 4.1 show the result of compressive strength for 14 days and 28 days of curing. From the result it shows that the composition of the concrete containing crumb rubber, nano silica and fly ash have lower compressive strength than normal concrete. This is due to the properties of crumb rubber that repel the water during mixing process. However, by adding nano silica the compressive strength will be increase a little bit. From the compressive strength result of 30 trial mix, the optimum design for rubbercrete can be getting from the RSM. Five optimum mixes design with different grades will be prepare for pull-out test to test the bond strength between the steel bar and rubbercrete.

4.1.1 Response Surface Methodology (RSM) for Compressive Strength

Response surface methodology (RSM) explores the relationship between several explanatory variable and one or more variable. In this research paper, there are more than one variables which are crumb rubber, nano silica, fly ash and water/cement ratio. RSM is used in a designed experiments to obtain the optimum design response which can develop models and evaluating the effect of each variables. In RSM, ANOVA was used to approximate the significance of model coefficients. Here the p values were given and it indicates the significant for each variables and also showed the interaction strength between each independent variable.

RESPONSE 1: 14 DAYS

Table 4.2: Analysis of variance (ANOVA) for the 14 days of the curing

Source	Sum of Squares	DF	Mean Square	F 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				

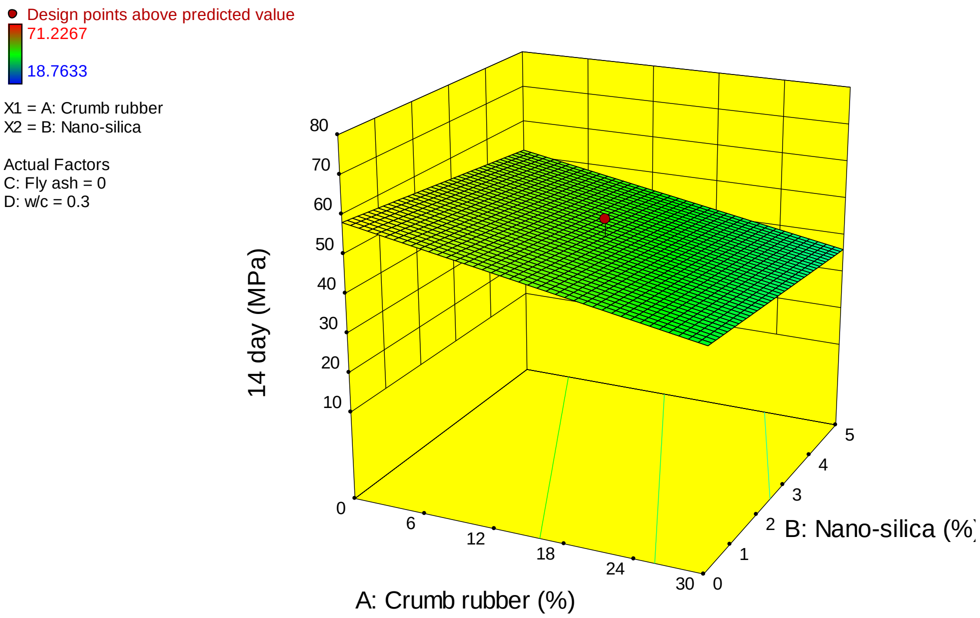
Standard Deviation	8.22	Adjusted R^2	0.5919
Mean	41.21	Prediction R^2	0.4225
R^2	0.6482	Adequate Precision	15.013

Table 4.2 shows the analysis of variance (ANOVA) for the 14 days curing in this experiment. The Model F-value of 11.51 implies the model is significant. There is only a 0.01% chance that an F-value could occur due to noise. The model is highly significant ($p < 0.0001$) and the coefficient determination (R^2) was shown 0.6482, indicating the 64.82% of the variability in the response could be explained by the model and about 35% of the total variations were not explained by the model. The prediction R^2 of 0.4225 is in reasonable agreement with the Adjusted R^2 of 0.5919, because the difference is less than 0.2. Adequate precision is to measure the signal to noise ratio. A ratio greater than 4 is desirable. In this model the adequate precision is 15.013 which indicate and adequate signal. This model can be used to navigate the design plan. The model in terms of actual variables can be used to make predictions about the response for given level of each factors. The level should be specifies in the original units for each factor.

