Pore Structures and Abrasion of Concrete Containing Crumb Rubber from Scrap Tyre as a Partial Replacement to Fine Aggregate

by

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18815

Dissertation submitted in partial fulfilment of the
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CERTIFICATION OF APPROVAL

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Approved by,

……………………………………………

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TRONOH, PERAK

SEPTEMBER 2017

CERTIFICATION OF ORIGINALITY

I, Nyanambkai A/P Perumal, therefore announce that this dissertation submission is my authentic work to the excellent of my understanding except substances that I have acknowledged and designated in the reference. Any dedication devoted by the research colleagues, for whom I have labored collectively during my final year challenge at the University of Technology PETRONAS is, completely identified.

I additionally announce that the one's knowledgeable help substances for this dissertation is the result of my very own work, but of the degree that supports from others inside the undertaking idea and thought absolutely acknowledged as well.

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NYANAMBKAI A/P PERUMAL

ABSTRACT

Crumb rubber concrete (CRC) displays various advantages contrasted with conventional concrete, for example, low density, higher ductility, enhanced plastic limit, higher durability, higher impact resistivity, low thermal conductivity, better sound absorption and better electrical resistivity. However, the primary disadvantages of CRC which prevents its utilization in construction field is the low compressive strength. So, to enhance the properties of the CRC, the pozzolonic material such fly ash and nanosilica was added in the CRC mixture. Using Response Surface Methodology (RSM), thirty trial mixtures with three levels of crumb rubber (0%, 15%, 30%) replacement by volume to fine aggregate, three levels of nano silica (0%, 2.5%, 5%) addition by weight of cementitious material, three levels of fly ash (0%, 35%, 70%) addition by weight and three level of water/cement ratio (0.25,0.30,0.35) were prepared and tested for compressive strength of CRC after curing of 14 days and 28 days to find the optimum mix design. The compressive strength result was used in Analysis of Variance (ANOVA) process in RSM to develop six mixtures that can achieve desirable strength of M20, M25, M30, M40, M50 and M60.These mixture developed with two levels of crumb rubber (10%,30%) replacement by volume to fine aggregates, four levels of nanosilica (0%,1%,2%,4% ,5%) addition by weight, two levels of fly ash (30%,70%) addition by weight and two levels of water/cement ratio (0.25,0.35) to study the effect of these variables on the hardened properties CRC. The pore structure and abrasion of CRC were tested and analyzed through Cantabro abrasion loss test, field emission scanning electron microscope (FESEM) test and mercury intrusion porosimetry (MIP) test. The findings show that CRC abrasion resistance improved significantly, have more refined microstructure and porosity volume decreases with increment in nanosilica addition along with low content of crumb rubber, fly ash and water/cement ratio. Because nanosilica can fill in the pores, increases pozzolonic reaction and reduces the Interfacial Transition Zone (ITZ) thickness between the cement paste and crumb rubber. Hence, it improves the strength, abrasion resistance of CRC and develop more refined microstructure of CRC as it reduces the porosity. It was found that mixture M60 which has 5% nanosilica, 10% crumb,30% fly ash and 0.25 water/cement ratio produce most desirable result.

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Abbreviation and Nomenclatures

ASTM	American Society for Testing and Materials
CRC	Crumb Rubber conrete
ITZ	Interfacial Transition Zone
FESEM	Field Emission Scanning Electron Microscope
MIP	Mercury Intrusion Porosimetry
OPC	Ordinary Portland Cement
W/C	Water/cement ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Generally, countries around the world produces rubber at different rate. Each year about 200 000 tons of rubber is produced by Malaysia (A. Mohammad Mustafa al bakri, S.A. Syed Nuzul Fadli, M.D. Abu bakar and K.W leong).According to Monthly Rubber Statistics Malaysia, natural rubber production shows an increase of 15.1% as it increase from 43,962 tonnes in May 2017 to 50,614 tonnes in June 2017.It also shows increment of 7.3% when compared to June 2016 that had produce 47188 tonnes of natural rubber. The number of rubber production rise along the increase in vehicle production. As stated in reports from the largest associations of tyre and rubber product producers, the annual global production of tyres is about 1.4 billion units, which corresponds to an approximated 17 million tonnes of used tyres every year. (RMA, 2009; JATMA, 2010; ETRMA, 2011; WBCSD, 2010). India, China, Japan and USA produce significant amount of waste tyre which is about 88% of discarded tyres in worldwide (JATMA, 2010). More than 100 000 tonnes of scrap tyres are produced in Taiwan each year (Yung et al., 2013). Accumulation of scrap tyres was rising at the rate of 2% in Australia and it was predicted that by the year of 2010 more than 20 million scrap tyres were disposed in landfill (Mohammadi et al., 2014) Approximately, almost 1000 million tyres end their service life and about more than 50% are disposed in landfills without any treatment. The quantity would attain to 1200 million tyres yearly and there would be 5000 million tyres to be discarded on an everyday basis including the stockpiled tyres by the year of 2030 (Azevedo, F., Pacheco-Torgal, F., Jesus, C., de Aguiar, J. B., & Camoes, A. F., 2012).

Basically, old tyres that cannot be further used as tyre or has any deformity which cause it to be worthless on automobile are discarded as scrap tyres. Over the years, the disposal of scrap tyres that are non-biodegradable are causing severe problems to health and environment and becoming major concern worldwide. In Peninsular Malaysia, there are no facilities specifically arranged for scrap tyres disposal which leads to illegal disposal of scrap tyre such as open burning, landfills and illegal dumping and stockpiling (National Solid Waste Management Department, Ministry of Housing and Local Government Malaysia, 2011).

The exercise of disposal through burning has proved to create extreme health risks and environmental pollutants. Disposal with the aid of manner of landfilling has ended up hard due to the depletion of the available sites and due to sanitary infections caused by insects and rodents (Garrick, 2001; Benazzouk et al., 2007; Onuaguluchi and Panesar,2014; Su et al., 2014; Thomas et al., 2015a, b). Even though, the very best and most inexpensive approach of scrap tyre disposal is tyre burning, it turned into the cause of important hearth risks (Gosoğlu,M and Guneyisi,E 2011; Wang et al., 2013). As quickly as ignited, it's very difficult to extinguish due to the fact tyres have 75% free space which can save lot of oxygen and it pollutes the air via freeing massive amount of carbon dioxide, toxic gases (Srinivas, K., S. Reddemma, and N. P. N. Murthy,2015). According to United States of America Environmental protection agency (1993),7 million scrap tyres caught on fire in Virginia and it lasted for approximately nine months which polluted supply of water nearby in 1983. Furthermore, according to Eldin and Senouci (1994), soil and water pollution additionally happens whilst the residue powder left after burning pollutes the soil and the oil that became generated from the melting of tyres pollute both soil and water. The tyres preserve water for a extended period due to its unique shape and impermeable nature presenting a perfect breeding habitat for mosquitoes and pests (Eldin, N.N and Senouci, A.B 1994; Mohammed et al., 2012; Thomas et al., 2015, 2016).

According Toutanji, H. A. (1996), rubber taken from scrap tyres seem as the precious waste fabric that might gain the construction area. Commonly, a tyre consists of rubber, which makes up approximately 70–80% of the tyre mass and it also encompasses metal belts and textile overlays, which offer the tyre its ultimate shape and utilitarian homes (Pehlken, A., and Müller,D.H., 2009; Ganjian et al., 2009).The rubber received from tyre can be utilized in an expansion of civil and non-civil engineering programs including in geotechnical works, roadwork, as fuel for cement kilns, incineration for manufacturing of current, a feedstock for carbon black production, reefs in marine environments, and as a mixture in cement-based products. However, hundreds of thousands of tyres are being buried, thrown away or burnt all around the international (Segre and Joekes, 2000; Oikonomou, N., and Mavridou, S., 2009). Lafarge Malaysian Cement used scrap tyre as source of fuel in cement klins however that bring about releasing of carbon dioxide gas, excessive cost and has no recuperation of material (National Solid Waste Management Department, Ministry of Housing and Local Government Malaysia, 2011). Hence, the chances of recycling scrap tyres which can be economical and environmentally pleasant turned into narrow.

However, one of the most sensible and progressive technique to manage scrap tyre trouble is by recycling it in concrete manufacturing in the form of crumb rubber. As reported by Cement Association of Canada, concrete produced globally is about five billion cubic yards and it is getting used two times as plenty in construction enterprise globally than the different material used for building. Therefore, construction sustainability may be supported by generating rubberized concrete and it may make a contribution to the improvement of the civil engineering vicinity using commercial waste, restrict the intake of natural property and produce a green material (Li et al., 2004a). The carbon dioxide emission also may be reduced with the aid of stopping the tyre fires. In line with Mohammed, B. S., Anwar Hossain, K. M., Eng Swee, J. T., Wong, G., & Abdullahi, M. (2012), elimination of fibers and metal inside scrap tires and slicing and granulating can produce crumb rubber. The usage of the crumb rubber as replacement of some portion of aggregates in cement-based substance may be cost-powerful and environmentally friendly (Pappu et al., 2007; Mohammed et al., 2012; Thomas et al., 2015, 2016; Thomas and Gupta, 2015a, 2015b). Moreover, utilization of crumb rubber in construction field can also make contributions in the preservation of natural sources and preserve ecological balance (Mohammed,2010).

Consequently, many studies has been carried out via the usage of crumb rubber as a partial substitute to fine aggregate to determine its properties. The incorporation of rubber as aggregate in concrete changed into first recommended by Eldin and Senouci (1993). Study was carried out using concrete samples with tyre chips and crumb rubber debris. Concrete produced the usage of crumb rubber maximum commonly referred to as rubberized concrete or crumb rubber concrete (CRC).Previous studies indicates that CRC has many advantages compared to conventional concrete which includes improved toughness (Mohammed et al., 2011), better resistance (Ganjian, E., Khorami, M., Maghsoudi, A.A., 2009), advanced resistance to chloride penetration (Bravo and Brito, 2012) ,reduced thermal conductivity,(Mohammed et al., 2012) and higher noise reduction component (Li, G., Garrick, G., Eggers, J., Abadie, C., Stubblefield, M.A., Pang, S.-S.,2004b).

However, the primary flaw of the crumb rubber concrete is reduction in compressive strength as using crumb rubber as partial substitute of fine aggregate increases (Mohammed at al., 2012). Rashad, A. M. (2014), states that vulnerable compressive strength of crumb rubber is due it feeble bonding among cement matrix and crumb rubber. In line with the research carried out by Vadivel and Thenmozhi (2012), the strength of concrete reduces when the proportion of rubber used as an alternative increase. This is due to crumb rubber hydrophobic nature which repels water throughout mixing and traps air in the surface. The hydrophobic nature of crumb rubber is because of the addition of zinc stearate throughout production of tyres (Youssf et al., 2014). According to Shu and Huang (2014), reduction in strength of rubberized concrete is due to the difference in stiffness among cement paste and rubber particle. Brand (2015), additionally states that hydrophobic nature of rubber causes the deficient bonding among cement matrix and rubber which result in a crack without problems while there's external stress. Furthermore, a non-polar layer of crumb rubber causes the increase in thickness of interfacial transition region(ITZ) between the cement paste and crumb rubber as it repels water and traps air which sooner or later results in negative bond formation (Onuaguluchi and Panesar, 2014; Mohammed et al., 2012). Subsequently, microcrack occurs without difficulty while strain is carried out on the vulnerable bond and bring about premature failure of concrete (Thomas et al., 2016; Mohammed et al., 2012; Li et al., 2016; Sadek and El-Attar, 2015).

Hence, numerous research was conducted to overcome the shortcomings and to widens its application in construction discipline. Previous researches discovered that nano silica has the functionality to enhance compressive strength of rubberized concrete. According to Senff, L., Hotza, D., Lucas, S., Ferreira, V. M., & Labrincha, J. A. (2012), nano silica provide excellent chemical reactivity due to its nano-sized particle that associated with more surface area to volume ratio. Nano silica has pozzolonic properties and filler effect which improves the durability and compressive electricity of crumb rubber concrete (Abd.El. Aleem et al., 2014). Therefore, the usage of nano silica that can act as filler, it could fill the void of C-S-H bond by reacting with calcium hydroxide (Nili and Ehsani, 2015; Mukharjee and Barai, 2014a). This in the end enhance its compressive strength by means of upgrading the pore structures of crumb rubber concrete and reducing the thickness of interfacial transition area (Mukharjee and Barai, 2014c).

Apart from nanosilica addition, fly ash was also can be added in crumb rubber concrete to improve its properties. One of the common use of fly ash in cement industry is to decrease heat of hydration, to lessen the usage of water and for strength gain in long term (Yilmaz & Degirmenci, 2009). According to Guneyisi (2010), usage of crumb rubber in concrete delays the setting time and increase its viscosity. Hence, fly was utilized to minimize the adverse effect of the crumb rubber and to reduce the viscosity of the concrete. Chemically, fly ash is also a pozzolanic material which is responsible for to the involvement of SiO_2 and $Al2O_3$ that reacts with calcium hydroxide (CaOH) during cement hydration process, to form additional calcium silicate hydrate (CSH) gel and calcium aluminate hydrate (CAH) which can form denser matrix leading to higher strength and higher durability (Malvar & Lenke ,2006; Tahir & Sabir,2005).

Besides that, based on the previous researches, it was found that study on rubber aggregate and the impact of different level of water/cement ratio was not done thoroughly. Hence, detailed studies are needed to assess various properties of rubberized concrete with varied water/cement ratio. (Gupta, Chaudhary, & Sharma,2014). However, according to Albano, Camacho, Hernández, Bravo, Guevara, & Paricaguan (2013), the research conducted with water/cement ratios of 0.45 and

0.60, shows that better mechanical properties was achieved for lower w/c ratio for concrete containing rubber. Hence, this study was conducted to determine the pore structures and abrasion of concrete containing crumb rubber from scrap tyre as partial replacement of fine aggregate. The pore structures and abrasion of CRC were evaluated through laboratory test such as Cantabro abrasion loss test, field emission scanning electron microscope (FESEM) test and mercury intrusion porosimetry (MIP) test and to determine its abrasion resistance, to study the microstructure and to evaluate its porosity. Moreover, the research was conducted by using different percentage of nanosilica, crumb rubber, fly ash and varied water/cement (w/c) ratio in concrete mixture to analyze the effect of these variables in CRC and to determine the optimum mix proportions that produce CRC with better pore structures and abrasion.

1.2 Problem Statement

Innovative approach was taken to recycle the disposed scrap tyre in landfills to lessen problems associated with environment, human health and aesthetic vaule by way of incorporating scrap tyre in concrete manufacturing in the form of crumb rubber as partial substitute of fine aggregate or sand to produce the crumb rubber concrete (CRC) or in other term its referred as rubbercrete. CRC has many advantage, but its main downside is it has decreased compressive strength in comparison to traditional concrete. Several methods have been developed to reduce the negative effect of crumb rubber in concrete. For example, CR has been treated with NaOH, pozzolanic materials such as silica fume were also used. However, the method was proven not effective. Hence, this research, utilizing nanosilica to mitigate the loss due to properties of nanosilica. Besides, the world is now focusing on reducing carbon dioxide emission for environmental sustainability. About 10% of carbon dioxide is emitted to the environment by the cement industry. Hence, construction industry is trying to shift from conventional concrete to green concrete by reducing the usage of cement in concrete. This can be achieved by using the supplementary cementitious material such as fly ash as partial replacement to cement in concrete. However, the disadvantage of fly ash is that the strength of the concrete at early stage is low. Thus, addition of nanosilica will strengthen the bond between the cement paste and crumb rubber and will help to enhance the strength development in concrete by igniting pozzolanic reaction of fly ash at early stage.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The goal of the research is as shown below:

I. To determine the optimized crumb rubber concrete mixture using response surface methodology.

II. To investigate the effect of crumb rubber, nanosilica, fly ash and w/c ratio on the hardened properties of crumb rubber concrete.

III. To investigate the effect of crumb rubber, nano silica, fly ash and water/cement ratio on the pore structures and abrasion of crumb rubber concrete.

1.3.2 Scope of the Study

This study is mainly focused on the scope shown below:

1. This study attempts to use the pozzolan material such as nanosilica and fly ash as partial replacement of cement and crumb rubber as partial replacement of fine aggregate in CRC mixture.

2. The pore structures and abrasion of the crumb rubber concrete in this study were evaluated by Cantabro abrasion loss test, Mercury Intrusion Porosimetry (MIP) Test and Field Emission Scanning Electron (FESEM).

3. This study obtained compressive strength of CRC for thirty trial mixtures with three levels of crumb rubber (0%, 15%, 30%) replacement by volume to fine aggregate, three levels of nano silica (0%, 2.5%, 5%) addition by weight of cementitious material, three levels of fly ash (0%, 35%, 70%) addition by weight and three level of water/cement ratio (0.25,0.30,0.35) and result obtained incorporated into Response Surface Methodology to develop six mixture on grade basis (M20, M25, M30, M40, M50, M60) by using different percentage of crumb rubber, nanosilica,fly ash and w/c ratio.

1.4 Relevancy and feasibility

The project may be taken into consideration as relevant and possible as it introduces usage of crumb rubber in concrete manufacturing. Since, crumb rubber is obtained by way of granulating the scrap tyres, it allows to reduce the disposal of unused tyres because it could be recycled to produce rubbercrete. accordingly, environmental troubles and health issue related to scrap tyres can be reduced progressively. This is due to the fact in step with the Cement Association of Canada, the worldwide production of concrete is about 5 billion cubic yards and concrete is one the construction material which being used two times as much around the world. Similarly, incorporating crumb rubber in concrete manufacturing affords a cost-effective solution.

Moreover, this research is applicable due to the attributes exhibited by rubbercrete based on the various preceding research conducted by means of researchers around the world. CRC exhibits many advantages as compared to traditional concrete except it has low compressive strength. Hence, this research is important to understand the properties of CRC and to find a solution which could triumph over its the weakness. Pozzolonic material inclusive of fly ash and nanosilica become introduce in CRC mix design to improve its compressive strength whilst taking sustainable method to lessen the carbon dioxide emission and to lessen utilization of natural resource which is the sand. Therefore, an effective solution can be capable of provide pathway for the utilization of rubbercrete in construction industry in the future.

1.5 Outline of Dissertation

This dissertation consist of five chapters as follows:

Chapter 1 is the background study on the crumb rubber concrete. This chapter explains about crumb rubber concrete, the objective and the scope of this study.

Chapter 2 is the literature review of crumb rubber concrete. This chapter discusses the advantages, disadvantages of CRC based on review of previous researches and effect of adding pozzolan materials such nanosilica and fly ash in CRC.

Chapter 3 explain the methodology of the findings in this study. Furthermore, method used to obtain the desirable mix design were also discussed. Method of preparation and testing also been explained in this chapter.

Chapter 4 show the experimental result and analysis of for the Cantabro abrasion loss, MIP and FESEM test. The effect of adding different percentage of nanosilica, fly ash, crumb rubber and w/c ratio were also discussed.

Chapter 5 presents the conclusion of this study and few recommendations for further research work.

CHAPTER 2
LITERATURE REVIEW

2.1 Review of literature on studies conducted on rubbercrete properties

Basically, Eldin and Senouci (1993), were the primary researchers who conducted a study on aggregates produced from waste tyres were first conducted by replacing the coarse aggregates (6 mm, 19 mm, 25 mm and 38 mm) and fine aggregates (1 mm tyre crumb). The findings show that the concrete had reduce compressive strength workability, and tensile strength and higher tenacity. The reduction in mechanical properties was due to the loss of adhesion between cement paste and rubber particle surface. Furthermore, when the size of aggregate produced from waste tyre increases, the loss in strength also increases. Hence, to produce crumb rubber concrete with improve strength, researches conducted several studies to enhance the bond between crumb rubber and cement matrix.

Rostami et al. (1993), treated the exterior of the CR and outcomes displayed that external treatment using latex admixture cleaner, carbon tetrachloride solvent and water increased the compressive strength by 57%, 42% and 16%; correspondingly compared to reference mix. Then, Li et al. (1998), conducted research by pre-coating the crumb rubber with METHOCEL cellulose ether solution and cement paste. The studies show that the strength of the concrete upgraded to some extent with cement paste as pre-coat while cellulose ether solution further lower its strength. Segre and Joekes (2000), informed that bond between CR and cement matrix bettered when CR exterior was treated with NaOH aqueous solution. Guneyisi et al. (2004), also examined the quality of rubber concrete by adding silica fumes. Crumb rubber and tyre chips were used to substitute fine and coarse aggregate correspondingly from 2.5% to 50% by volume. Silica fume was used to substitute cement from 5% to 20%

and w/c ratios of 0.6 and 0.4 were implemented. The rubberized concrete was workable to a certain limit with and without silica fume and usage of silica fume lessen the degree of loss in strength. Using 15% rubber content and 0.4 w/c ratio, concrete with 40MPa compressive strength was achieved.

Besides, Albano et al. (2005), also determined the result of partially replacing fine aggregate with CR-pretreated with sodium hydroxide and silane A-174 coupling agent by weight on mechanical properties of rubberized concrete. The result exhibit that neither of the method able to upgrade mechanical strength of the rubberized concrete effectively. Mehmet and Erhan (2007), inspected rubberized concretes to determine the development of strength and chloride penetration. The result showed that with increment in rubber content addition, the unit weight of rubberized concrete declined up to 18%. The strength progress order for normal and rubberized concrete between 3 and 7 days were moderately high, slower during period between 7 and 28 days, and fairly slower rate was observed between 28 and 90 days. As the percentage of rubber was increased, the compressive strength reduced steadily regardless of the w/c ratio and curing period. For increment in the rubber content, with and without silica fumes, there was an efficient rise in chloride penetration depth.

Gesoglu and Guneyisi (2007), used 10% silica fume as partial replacement of cement and the findings specified that silica fume boosted resistance of chloride penetration and the strength of the rubbercrete due to development of stronger bond between cement paste and crumb rubber. However, the control mix strength was higher than the rubbercrete. Apart from that, Ganjian et al. (2009), used two different form of rubber in concrete mix with different percentages of rubber aggregate (5%, 7.5%, 10%). The coarse aggregate was substituted by chipped rubber in the first set while in the second set, the scrap–tyre powder was used to substitute cement. Finding displays that by replacing 5% chipped rubber the compressive strength of the concrete was improved. Moreover, in comparison with ground rubber concretes, chipped rubber concretes showed an enhanced compressive strength.

On the other hand, Mavroulidou and Figueiredo (2010), used Coarse Rubber Aggregate (CRA) and Fine Rubber Aggregate (FRA) in their research and stated that for 40% rubber content, a significant loss in the compressive strength was observed. They also explain that, in the same percentage, coarse rubber aggregate has a better compressive strength than concrete containing fine rubber aggregate. Additionally, the results of split cylinder tensile strength after 28 days of curing, showed that a specimen with 10% rubber content of CRA and FRA decreased about 32.5% and 29.9% correspondingly. While, the flexural strength test, for 10% rubber content exhibited a decrease in flexural strength for both CRA and FRA.

According to Chou et al. (2010), finds that CR that treated with organic sulphur increase the strength of rubbercrete as it produces hydrophilic group on exterior of CR. Pelisser et al. (2011), reported that rubbercrete with addition of silica fume and CR treated with NaOH have improved strength compared to rubbercrete without silica fume. Miguel and Jorge (2012), discovered that when the percentage of rubber content and size replace increases, the water absorption also increases. Camille and George (2013) noticed for less than 25% replacements fine aggregate using of crumb rubber resulted in better compressive strength and about 8% reduction in density but shows massive reduction in strength when 25% of crumb rubber was used.