The equation for 14 days of compressive strength in terms of actual variables shows in Eqn [3]:

14 days of compressive strength [3]

= +105.36626 – (0.52188 *x Crumb Rubber*) - (1.27526 x *Nano Silica*) – (0.18235 x *Fly Ash*) – (-155.87407 x *w/c*)



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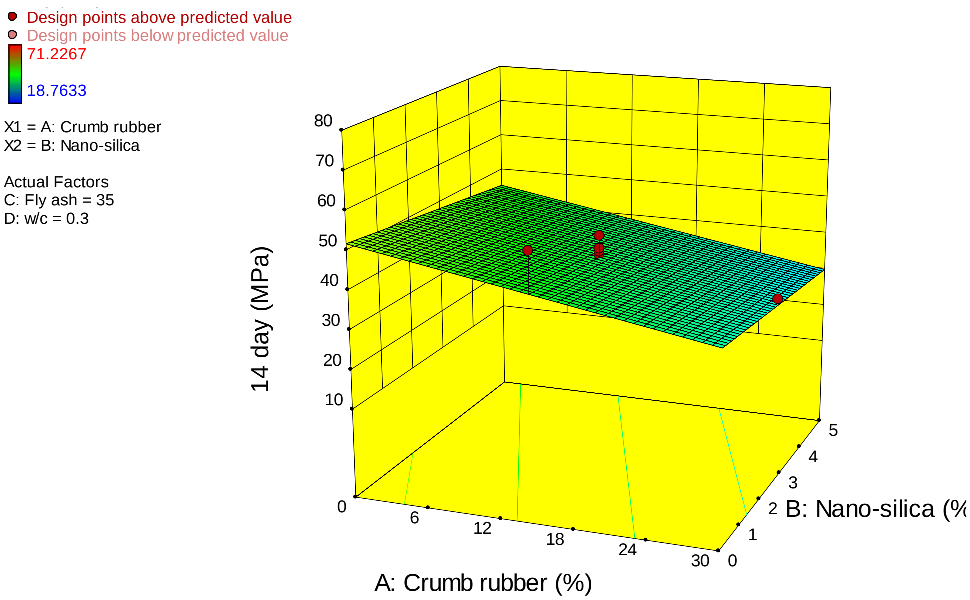

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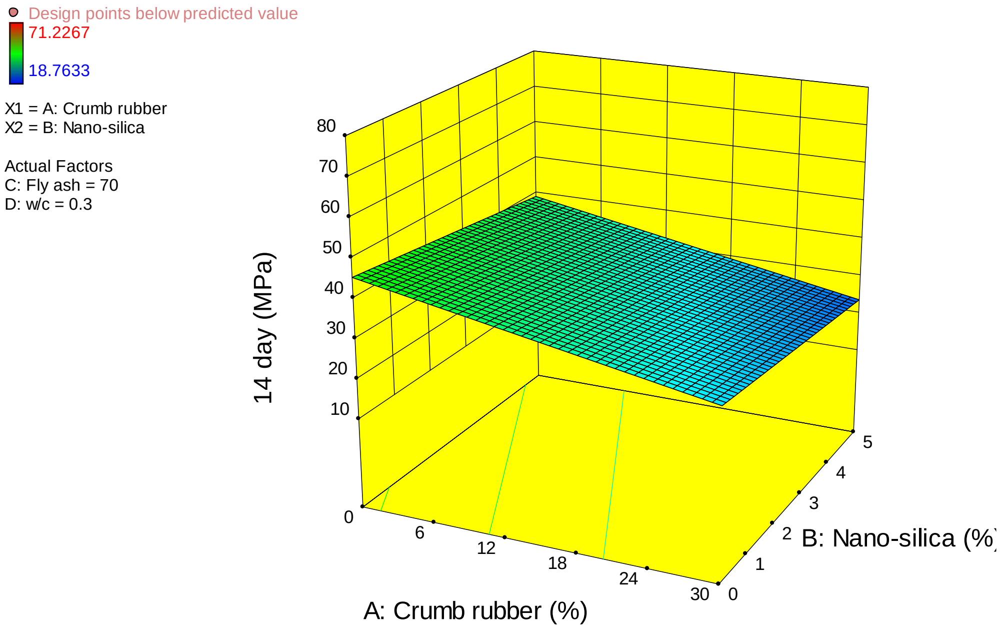


(c)

Figure 4.1: Response surface curve (3D) for 14 days of compressive strength showing the percentage of crumb rubber and nano silica with 0.3 of water per cement ratio (a) Fly ash 0% (b) Fly ash 35% (c) Fly Ash 70%

From the response surface curve (3D) in figure 4.1 shows that the graph of the 14 days of compressive strength with the different variables of constant water per cement ration which is 0.3, different percentage of fly ash, nano silica and crumb rubber. From the graph it shows that the higher compressive strength is when the percentage of fly ash is 0%, crumb rubber is 0% and nano silica is 0%. This indicate the mixture is a normal concrete. Thus, it shows that the compressive strength of the design mix that contain crumb rubber, nano silica and fly ash will not exceed the compressive strength of the normal concrete. This is because, design mix that contain crumb rubber will reduce the compressive strength due to the attribute of the crumb rubber that repels the water and causes the weak bonding between cement matrix and the crumb rubber particles.

In overall design mix for 14 days, it shows that the compressive strength reduces with the increase amount of fly ash. The inclusion of fly ash in the design mix should improve concrete performance. However, the result of 14 days does not show the behavior of fly ash that will improve the performance of concrete due to the design mix does not fully react with each other.