While, Onuaguluchi and Panesar (2014), examined that CR coated with limestone powder and inclusion of silica fume in cement rubbercrete mixture cause increment of strength about 29% in comparison with control mix. The increment in strength was due to the contact between silica fume and limestone powder which reinforce the bond between cement matrix and CR. Besides, Thomas and Gupta (2015), also studied influence of using three different size of CR in rubbercrete and explained that sulphate attack resistance and the strength were lower compared to reference mix. On recent note, Li et al. (2016), discovered that treating used tyre fiber with carboxylated styrene-butadiene rubber latex and silane coupling agent improve the cement matrix and CR bond and resulted in increment of flexural strength and compressive strength of the rubbercrete by 13% and 4% correspondingly compared to control mix.

2.2 Review of literature on nanosilica effect on rubbercrete properties

Nanotechnology is being incorporated in the research as it proven to display undoubted future in progression of nano materials and enables the researches to regulate the attributes of invention. Mukharjee and Barai (2014b), states that originality of nano silica in construction industry has been a resolution for material with high performance with feasible product cost. According to Abd.El.Aleem et al. (2014), research exhibit that nanosilica has large area to volume ratio enable it to act as filler for nano pores with cement matrix result in improved strength of concrete. Furthermore, nanosilica is an activator of pozzolanic activities which allow more production of C-S-H gel that enhance the microstructure of the concrete (Nili and Ehsani, 2015; Mukharjee and Barai, 2014a). Also, nanosilica decrease the permeability and capillary porosity of concrete as it has blockage (Du et al., 2014). Nanosilica helps to reduce the ITZ thickness between aggregates cement paste and aggregates and subsequently upgrade concrete strength (Mukharjee and Barai, 2014c).

2.3 Review of literature on fly ash effect on rubbercrete properties

Basically, fly ash is a byproduct of coal which commonly made by thermal power station in massive amount. Usage of fly ash in construction field has obtained more interest due to strong and sustainable opportunity for a various concrete application (Yilmaz, & Degirmenci, 2009; Crouch, Hewitt, & Byard, 2007; Naik, & Singh ;1991). Utilization of fly ash in cement industry is due to lesser water usage, lower heat of hydration and long-term strength gain to cement (Yilmaz, & Degirmenci, 2009). According to Bala, Sehgal and Saini (2014), density of concrete rise slightly when fly ash content as replacement of cement increases. In addition, increment in rubber and fly ash content lowers the compressive strength of the concrete significantly. According to Supit & Shaikh (2015), nanosilica in high volume fly ash concrete, responsible pozzolanic activities at early stage compared to Class F fly ash because it is a nano size particles and have large surface area to volume which allows to react rapidly with lime in hydration reaction that form C-S-H gel and close the nano voids in the cement matrix. Moreover, nanosilica have capability to reduce pore diameter and capillary pores of high volume fly ash concrete.

2.4 Review of literature on water/cement ratio effect on rubbercrete properties

Based on previous research, the compressive strength of rubbercrete made using different water/cement ratio, different proportion and size of particles indicate that the strength increases with curing time due to longer hydration period (Albano, Camacho, Hernández, Bravo, Guevara, & Paricaguan, 2013). The increment in strength were accelerate for the first 28 days and slows down with time due to low reaction between water and cement. Furthermore, it was determined that the ultrasonic pulse value for normal concrete was higher for w/c ratio of 0.45 as there is higher amount of cement reacting with water to produce bond that connect the aggregates which improve sound wave propagation (Albano et al., 2013).

However, for concrete containing rubber and w/c ratio 0f 0.60 shows reduction in density due to increment of voids that result in lower value of ultrasonic pulse. These areas are referred as dead zone as it increases the possibility of fracture instead of resistance. The study also shows that for 10% of rubber content in concrete contribute more negative impact compared to 5% because higher content of rubber and higher w/c ratio can produce more empty spaces in the concrete that eventually reduces the ultrasonic pulse velocity (Albano et al., 2013).

2.5 Review on literature on advantages and disadvantages rubbercrete

System of shredding and granulating old tyres after disposing all the steel and fiber within the tyre offer crumb rubber. To preserve natural resources and manage ecological balance, numerous application of crumb rubber is being implemented in construction field for sustainable development. Several researches had been carried out on the application of crumb rubber in concrete (Mohammed, Anwar Hossain, Eng Swee, Wong, & Abdullahi, 2012). Partial substitute to fine aggregate in Portland cement concrete using crumb rubber from scrap tyre produces rubberized concrete referred as crumb rubber concrete or rubbercrete which exhibits many benefits compared to the conventional concrete (Mohammed, Awang, Wong, & Nhavene,2016).

Advantages of crumb rubber concrete or rubbercrete based on the previous researches are decrease density (Demir, Yesilata, Turgut, Bulut, Isiker, 2015), better durability (Shu & Huang, 2014), better toughness(Mohammed, 2010), good impact resistance (Ganjian, Khorami, Maghsoudi,2009), better resistance to chloride penetration (Bravo & Brito, 2012),reduced thermal conductivity (Mohammed et al., 2012), improved noise reduction component (Li, Garrick, Eggers, Abadie, Stubblefield, Pang, 2004b) and advanced electrical resistivity (Onuaguluchi & Panesar,2014). It has also been recognized to have greater energy dissipation, durability and damping ratio (Youssf, El Gawady, Mills,Ma, 2014).

Aside from that, rubbercrete also have improved workability, better shock absorbance, higher resistance impact, low thermal conductivity, improved electrical resistivity and has more air content (Onuaguluchi & Panesar 2014; Shu & Huang 2013; Bravo & De Brito 2012; Mohammed et al., 2012; Mohammed & Azmi 2011; Mohammed et al., 2012; Ganjian et al., 2009; Li et al., 2004). Youssf et al. (2014), also said that rubbercrete possess better energy dissipation. due to numerous benefits of rubbercrete, Fatuhi, N.I., and Clark, N.A. (1996), advocated that rubbercrete can be implemented in a place in which damping of vibration is required along within railway stations and pad of foundation for rotating equipment, to be implemented wherein shock absorbance is needed and head of pile and bedding of pipe. Topcu and Avcular (1997a, b), also endorsed that usage of rubbercrete can be implemented in highway production as shock absorber.

Nonetheless, according to Youssf et al. (2014), rubbercrete has primary downside which is reduction in strength of flexural, tensile, splitting, compressive and young Modulus. Reduction in strength occurs whilst usage of crumb rubber as partial substitute of fine aggregate is higher. This is may be associated to the hydrophobic nature of crumb rubber because of utility of zinc stearate all through tyre production. The non-polar strata of crumb rubber traps air round it and repels water that ultimately purposes increment in thickness of ITZ among crumb rubber and cement matrix which cause the fragile bond (Onuaguluchi and Panesar, 2014; Mohammed et al., 2012).

2.6 Overall conclusion remark

Generally, numerous researches have been conducted to determine and to improve the properties of rubbercrete. However, most of the method was proven not effective enough to start utilizing it in the construction industry. Furthermore, since construction industry focusing on environmental sustainability byproduct such as fly ash which is a pozzolan material was used to diminish the cement usage in concrete production. Besides that, since crumb rubber in concrete increase the ITZ thickness that contribute to reduction of strength, nanosilica which is also a pozzolan material was introduced due to its properties to diminish the negative effect of crumb rubber and to ignite the pozzolanic reaction of fly ash at early stage. Even though, there are several researches on CRC or rubbercrete using nanosilica and fly ash, there is no research conducted using different w/c ratio along with nanosilica and fly ash in the crumb rubber concrete mixture. Therefore, with the aid of Response Surface Methodology (RSM), this research was attempted to investigate the pore structures and abrasion of crumb rubber concrete containing nanosilica and fly ash at different level of cement replacement, different level of crumb rubber replacement by volume to fine aggregate with different water/cement ratio.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter describes the mixture proportion of the crumb rubber concrete which has been utilized for this study. The preparation and procedure to do crumb rubber concrete specimen containing pozzolan materials are also described. The compressive strength test is to determine hardened properties of crumb rubber concrete. Meanwhile, Cantabro abrasion loss, mercury intrusion porosimetry (MIP) test and Field Emissions Scanning Electron Microscope (FESEM) is to determine the pore structure and abrasion of crumb rubber concrete. The methodology used had been schematically shown in Figure 3.1.

Table 3.1 The test, standards, sample dimension and number

Test	Standard	Dimension	Number of samples / mixture
Cube compressive strength	ASTM C39	100 mm x 100 mm x 100 mm	3
Field Emission Scanning Electron Microscope (FESEM)	-	20 mm x 20 mm x 5 mm.	1
Mercury Intrusion Porosimetry (MIP) Test	ASTM D4284	10 mm x 10 mm x 5 mm	1
Abrasion test	ASTM C1747	150 mm x 100 mm (cylinder concrete)	3

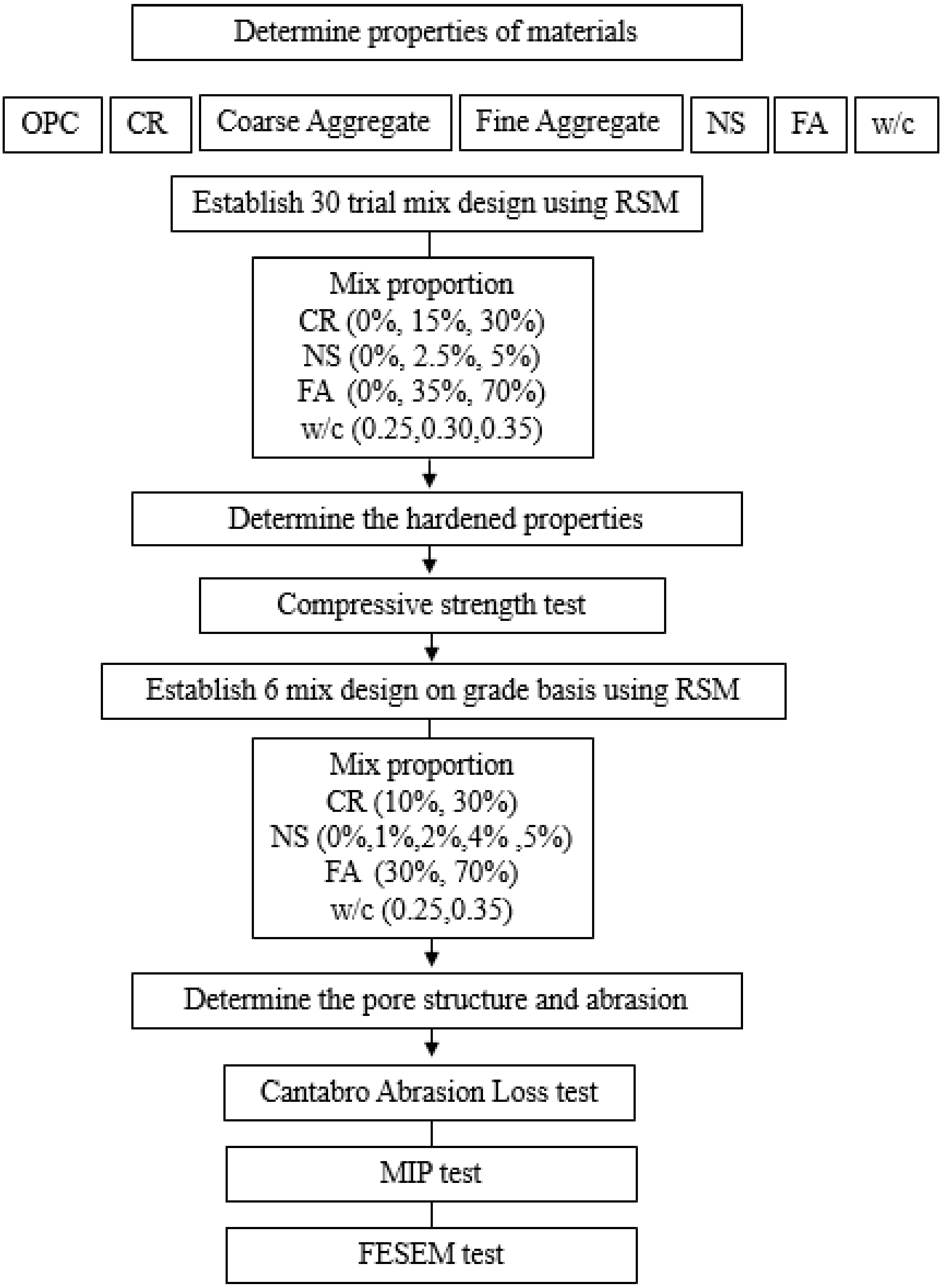

Figure 3.1 Schematic flow chart of the methodology of the study

3.2 Materials

3.2.1 Ordinary Portland Cement (OPC)

Type I Ordinary Portland Cement (OPC) was used to produce crumb rubber concrete in accordance to ASTM C 150-04. The specific gravity of OPC is 3.15.