The lowest compressive strength concrete is when the percentage of fly ash is 70%, water per cement ratio is 0.3, crumb rubber is 30% and nano silica is 0%. This is due to the crumb rubber attribute to the hydrophobic properties that repels the water that result in weak bond. Other than that, the introduction of nano silica in design mix can improve the compressive strength of concrete that contain crumb rubber as nano silica act as filler that will produce C-S-H gel that will decrease the ITZ between the crumb rubber and cement matrix. Thus, the lowest compressive strength of the design mix have 0% of nano silica, and it contain highest crumb rubber which is 30%, so it has a weakest bonding between cement matrix and the crumb rubber. Fly ash in this design mix does not fully react fly react with each other.

RESPONSE 2:28 DAYS

Table 4.3: Analysis of variance (ANOVA) for the 28 days of the curing

Source	Sum of Squares	DF	Mean Square	F 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				

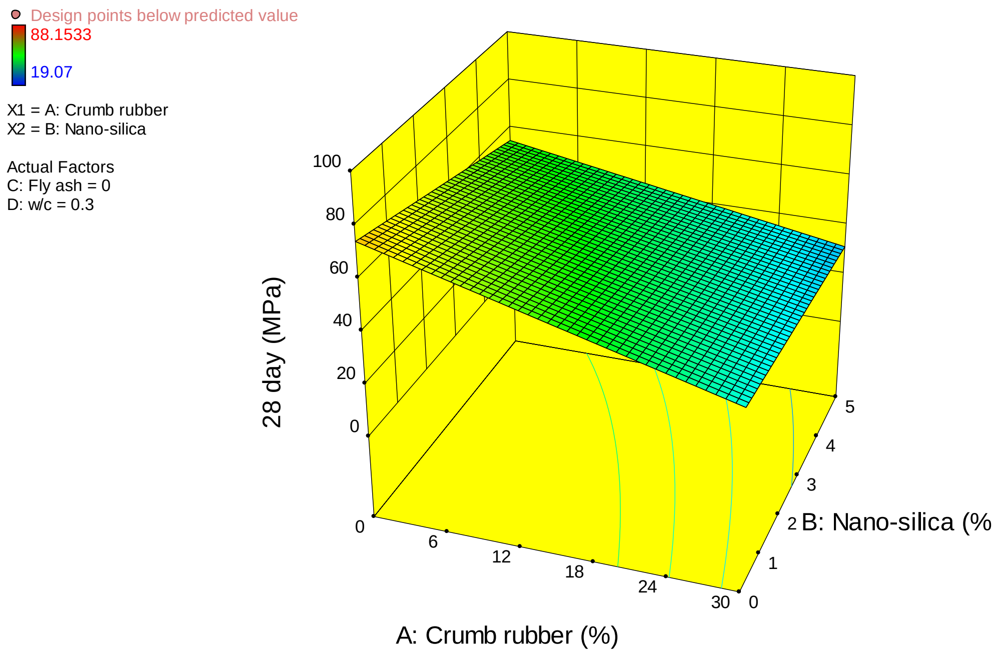
Std. Dev	5.51	Adj R^2	0.8638
Mean	44.68	Prediction R^2	0.7473
R^2	0.9108	Adeq Precision	20.133

Table 4.3 shows the analysis of variance (ANOVA) for the 28 days curing in this experiment. The Model F-value of 19.40 implies the model is significant. There is only a 0.01% chance that an F-value could occur due to noise. Value of “Prob > F” less than 0.0500 indicate model terms are significant. In this model A (Crumb rubber), B (Nano silica), C (Fly Ash), D (water per cement ratio), AB, AC, AD and BC are significant model terms. The values that greater than 0.1000 indicate the model terms are not significant. The model is highly significant ($p < 0.0001$) and the coefficient determination (R^2) was shown 0.9108, indicating the 91.08% of the variability in the

response could be explained by the model and about 9% of the total variations were not explained by the model. The prediction R^2 of 0.7473 is in reasonable agreement with the Adjusted R^2 of 0.8638, because the difference is less than 0.2. In this model the adequate precision is 20.133 (more than 4) which indicate and adequate signal. This model can be used to navigate the design plan. The model in terms of actual variables can be used to make predictions about the response for given level of each factors. The level should be specifies in the original units for each factor. The equation for 28 days of compressive strength in terms of actual variables shows in Eqn [4]:

28 days of compressive strength [4]

= 146.64748 – (3.09460 x *Crumb rubber*) + (1.15787 x *Nano silica*) – (0.84752 *x Fly Ash*) – (239.52037 x *w/c*) + (0.085133 x *Crumb rubber* x *Nano silica*) + (0.010717 x *Crumb Rubber* x *Fly Ash*) +6.25944 x *Crumb rubber* x *w/c*) + (0.10619 x *Nano silica* x *w/c*) – (16.74333 x *Nano Silica x w/c*) + (0.89095 x *Fly Ash* x *w/c*)



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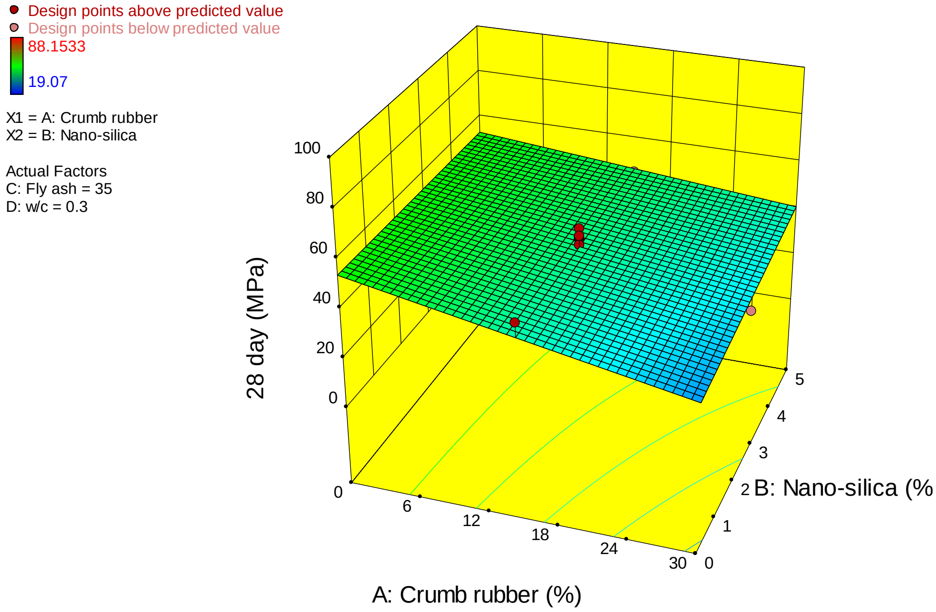

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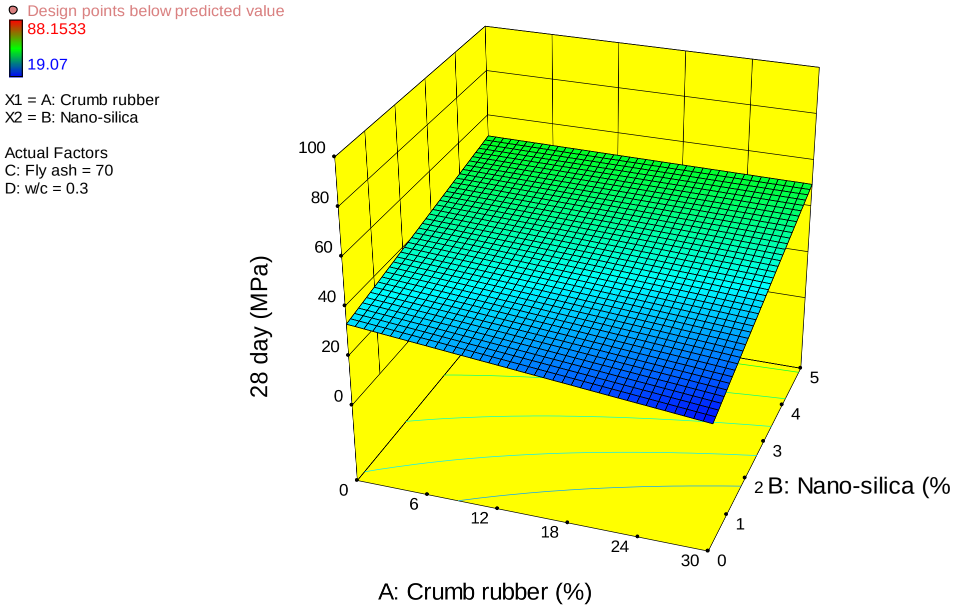


(c)

Figure 4.2: Response surface curve (3D) for 28 days of compressive strength showing the percentage of crumb rubber and nano silica with 0.3 of water per cement ratio (a) Fly ash 0% (b) Fly ash 35% (c) Fly Ash 70%

From the response surface curve (3D) for 28 days in figure 4.2 shows that the normal concrete has higher compressive strength. In overall design mix, it shows that as increase the amount of fly ash, the compressive strength increase. This is due to the assistance of pozzolanic reaction of fly ash. Other than that, as the amount of nano silica increase, the compressive strength also will be increase. This is because nano silica act as filler that will produce C-S-H gel that will enhance the microstructure of the concrete and it is also act as cementitious properties in the design mix.