3.2.2 Coarse Aggregate

Coarse aggregate with nominal size of 10mm was used in accordance to ASTM C 33-03. Sieve analysis was conducted in accordance to ASTM C 136 to obtain the grading curve of coarse aggregate as shown in Graph 1.

3.2.3 Fine Aggregate

Fine aggregate that was utilized in the production of crumb rubber concrete was river sand. The specific gravity of the sand is 2.6. Sieve analysis was conducted in accordance to ASTM C 136 to obtain the grading curve of fine aggregate as shown in Graph 1.

3.2.4 Crumb Rubber

Shredding scrap tyres and granulating it via primary and secondary granulation process after removing the steel wires from scrap tyres produces crumb rubber. Crumb rubber was used as partial substitute of fine aggregate in different percentage to produce crumb rubber concrete. Specific gravity of the crumb rubber is 0.95.

3.2.5 Pozzolan Materials

3.2.5.1 Nanosilica

The nanosilica is a material which is made of nano particles was incorporated in the production of crumb rubber concrete using different percentage. Nanosilica has loss of ignition of 6% and consist of silicon oxide (SiO_2) about 99 %Nanosilica acts as filler as it can fill the nano porosity between particles of C-S-H gel at the interfacial transition zone between cement and aggregate particles.

3.2.5.2 Fly ash

Addition of different levels of Class F fly ash was used as partial replacement of OPC in production of rubbercrete in accordance to ASTM C 618.It consist of silicon oxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) of more than 80% and loss of ignition below than 6% Basically, addition of fly ash contributes to the properties of hardened concrete through the pozzolonic activity.

3.2.6 Water

The water was used for the preparation crumb rubber concrete mix. Tap water was used in accordance to ASTM C 1602 as the potable water is the standard legalized to be used for the mixing without any prior testing.

3.2.7 Superplasticizer

Superplasticizer is classed as chemical admixture according to ASTM C 494 and it is used in concrete mixing to enhance its workability. Superplasticizer reduces water usage while retaining concrete workability as well as its consistency.

3.3 Mix proportion for crumb rubber concrete

Mix proportion CRC was done in accordance to ACI code through the Response Surface Methodology (RSM) to achieve concrete with medium slump workability. RSM is a statistical approach used to replicate processes and experiments through analysis of variance (ANOVA) process (Yolmeh,2017). The ANOVA process can determine desired reaction for 14 days and 28 days, capable of make prediction about the response the usage of the coded factors and offer a graphical illustration of the models in terms of residual vs run graphs, regular plot of residual and residual vs predicted. Hence, using RSM, 30 trial mix proportion were created to study the hybrid effect of 4 variables which is CR,NS,FA and w/c ratio by using three levels of crumb rubber substitution by volume to fine aggregates (0%, 15%, 30%), three levels of nano silica inclusion (0%, 2.5%, 5%) and three levels of fly ash addition (0%, 35%, 70%) with different water/cement ratio (0.25,0.30,0.35) as shown in Table 3.2.A minimum w/c ratio of 0.25 were established since water cement ratio required for normal concrete hydration process is about 0.24.Manual calculation was done to determine quantity of each material required for all the 30 mix proportions. Basically, these 30 mix proportions are the trial mix to find the optimum mix design for the research.

Table 3.2 Mix proportions provided by Response Surface Methodology (RSM)

Run	CR %	NS %	FA %	w/c	Run	CR %	NS %	FA %	w/c
1	0	0	0	0.25	16	15	2.5	35	0.3
2	15	2.5	35	0.3	17	30	5	0	0.25
3	15	2.5	0	0.3	18	15	2.5	35	0.25
4	15	2.5	35	0.3	19	0	5	70	0.35
5	15	2.5	35	0.3	20	0	0	70	0.35
6	30	5	70	0.35	21	30	5	70	0.25
7	15	5	35	0.3	22	0	2.5	35	0.3
8	0	5	70	0.25	23	0	5	0	0.25
9	30	0	0	0.35	24	0	0	0	0.35
10	15	0	35	0.3	25	15	2.5	35	0.3
11	0	5	0	0.35	26	30	2.5	35	0.3
12	30	5	0	0.35	27	15	2.5	35	0.35
13	0	0	70	0.25	28	15	2.5	35	0.3
14	15	2.5	70	0.3	29	30	0	0	0.25
15	30	0	70	0.25	30	30	0	70	0.35

After obtaining compressive strength for all 30 mixes, the result was analyzed using the RSM which uses ANOVA procedure as it can determine the significant models. Based total analysis, 6 mixes with desirable strength was developed for further research. Subsequently, 6 mixes design that was created based on grade foundation of M20, M25, M30, M40, M50 and M60 as shown in table 3.3 which has a different ratio of material within the mix proportion.

Table 3.3 Six mix design for crumb rubber concrete.

Mix	CR %	NS%	FA%	w/c
M20	30	0	70	0.35
M25	30	1	70	0.35
M30	30	2	70	0.35
M40	30	4	70	0.35
M50	30	5	70	0.35
M60	10	5	30	0.25

Furthermore, manual calculation was done to determine specified quantity of materials used to make concrete specimen for every mix design for abrasion test, mercury intrusion porosimetry test and field emission scanning electron microscope test. The tables 3.4 and table 3.5 below shows the quantity of materials used to prepared the concrete.

Table 3.4 Constituent material used for abrasion test samples

Mix	CR (m3)	CR (kg)	NS (kg)	FA (kg)	w/c	Cement (kg)	Sand (m3)	Sand (kg)
M20	0.49	0.47	0.00	2.42	1.21	1.04	1.15	2.98
M25	0.49	0.47	0.03	2.42	1.21	1.04	1.15	2.98
M30	0.49	0.47	0.06	2.42	1.21	1.04	1.15	2.98
M40	0.49	0.47	0.13	2.42	1.21	1.04	1.15	2.98
M50	0.49	0.47	0.17	2.42	1.21	1.04	1.15	2.98
M60	0.16	0.16	0.17	1.04	0.86	2.42	1.48	3.84

Table 3.5 Constituent material used for MIP and FESEM test samples

Mix	CR (m3)	CR (kg)	NS (kg)	FA (kg)	w/c	Cement (kg)	Sand (m3)	Sand (kg)
M20	0.023	0.022	0.000	0.114	0.057	0.049	0.054	0.141
M25	0.023	0.022	0.001	0.114	0.057	0.049	0.054	0.141
M30	0.023	0.022	0.003	0.114	0.057	0.049	0.054	0.141
M40	0.023	0.022	0.006	0.114	0.057	0.049	0.054	0.141
M50	0.023	0.022	0.008	0.114	0.057	0.049	0.054	0.141
M60	0.008	0.007	0.008	0.049	0.041	0.114	0.070	0.181

3.4 Preparation of crumb rubber concrete

3.4.1 Preparation of crumb rubber concrete for trial mix

The concrete mixers were used to make crumb rubber concrete for trial mix of 30 combinations. For every batch of concrete aggregate, 6 cube molds with dimension of 100 x 100 x 100mm use to prepare cubes for compressive strength test. As soon as concrete had passed the slump test, freshly made crumb rubber concrete was placed into each mold and tamped for 25 times in three layers with the use of the tamping rod. Then, it was left for twenty-four hours before demolded and cured for 14 days and 28 days accordance to ASTM C 192-02.

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Figure 3.2 Slump test

Figure 3.3 Concrete mix in mould

Figure 3.4 Curing tank

Figure 3.5 Compressive strength test

3.4.2 Preparation of crumb rubber concrete from chosen mix design

The concrete mixer was used to make crumb rubber concrete ash shown in the Figure 3.6

Figure 3.6 Concrete Mixer

For every mix design, 2 cylindrical concrete with a150 mm in diameter and 300 mm height were organized for the abrasion test. The cylindrical mold prepared prior to mixing of the concrete. The fresh concrete is then stuffed into the mould in three layers and tamping rod used to tamp every layer for 25 times for compaction. For mercury intrusion porosimetry (MIP) test and field emissioning scanning electron microscope (FESEM) test, 2 small cubes of 50mm x 50mm x 50 mmm were prepared. After 24 hours, the specimens have been demolded and placed in curing tank for curing process for 28 days in accordance to ASTM C 192.

Figure 3.7 Hardened cylinder concrete

Figure 3.8 Hardened cube concrete

3.5 Sieve analysis for coarse aggregates, fine aggregates and crumb rubber

The sieve analysis was conducted to determine the gradation of the material such as for river sand and coarse aggregate and crumb rubber. The sieve analysis for river sand and crumb rubber was performed in accordance to ASTM C136.The result obtained are as shown in Figure 3.9 below:

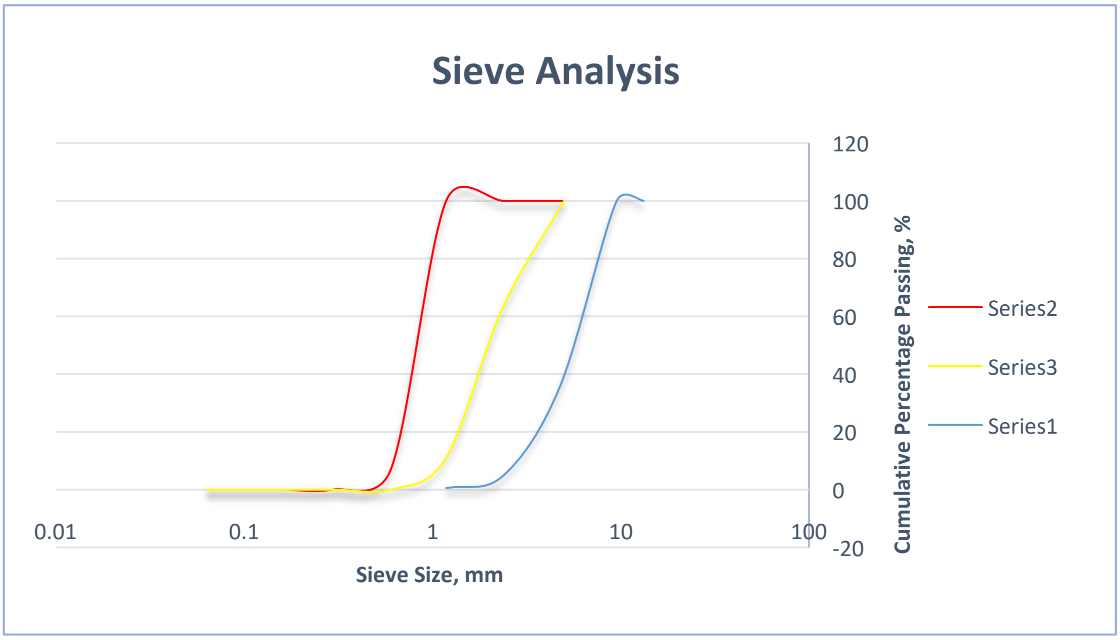


Figure 3.9: Sieve Analysis Graph for Coarse Aggregate, Fine Aggregate & Crumb rubber

3.6 Test methods

3.6.1 Slump Test

For every batch of crumb rubber concrete, slump test was performed in accordance to ASTM C 143 before shifting the freshly made concrete into the cube mold. Slump test was accomplished to determine the workability and consistency of the concrete mix. It also acts as an indicator of an improperly combined concrete.

Essentially, the freshly made concrete placed in mould which is vicinity on the non-porous base plate. The mould is then filled with 4 identical layers of concrete and every layer was tamped with 25 strokes in a uniform way over the mould using tamping rod. The excessive concrete above was removed the use of trowel and any water leak between base plate and mould may was cleared. Next, the mould was removed straight and slowly in vertical direction. Ultimately, the peak difference among the mould and specimen was measured.

Figure 3.10: Slump Test

3.6.2 Compressive strength test

The compressive strength test was done in accordance to ASTM C39-03. Basically, 3 samples of 100mmx100mmx100mm cubes were prepared and tested at the age of 28 days. The specimen was placed at the middle of a base plate of a compression machine in which load will be carried out at opposite site of the cube and forces implemented until the failure of the concrete. The compressive strength of every cube was calculated with the by dividing maximum load implemented on the cross-section of the concrete cube. Average value of compressive strength of 3 cube samples from same mixture were taken.

Size of the cube =100mmx100mmx100mm

Area of the specimen = 1000000mm2

Figure 3.11: Compressive strength test

3.6.3 Cantabro Abrasion Loss test

Abrasion test needed to determine the resistance of a concrete considering in many situations concretes are subjected wear. The abrasion check for the crumb rubber concrete is to assess the abrasion resistance of the concrete surface. Basically, the Cantabro abrasion resistance was conducted using Los Angeles machine in accordance to ASTM C 1747 and metal balls for abrasive charges were not used. Basically, for abrasion test, 3 cylindrical specimens of length 150 mm diameter and 100 mm height for each mix have been placed in Los Angeles abrasion machine. Prior to the test, the initial weight of each specimen (w1) was recorded. Then the abrasion system machine was allowed to rotate for 300 revolutions. The weight reduction after every 100, 200 and 300 revolutions were recorded after the loose particles from the abraded specimens had been wiped clean and weighed appropriately to degree final weight, w2. The Cantabro loss was calculated the usage of the subsequent equation:

$$Cantabro\ loss, \% = \frac{W1 - W2}{W1}\ X\ 100$$

w_1 = Initial weight of the test specimen, g

w_2 = Final weight of the test specimen, g.

Figure 3.12 Los Angeles abrasion machine

Figure 3.13 Specimen initial weight

Figure 3.14 Specimen final weight

Figure 3.15 Shape of specimen before abrasion test

Figure 3.16 Shape of specimen after abrasion test for 300 revolutions

3.6.4 Mercury Intrusion Porosimetry (MIP) test

Mercury Intrusion Porosimetry test were conducted to determine the pore volume distribution in CRC in accordance to ASTM D 4284. Pore exist in the dry crumb rubber concrete mixture are due to poor compaction and air entrainment caused by hydrophobic nature of the rubber which repels water and traps air. Besides, gel pores also occur when product of hydration undergo water evaporation and only nano sized particle could fill the pores. Hence, MIP test was conducted to study the performance of nanosilica which has a filler effect. Basically, the concrete sample was outgassed and the weight of the outgassed sample was recorded. The sample is then placed in the penetrometer which is then placed in an appropriate chamber of porosimeter. The penetrometer is then filled with mercury under low pressure. The filled penetrometer is then transferred to porosimeter pressure vessel for pressurization and intrusion process where mercury will seep into the pores of the concrete. The pressure was raised gradually until 20MPa and the intruded mercury volume and absolute pressure was recorded. The intruded mercury volume was recorded to determine the intruded pore volume. The equation below shows the relationship between pressure and pore diameter.

$$d = \left| \frac{-4\gamma(\cos\theta)}{P} \right|$$

where:

d = apparent diameter of the pore being intruded,
γ = surface tension of the mercury,
θ = contact angle between the mercury and the solid,
P = absolute pressure causing the intrusion.

Figure 3.17 Mercury Intrusion Porosimeter machine

3.6.5 Field Emission Scanning Electron Microscope (FESEM) test

FESEM is a microscope that uses electron instead of light to examine object that may be as small as one nanometer. Basically, electron microscope can overcome the limitation of light microscope which can only magnify 500x or 1000x and have a resolution of 0.2 micrometers. In FESEM, the electrons are discharged from field emission source and it accelerate at high electrical field gradient. The object is scanned by electron in zig-zag pattern which produce high resolution digital image that allows observation of specimen from a scale of nanometer to micrometer. Basically, the surface of the CRC sample was outgassed and coated with extremely thin layer of gold for conductive of current. The sample is then mounted on special holder in the microscope. The sample was inserted to exchange chamber through a high vacuum part. When electrons are discharged, the electron from gold coating were projected onto a screen and image was magnified to examine the morphology of the concrete and the image was saved. Mainly this test was conducted to determine the thickness of ITZ between coarse aggregate and matrix and ITZ between crumb rubber and matrix and to examine the effect of nanosilica inclusion which can fill the nano voids and increase production of C-S-H gel.

Figure 3.18 Field Emission Scanning Electron Microscope

CHAPTER 4

RESULT & DISCUSSION

4.1 Response Surface Methodology for Compressive Strength of CRC

Compressive strength result at 14 days and 28 days was obtained for all 30 trial mixes. The result obtained was incorporated into RSM to design further 6 mixes to conduct research regarding pore structures and abrasion of CRC.The table 4.1 shows the summary of average compressive strength result obtained for 14 days and 28 days.

Table 4.1: Result of average compressive strength test for trial mix

Mix Design	Average (14 days) MPa	Average (28 days) MPa	Mix Design	Average (14 days) MPa	Average (28 days) MPa
Mix 1	66.04	82.41	Mix 16	43.5	45.3
Mix 2	44.31	45.68	Mix 17	46.18	36.42
Mix 3	50.38	39	Mix 18	55.57	36.91
Mix 4	36.67	43.89	Mix 19	38.56	43.11
Mix 5	37.83	43.98	Mix 20	27.85	24.55
Mix 6	27.46	42.88	Mix 21	32.43	54.97
Mix 7	33.58	40.44	Mix 22	41.18	43.64
Mix 8	35.71	64.64	Mix 23	54.33	75.64
Mix 9	31.36	33.25	Mix 24	63.23	58.47
Mix 10	46.10	42.31	Mix 25	43.66	47.82
Mix 11	25.89	34.08	Mix 26	34.93	29.43
Mix 12	33.63	26.09	Mix 27	26.95	40.69
Mix 13	62.94	39.41	Mix 28	42.68	48.74
Mix 14	32.53	42.95	Mix 29	37.25	39.11
Mix 15	25.54	32.22	Mix 30	18.76	16.53

4.1.1 14 days compressive strength

Based, on the 14 days compressive strength result, the following data as shown in table 4.2 was obtained from RSM.

Table 4.2 The 14 days analysis using RSM

ANOVA for Response Surface Linear model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3112.58	4	778.15	11.51	< 0.0001	significant
A-Crumb rubber	1103.04	1	1103.04	16.32	0.0004	
B-Nano-silica	182.96	1	182.96	2.71	0.1124	
C-Fly ash	733.23	1	733.23	10.85	0.0029	
D-w/c	1093.35	1	1093.35	16.18	0.0005	
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				

Basically, the 11.51 as F value of the model show that the model is significant. The probability of obtaining the F value as stated previously is only 0.01% due to noise. Moreover, Prob > F below 0.0500 shows that terms of the model are significant and for this case term A, C and D are significant. Model reduction can improve the model if there are numerous insignificant terms of the model. The F value for 'Lack of Fit' which is 2.42 infers that it is not significant relation to pure error. Besides, 16.64% shows the probability of occurrence of F value for 'Lack of fit' due to noise. For the fit model, non-significant lack of fit is good.

Table 4.3 Validation of the models

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

The vaule of Pred R-Squared is 0.4225 and Adj R-Squared is 0.5919 is in justifiable arrangement since the difference between the values is below 0.2. Adeq Precision act value show indication to ratio of noise and basically ratio more than 4 is required. Since the value shows 15.013, then it is accepted and the model can be utilized to direct the design space.

Final Equation for actual factors terms for 14 days compressive strength:

$$C_{14} = 105.36626 - 0.52188*CR - 1.27526*NS - 0.18235*FA - 155.87407* w/c$$

The equation above can be utilized to predict the possible response for each level of factors. There, the level must be stated in original unit for all the factors. However, the equation must not be used to evaluate the effect of each factors as it is only scaled to accommodate unit of factors and intercept is not at the centre of design space.