From the graph also it can be shown that as the amount of crumb rubber, fly ash and nano silica increase, the compressive strength also increase compare to the graph when crumb rubber and fly ash increase, but nano silica is 0%, the compressive strength is a little bit lower. This is because the introduction of nano will also act as filler that fill up the pore between the crumb rubbers and cement matrix.

For 28 days compressive strength, the lowest compressive strength that can be seen from figure 4.2 is when the percentage of fly ash is 70%, crumb rubber 30% and nano silica is 0%. As mention before in 14 days, this design have the highest percentage of crumb rubber which is 30% but have 0% of nano silica. This indicate that the compressive strength will reduces, as highest amount of crumb rubber, and does not have any nano silica that can act as filler between cement matrix and crumb rubber. Even though this design mix have higher amount of fly ash, but fly ash only replace the amount of cement and act as a binder but not as filler that can decrease the ITZ between the crumb rubber and cement matrix.

4.2 PULL-OUT TEST RESULT

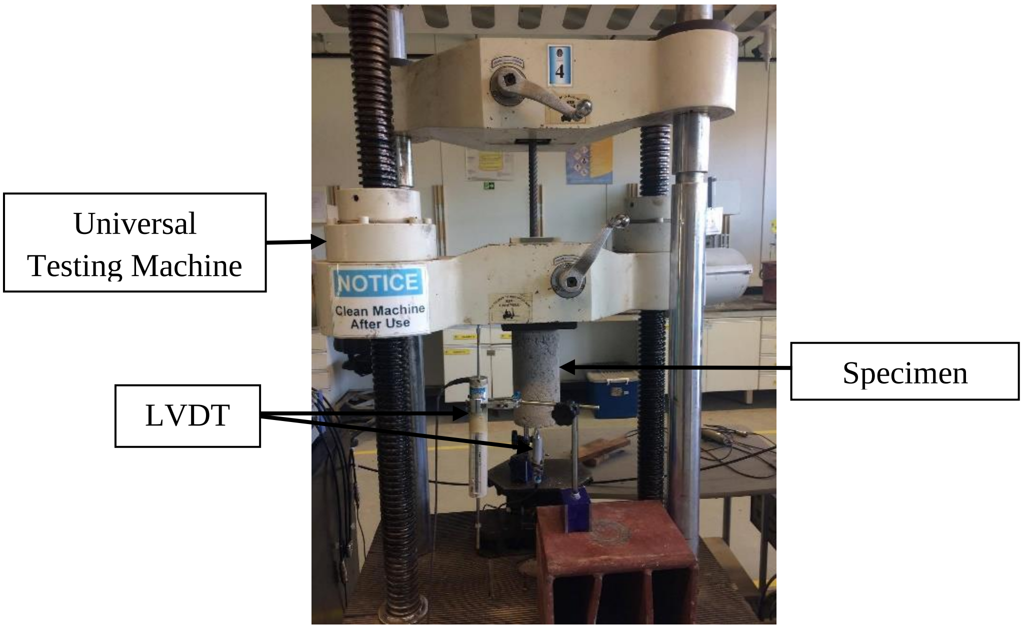


Figure 4.3: Pull-Out Test

From the RSM, the statistical model was verified to get the optimize design mix for every grade of concrete that contain crumb rubber, nano silica, fly ash and water per cement ratio. Thus, there is five optimum design mix that will be used in pull-out test. Figure 4.3 showed the pull-out test preparation. The LVDT used to measure the slip of the reinforcement bar. The grade of concrete is Grade 20, Grade 25, Grade 30, Grade 40 and Grade 50 as shown in Table 4.4. Table 4.5 shows the result of bonding strength, maximum loading applied to pull the steel rebar from the concrete and slip with respect to the compressive strength.

Table 4.4: Design mix for pull-out test

Design Mix	Crumb Rubber (%)	Nano Silica (%)	Fly Ash (%)	Water /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

Table 4.5 Result of bonding strength

Design Mix	Compressive Strength (N/mm²)	Max load applied (kN)	Bonding Strength (N/mm²)	Slip (mm)
M20	20	28.95	9	3.64
M25	25	31.41	9.76	4.75
M30	30	43.81	13.76	4.27
M40	40	49.86	15.50	4.81
M50	50	45.53	14.15	12.89

As can see from table 4.4, the percentage of crumb for all design mix is 30%, fly ash is about 70%, water per cement ratio is 0.35 and amount superplasticizer until the mixtures is workable. The bonding strength result get from the maximum load applied by the equation of [2]. The slip is at the maximum load applied before it failed. The result shows the increasing of bonding strength with increasing of compressive strength but only until 3.71% of nano silica. This is because nano silica produce the C-S-H gel to build up the strength by filling the voids of the microstructure of the concrete. It is also shows that the increasing amount of nano silica, there were proper bonding between rubbercrete and reinforcement bar. However, at 5% of nano silica, the result of bonding strength shows decreasing compare to at 3.71% of nano silica. Nili and Ehsani (2015) stated that this might due to the agglomeration of nano silica in the cement matrix.

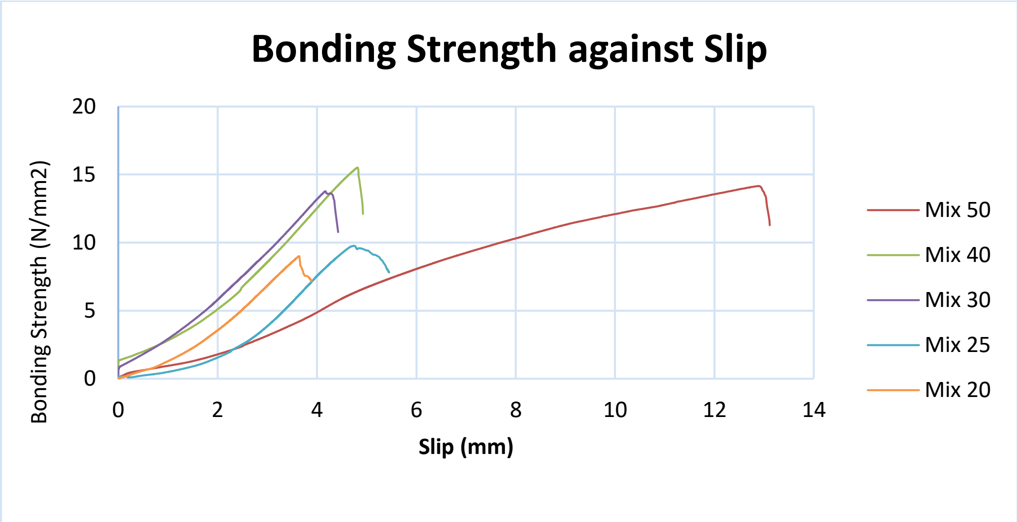


Figure 4.4: Graph of bonding strength against Slip

Figure 4.4 shows the graph of the bonding strength versus slip. The design mix present the compressive strength of the concrete. From the graph, Mix 20, Mix 25, Mix 30 and Mix 40 shows that as the bonding strength increase the slip also increase insignificantly. Even though for mix 50, the bonding strength decreasing but the slip shows the highest and drastically increase among the others. This result shows the behaviour of the crumb rubber which is ductile material. This show the rubbercrete can absorb the energy which is known as ductile material. As the amount of nano silica increase, the material still maintain its ductility to absorb the energy. The result of absorb energy, the slip also increase due to its take long time until elongation before it failed. This usage of concrete in the structures required high impact of resistance and more energy absorption such as partitions in the building and road barriers.

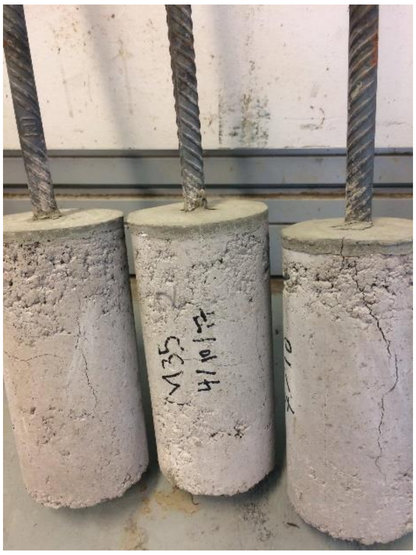
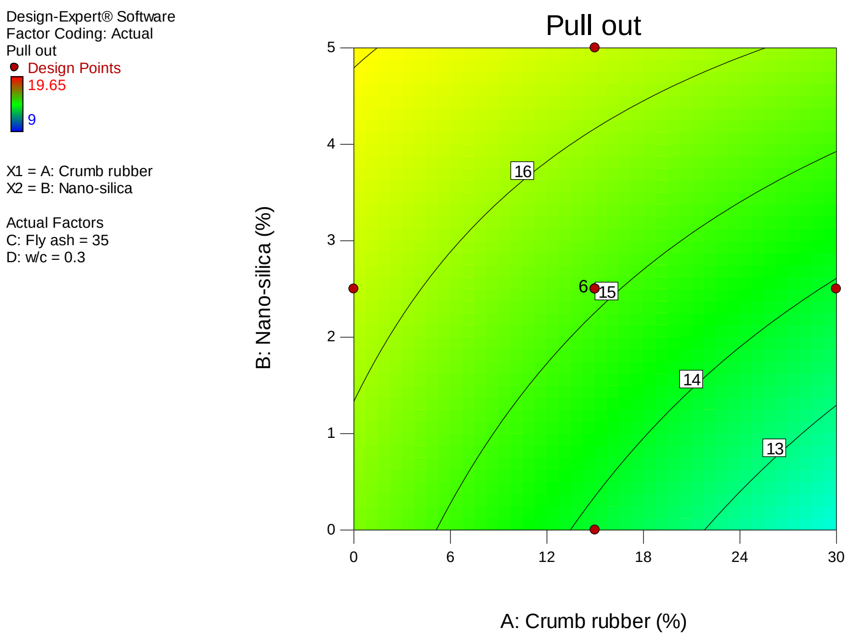