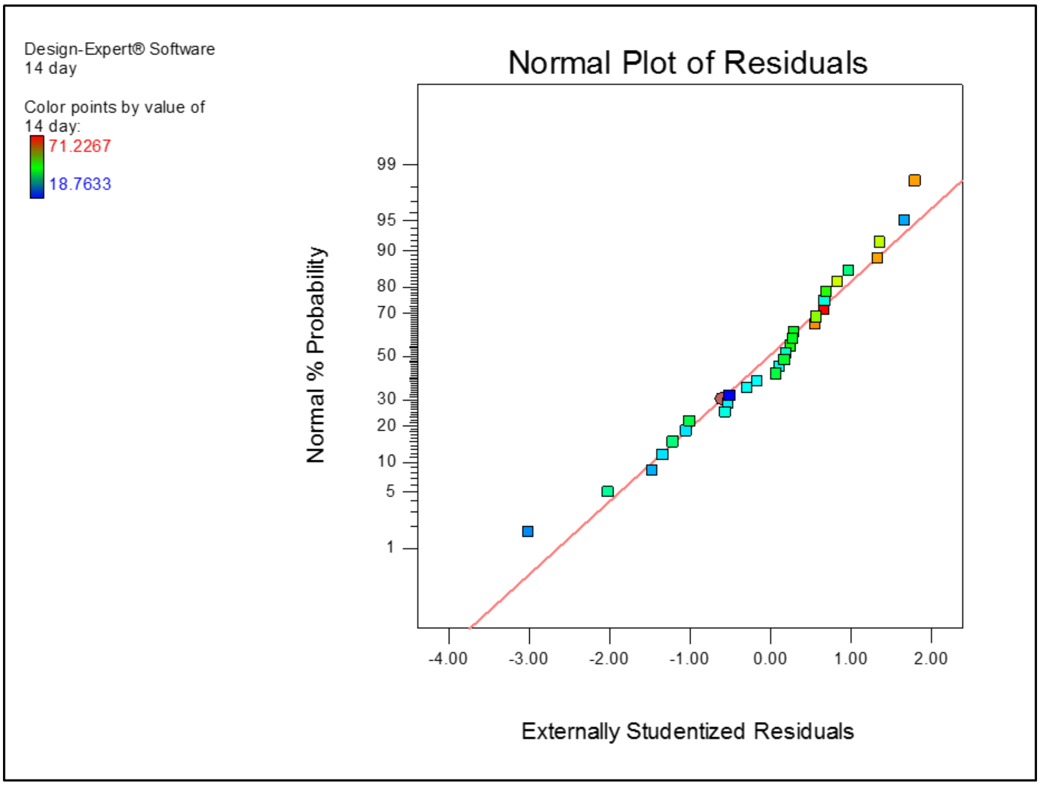


Figure 4.1 Normal plot of residuals for 14 days compressive strength

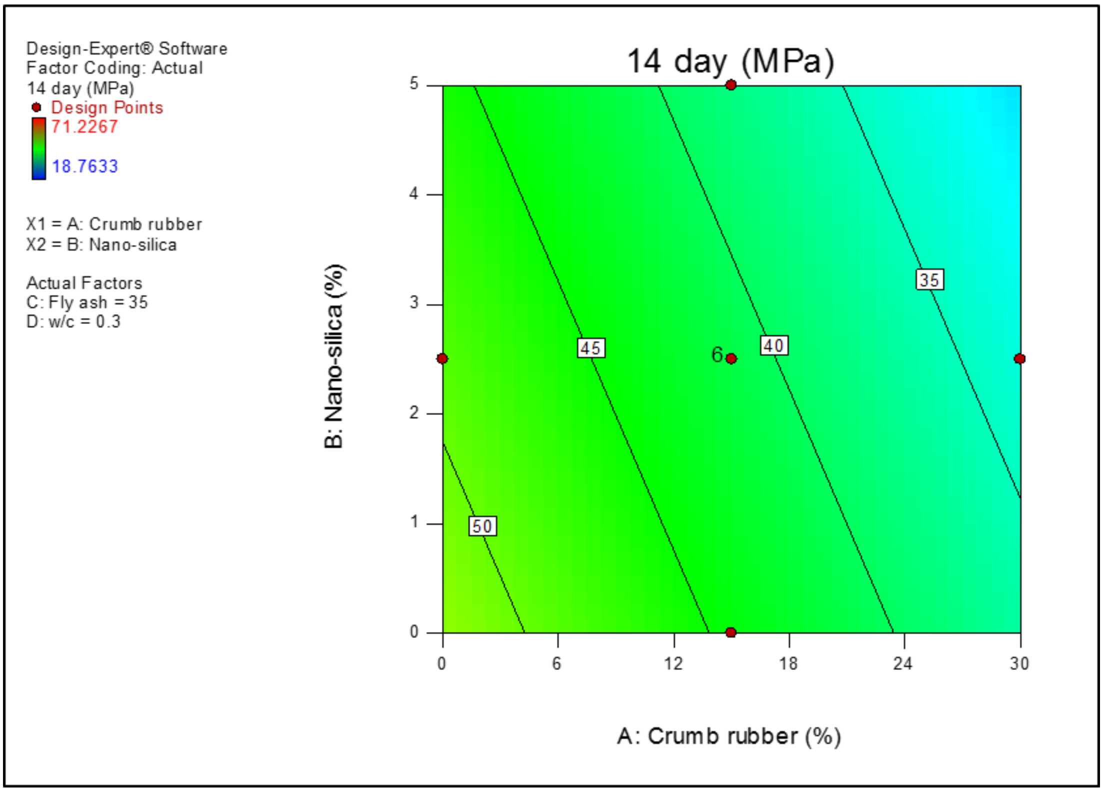


Figure 4.2 2D contour plot for 14 days compressive strength

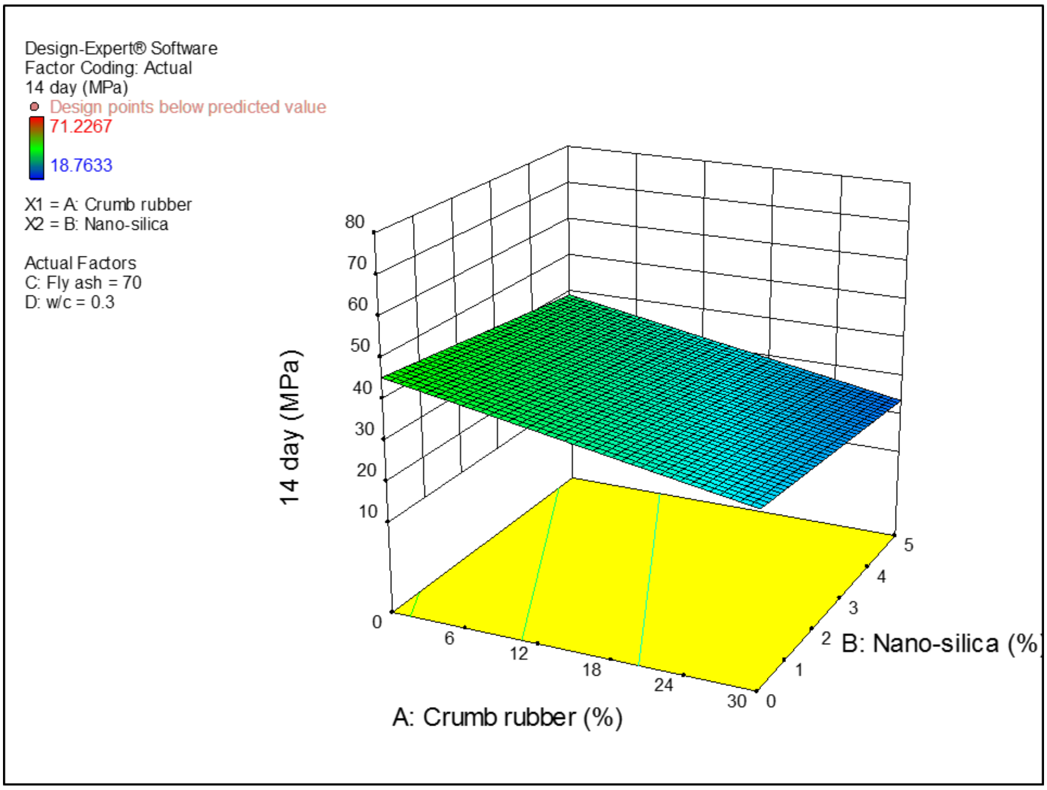


Figure 4.3 3D response surface plot for 14 days compressive strength

The normal plot of the model in Figure 4.1 shows an align and closely fir straight line is as the experimental data is appropriate and fit to the predicted result of the model. The 2D contour plots in Figure 4.2 shows the relationship between CR and NS for all 14 responses for compressive strength. While, the 3D response surface plots of model developed shown in Figure 4.3 displays that CR more negative impact on the response compared to NS.

4.1.2 28 days compressive strength

Based, on the 28 days compressive strength result, the following data as shown in table 4.4 was obtained from RSM.

Table 4.4 The 14 days analysis using RSM

ANOVA for Response Surface 2FI model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5879.69	10	587.97	19.40	< 0.0001	significant
A-Crumb rubber	1601.59	1	1601.59	52.84	< 0.0001	
B-Nano-silica	143.24	1	143.24	4.73	0.0426	
C-Fly ash	523.08	1	523.08	17.26	0.0005	
D-w/c	1099.39	1	1099.39	36.27	< 0.0001	
AB	163.07	1	163.07	5.38	0.0317	
AC	506.48	1	506.48	16.71	0.0006	
AD	352.63	1	352.63	11.63	0.0029	
BC	1381.24	1	1381.24	45.57	< 0.0001	
BD	70.08	1	70.08	2.31	0.1448	
CD	38.90	1	38.90	1.28	0.2714	
Residual	575.95	19	30.31			
Lack of Fit	551.54	14	39.40	8.07	0.0154	significant
Pure Error	24.41	5	4.88			
Cor Total	6455.64	29				

Basically, the 19.40 as F value of the model show that the model is significant. The probability of obtaining the F value as stated previously is only 0.01% due to noise. Moreover, Prob > F below 0.0500 shows that terms of the model are significant and for this case term A, B, C, D, AB, AC, AD AND BC are significant. Model reduction can improve the model if there are numerous insignificant terms of the model. The F value for 'Lack of Fit' which is 8.07 infers that it is not significant relation to pure error. Besides, 1.54 % shows the probability of occurrence of F value for 'Lack of fit' due to noise. For a fit model, non-significant lack of fit is good.

Table 4.5 Validation of the models

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

The vaule of Pred R-Squared is 0.7473and Adj R-Squared is 0.8638 is in justifiable arrangement since the difference between the values is below 0.2. Adeq Precision act value show indication to ratio of noise and basically ratio more than 4 is required. Since the value shows 20.133, then it is accepted and the model can be utilized to direct the design space.

Final Equation for actual factors terms for 28 days compressive strength:

$$C_{28} = 146.64748-3.09460*CR+1.15787*NS-0.84752*FA-239.52037*w/c +0.085133*CR*NS+0.010717*CR*FA+6.25944*CR*w/c +0.10619*NS*FA-16.74333*NS*w/c+0.89095*FA*w/c$$

The equation above can be utilized to predict the possible response for each level of factors. There, the level must be stated in original unit for all the factors. However, the equation must not be used to evaluate the effect of each factors as it is only scaled to accommodate unit of factors and intercept is not at the center of design space.