Figure 4.5: Sample after pull-out test

Figure 4.5 showed the splitting bond failure along the reinforcement bar. Splitting failure occurred when the cracks flowing from the contact area of the reinforcement bar

4.2.1 Response Surface Methodology (RSM) of Pull-Out Test

The result of five mixtures of grade 20, 25, 30, 40 and 50 then will be analysed using the RSM using Design Expert Software. Here, it showed the results of pull-out test of other grade with different percentage of crumb rubber, nano silica, fly ash and water per cement ratio. The figure showed two type of view which are from top view and 3D view as shown in figure 4.6 and figure 4.7.



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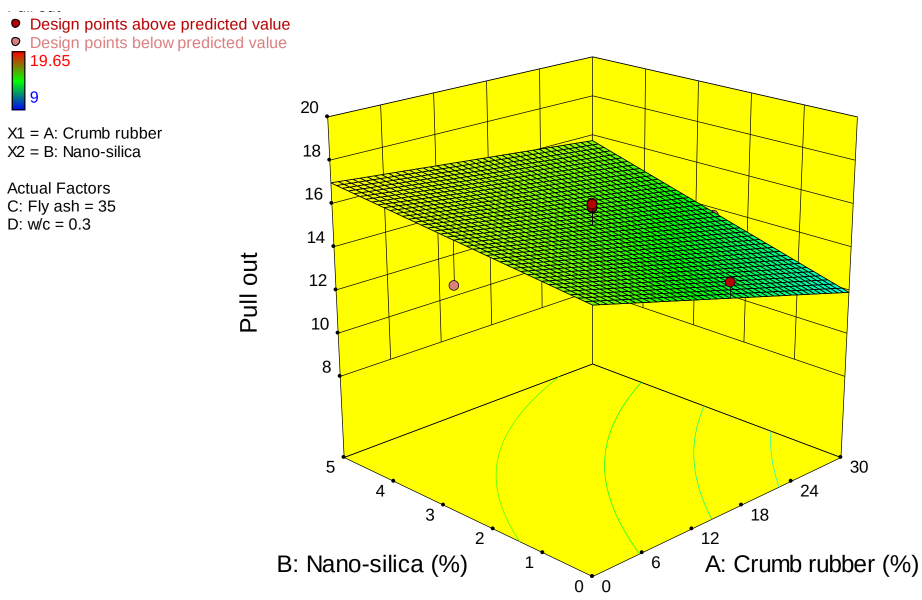
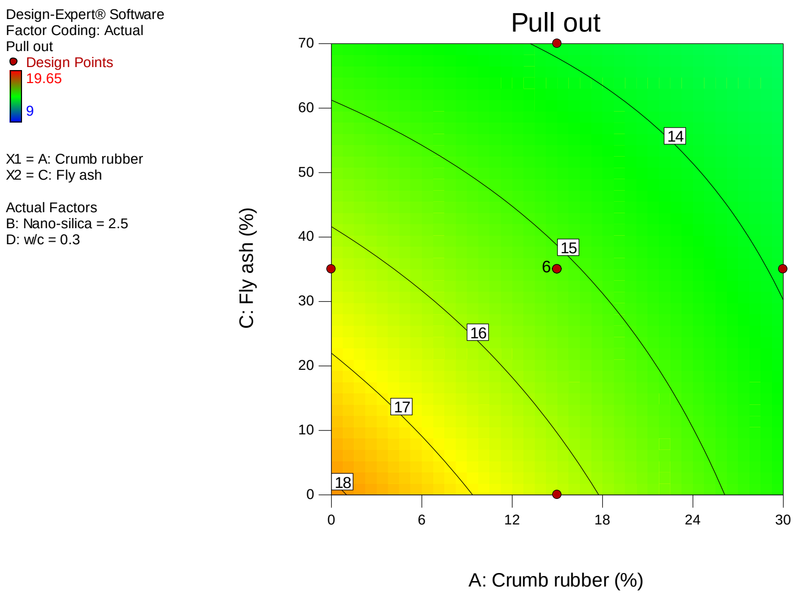
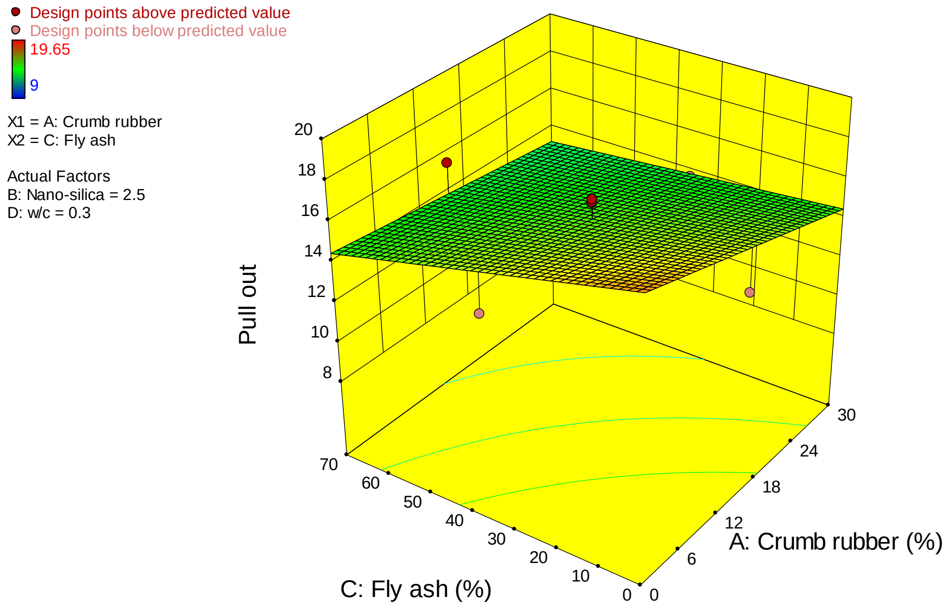


(b)

Figure 4.6: Response surface curve (3D) for Pull-Out Test showing the percentage of crumb rubber and nano silica with 0.3 of water per cement ratio and 35% of fly ash (a) from top view (b) 3D view



(a)



(b)

Figure 4.7: Response surface curve (3D) for Pull-Out Test showing the percentage of crumb rubber and fly ash with 0.3 of water per cement ratio and 2.5% of nano silica (a) from top view (b) 3D view

Figure 4.6 showed 35% of fly ash, 0.3 of water per cement ratio with different percentage of crumb rubber and nano silica. The highest bonding strength can be seen when the amount of crumb rubber is 0% while nano silica at his highest which is 5%. The lowest bonding strength can be seen when the amount of crumb rubber is 30% and 0% of nano silica. This is because there were no proper interaction or bonding between the rubbercrete and reinforcement bar. This is because as the amount of crumb rubber is higher, it increase the ITZ between the crumb rubber and cement matrix while nano silica will help in densifying the microstructure of the rubbercrete.

In figure 4.7 showed the result of bonding strength with 2.5% of nano silica, 0.3 water per cement ratio with different percentage of crumb rubber and fly ash. The highest bonding strength can be seen from RSM is when the amount of crumb rubber and fly ash is 0%. This is because concrete consists of nano silica that help in improving the strength of the concrete. The lowest bonding strength can be seen when crumb rubber is 30% while fly ash is 70%.This is due to the presence of highest percentage of crumb rubber that repels the water but only 2.5% of nano silica which is not enough in improving the bonding strength of concrete.

Thus, in overall design mix for bonding strength, it shows that the nano silica help in proper interaction between the rubbercrete and the reinforcement. Nano silica produce C-S-H gel that will fill the voids between the crumb rubber and cement matrix. But as the nano silica achieve 5% as shown in table 4.5 the bonding strength decreasing due to the agglomeration of the nano particles in the concrete microstructure.

CHAPTER 5

CONCLUSION

The introducing of rubbercrete is the good idea as it can solve the problem of the abundance of waste tire to be disposed and lack of natural fine aggregate. Rubbercrete showed ductile behavior compare to the normal concrete which is known as brittle material. Ductile behavior showed when the material have good capacity in absorbing the energy and resisting the repeated impact loading. However, as the amount of crumb rubber increase the strength of the concrete decrease due to the attribute of the crumb rubber which have non-polar layer that will repel the water and it cause the increasing of the voids. Here, the introducing of nano silica begin to enhance the strength of the rubbercrete by filling the voids between the crumb rubber and cement matrix by produce the C-S-H gel. Therefore, to overcome these issue, this research to study about the bonding strength of rubbercrete and reinforcement bar.

From the results obtained, it can be concluded that nano silica can increase the compressive strength significantly. Nano silica also acts as filler that fills the voids in the rubbercrete that cause the rubbercrete become more compactly dense and homogeneous, hence increasing its ability in absorbing the impact of the resistance. Other amount of materials such as fly ash, water per cement ratio and superplasticizer also governed the strength of the rubbrcrete. For bonding strength, the presence of nano silica also help in proper interaction between rubbercrete and reinforcement bar. However, as nano silica achieve 5%, the bond strength showed decrease. This is due to the agglomeration of nano particles and limitation amount of nano silica in the concrete microstructure. This application of rubbercrete which have good capacity in absorb the energy can be used in the structures that required high impact of resistance and more energy absorption such as partitions in the building and road barriers.

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