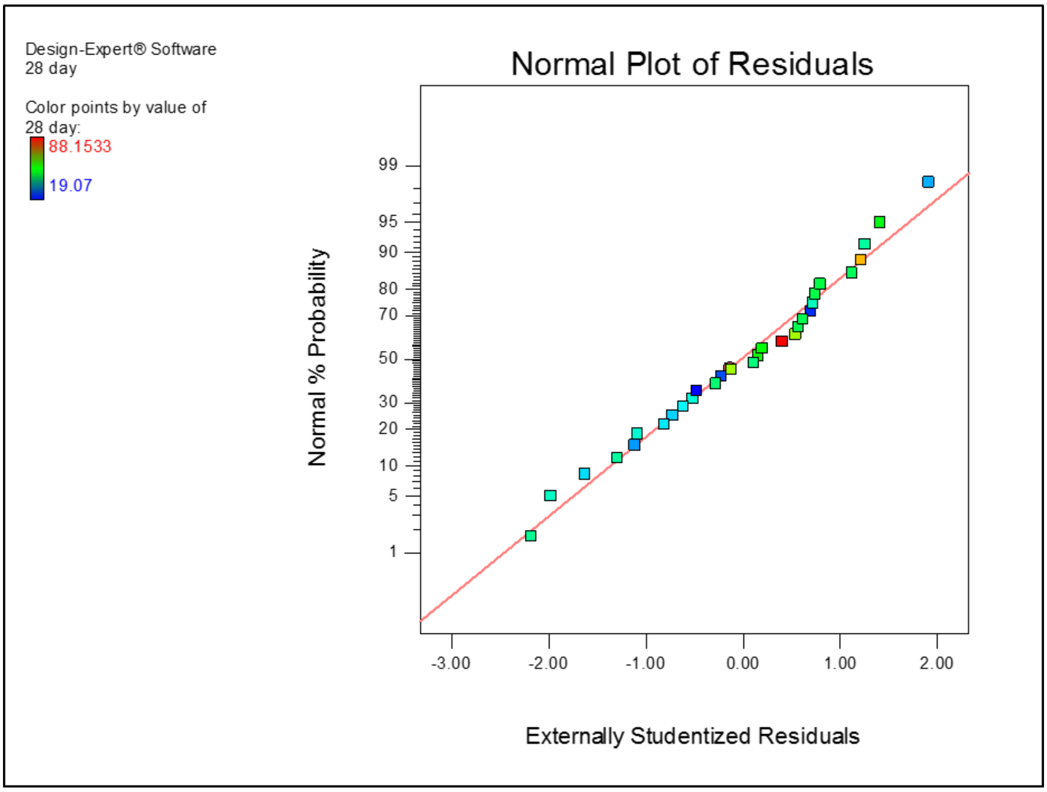


Figure 4.4 Normal plot of residuals for 28 days compressive strength

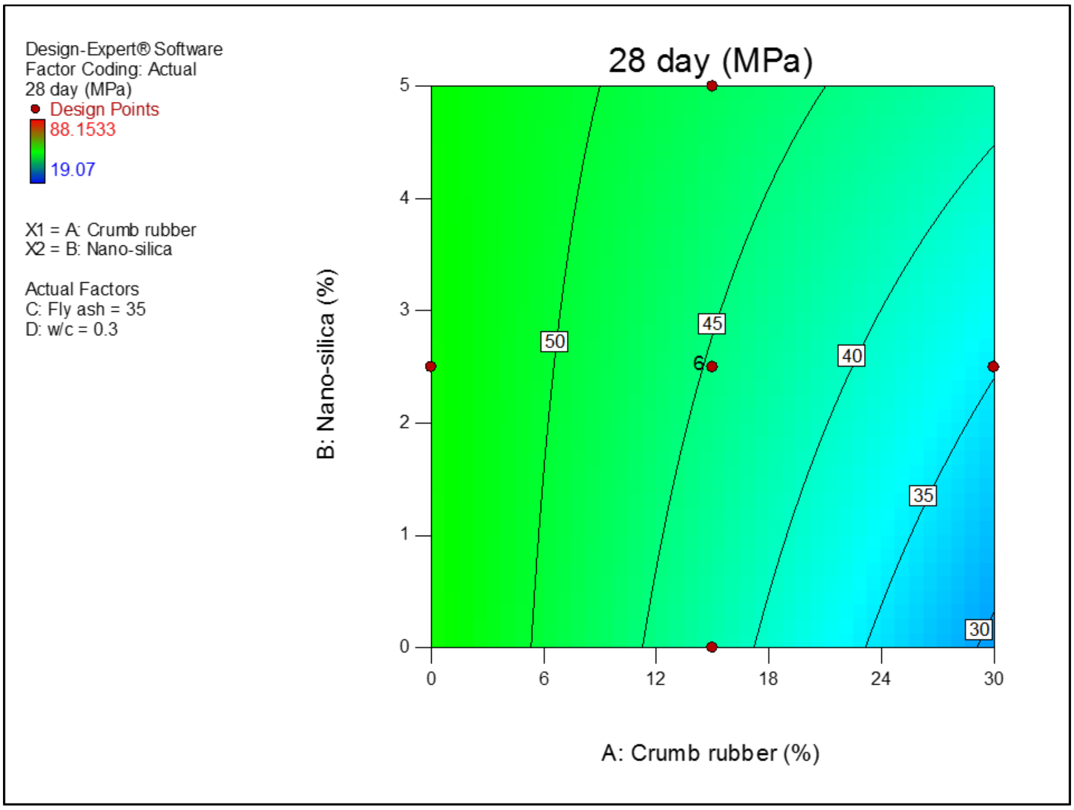


Figure 4.5 2D contour plot for 28 days compressive strength

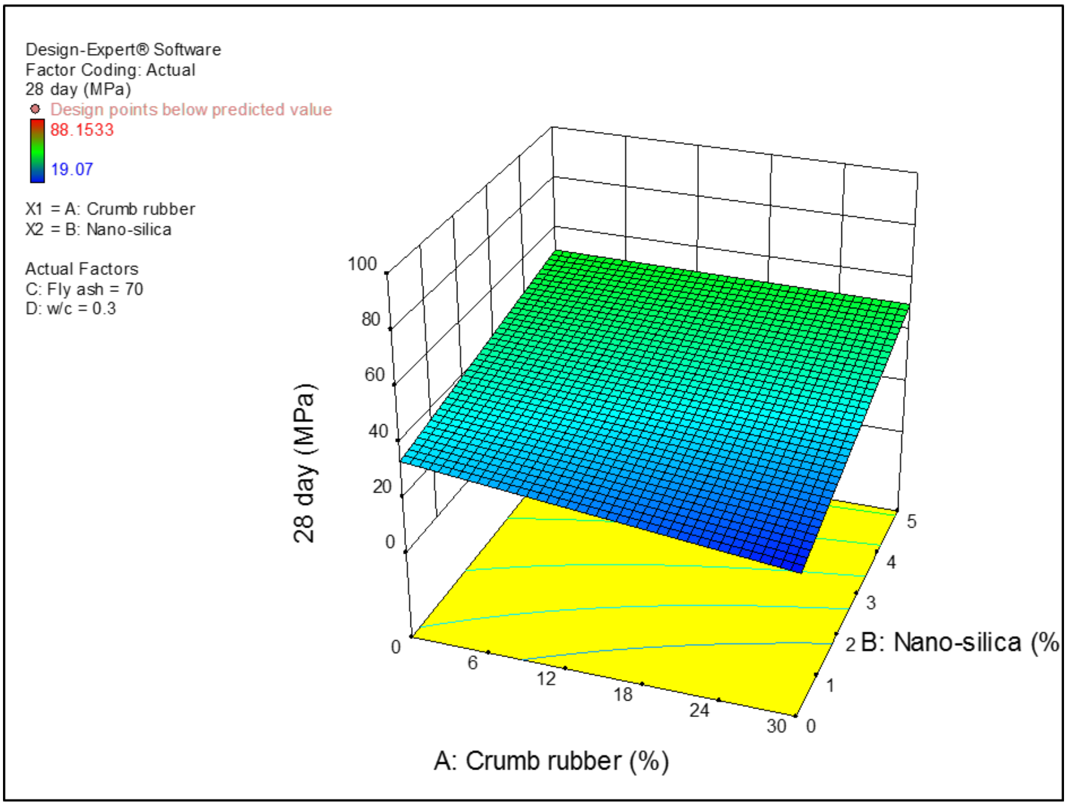


Figure 4.6 3D response surface plot for 28 days compressive strength

The normal plot of the model in Figure 4.4 shows an align and closely fir straight line is as the experimental data is appropriate and fit to the predicted result of the model. The 2D contour plots in Figure 4.5 shows the relationship between CR and NS for all 28 responses for compressive strength. While, the 3D response surface plots of model developed shown in Figure 4.6 displays that CR have more negative impact on the response compared to NS.

4.1.3 Multi-Objective Optimization

Using RSM, the multi optimization was carried out to create the finest optimum hybrid of CR, FA, NS that can produce maximum compressive strength and minimum water absorption by CRC.The result of optimization for 6 mixtures based on gradings are displayed in table 4.6.

Table 4.6 Summary of optimized mixtures

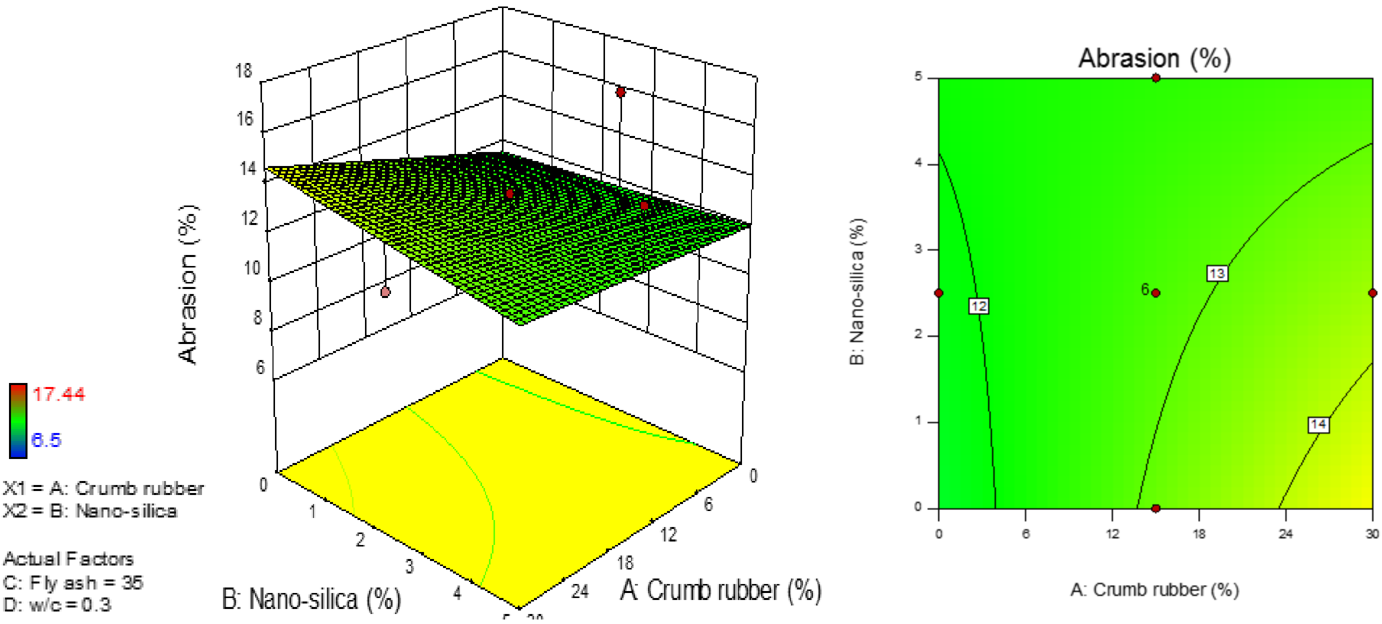
Mix	CR %	NS%	FA%	w/c	14 days strength	28 days strength	Desirability
M20	30.000	0.000	70.000	0.350	22.389	20.708	0.960
M25	29.998	0.811	69.937	0.350	21.372	25.000	0.975
M30	30.000	1.758	70.000	0.350	20.150	30.000	0.987
M40	29.464	3.712	68.295	0.349	18.410	40.000	1.000
M50	30.000	5.000	69.999	0.332	18.763	48.420	0.974
M60	10.000	5.000	30.000	0.269	46.340	56.496	0.812

4.2 Cantabro Abrasion Loss result

Basically, Cantabro abrasion loss was carried out to determine abrasion resistance of crumb rubber concrete through the percentage of weight loss for 3 specimens of each set of six crumb rubber concrete mixtures (M20, M25, M30, M40, M50, M60) in accordance to ASTM C 1747.Table 4.7 indicates the average Cantabro loss result for all mixtures acquired at 100 revolutions,200 revolutions, and 300 revolutions after curing of 28 days. The Cantabro loss (%) for M20, M25, M30, M40, M50 and M60 after 100 revolutions became 5.23%, 5.96%, 4.36%, 5.75%, 5.99e% and 3.90% respectively, whereas after 200 revolutions the loss become 10.23%, 11.06%, 8.58%,11.68%, 11.31% and 6.76% respectively, and after 300 revolutions, the Cantabro loss changed into 15.12%, 16.07%, eleven.77%,17.44%,15.89% and 9.43%.

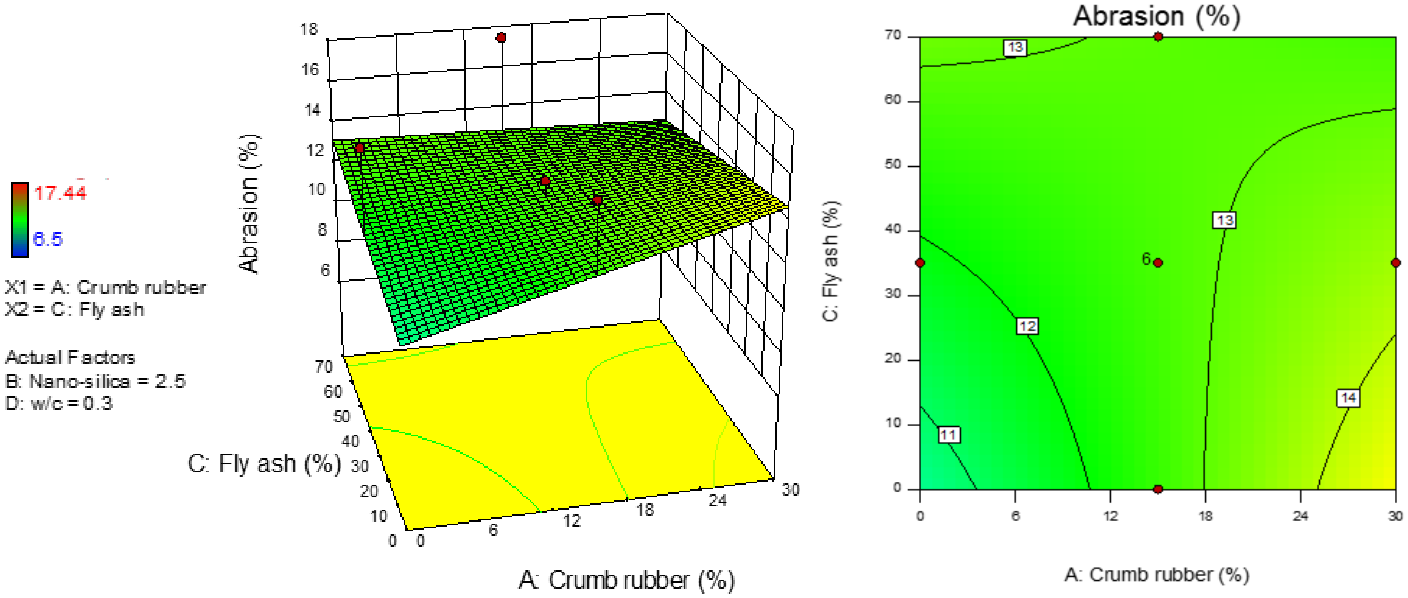
Table 4.7 Result of Cantabro Abrasion Loss

Mix	Initial weight, W1(g)	100 revolutions	Cantabro Loss (%)	Average loss (%)	200 revolutions	Cantabro Loss (%)	Average loss (%)	300 revolutions	Cantabro Loss (%)	Average loss (%)
Mix 20-1	3969.00	3737.20	5.84		3520.00	11.31		3322.90	16.28	
Mix 20-2	4152.00	3940.60	5.09	5.23	3737.80	9.98	10.23	3532.00	14.93	15.12
Mix 20-3	4076.30	3882.60	4.75		3693.40	9.39		3499.60	14.15	
Mix 25-1	4056.40	3814.80	5.96		3617.80	10.81		3400.00	16.18	
Mix 25-2	3928.30	3668.00	6.63	5.96	3435.80	12.54	11.06	3234.80	17.65	16.07
Mix 25-3	3865.30	3660.90	5.29		3485.80	9.82		3309.50	14.38	
Mix 30-1	3923.50	3750.90	4.40		3577.10	8.83		3499.20	10.81	
Mix 30-2	4161.00	3988.70	4.14	4.36	3822.10	8.14	8.58	3668.60	11.83	11.77
Mix 30-3	4040.50	3856.70	4.55		3686.60	8.76		3528.40	12.67	
Mix 40-1	4039.10	3815.50	5.54		3609.90	10.63		3393.30	15.99	
Mix 40-2	3862.40	3630.90	5.99	5.75	3379.70	12.50	11.68	3152.60	18.38	17.44
Mix 40-3	3935.90	3711.20	5.71		3466.40	11.93		3228.90	17.96	
Mix 50-1	3970.80	3758.30	5.35		3569.90	10.10		3398.90	14.40	
Mix 50-2	3819.00	3606.20	5.57	5.99	3405.20	10.84	11.31	3239.60	15.17	15.89
Mix 50-3	3965.00	3685.90	7.04		3450.10	12.99		3247.60	18.09	
Mix 60-1	4210.50	4047.30	3.88	3.90	3918.10	6.94	6.76	3798.90	9.78	9.43
Mix 60-2	4168.60	4000.00	4.04		3875.10	7.04		3755.90	9.90	



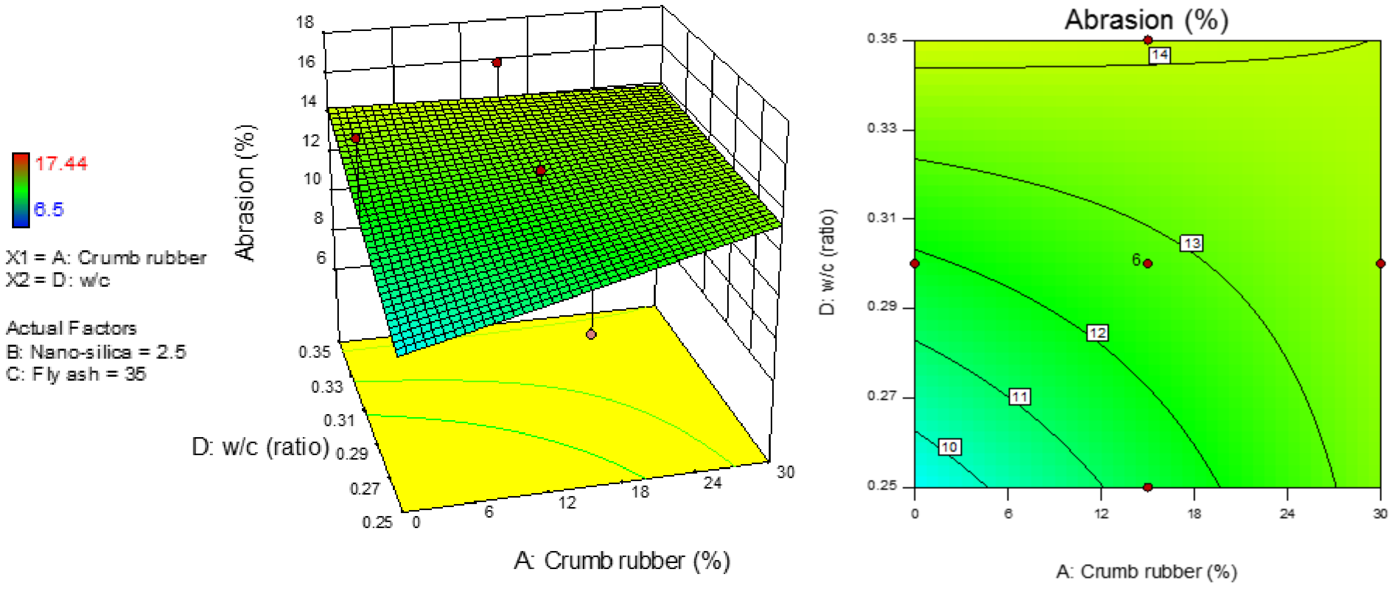
a) 3D surface model b) 2D contour plot

Figure 4.7 Abrasion Loss against Nanosilica and Crumb rubber



a) 3D surface model b) 2D contour plot

Figure 4.8 Abrasion Loss against Fly ash and Crumb rubber



a) 3D surface model b) 2D contour plot

Figure 4.9 Abrasion Loss against water/cement ratio and Crumb rubber

Basically, Figure 4.7-4.9 shows the 3D surface model and 2D contour plot obtained from ANOVA process in RSM based on the Cantabro abrasion loss result to show the relationship and interaction between different variables such crumb rubber, nanosilica, fly ash and water/cement ratio regarding the percentage of abrasion loss.

The higher the percentage of weight loss, the lower the abrasion resistance of the crumb rubber concrete. The Figure 4.7 shows the relationship of nanosilica and crumb rubber in the abrasion loss. Abrasion loss decreases gradually when there is gradual increment in percentage of nanosilica and gradual decrease in the percentage of crumb rubber used in the crumb rubber concrete. This is mainly because, nanosilica is a pozzolanic material and it has filler effect as it fill in the pores between the crumb rubber and cement matrix which reduce the thickness of interfacial transition zone (ITZ), densifying the concrete and strengthening the bond between crumb rubber and cement matrix. Hence, the crumb rubber concrete abrasion resistance increases.

The Figure 4.8 shows the relationship of fly ash and crumb rubber in the abrasion loss. When the percentage of fly ash inclusion in the crumb rubber concrete increases, the percentage of abrasion loss also increases. This is because fly ash tends to delay the strength gain of crumb rubber concrete. Fly ash which is a pozzolonic material react with calcium hydroxide slowly during hydration process and does not have significant effect on the concrete strength at early stage. Hence, when the percentage of both crumb rubber and fly ash addition is increases, the abrasion loss percentage also increases as the concrete full strength is not achieved and abrasion resistance is low.

The Figure 4.9 shows relationship between water/cement ratio and crumb rubber concrete regarding abrasion loss. Abrasion loss is high when the water/cement ratio increases. Basically, high water/cement ratio along with high percentage of crumb rubber lowers the abrasion resistance of the crumb rubber concrete as it reduces concrete strength. Air voids in the concrete depends on the water/cement ratio. Excessive water that is not consumed during hydration process, eventually will leave the concrete as it hardens, resulting in bleeding. Bleeding will cause microscopic pores in the concrete which reduce the final strength of the concrete. Furthermore, crumb rubber also entrap air in the concrete that weakens the bond between crumb rubber and cement matrix.

4.3 Field Emission Scanning Electron Microscope (FESEM)

Field emission scanning electron microscope (FESEM) test was conducted to study the microstructure of the crumb rubber concrete for different crumb rubber mixture. In conventional concrete, there are three faces of material such as coarse aggregate, hardened cement paste (matrix) and interfacial transition zone(ITZ). Basically, ITZ is a porous boundary between matrix and aggregate which is responsible for reduction in strength as it causes less bonding between matrix and aggregate. However, crumb rubber concrete has two different ITZ which between coarse aggregate and matrix and crumb rubber and matrix.

Factors affecting ITZ usually the water/cement ratio, texture and size of the aggregate. However, this FESEM study was conducted to investigate the effect of different percentage of nanosilica inclusion in six crumb rubber concrete mixture which has others variable such as crumb rubber, fly ash and water /cement ratio. The proportion of the crumb rubber mix with different percentages of nanosilica, crumb rubber, fly ash and water/cement ratio was obtained from ANOVA process in RSM to achieve the desirable grade of concrete of M20, M25, M30, M40, M50 and M60 in 28 days. Hence, the effect of nanosilica on different grades of crumb rubber concrete is as shown in the Figure 4.10 -4.15 which shows the microstrucre of each mix.

The reduction in strength of crumb rubber concrete increases when the addition of crumb rubber increases. This is because crumb rubber tends to increase the thickness of ITZ between cement paste and crumb rubber. Hydrophobic nature of crumb rubber repels water and traps air which cause the increment of air content or voids and weaken the bonding between cement paste and crumb rubber that result in reduced strength. However, as shown in Figure 4.1.8-4.1.13, the thickness of ITZ reduces gradually from crumb rubber concrete with grade of M20 to M60 as the addition of nanosilica increases from 0% to 5%, inclusion of crumb rubber reduces from 30% to 10%, fly ash content also decreases from 70% to 30% and water/ cement ratio reduces gradually from 0.35 to 0.25.

Main reason for reduction of ITZ thickness is due to increment of nanosilica addition. Nanosilica which is a nano particle that has filler effect and high pozzolonic reaction. It able to densify and fill in the ITZ by reacting with the remaining calcium hydroxide during hydration process to produce more C-S-H gel which acts as a glue that fill in the nano pores and improve the bond between crumb rubber and cement matrix. Reduction of crumb rubber, fly ash and water/cement ratio content in the concrete also reduces the ITZ thickness significantly as the presence of air voids and porosity of cement paste reduces. Hence, the crumb rubber concrete microstructure become denser and have refined microstructure.

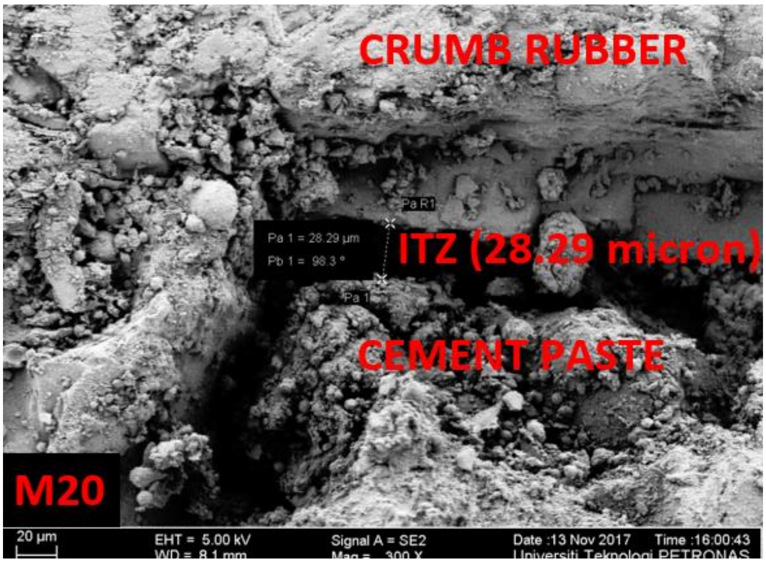


Figure 4.10 Microstructure of M20

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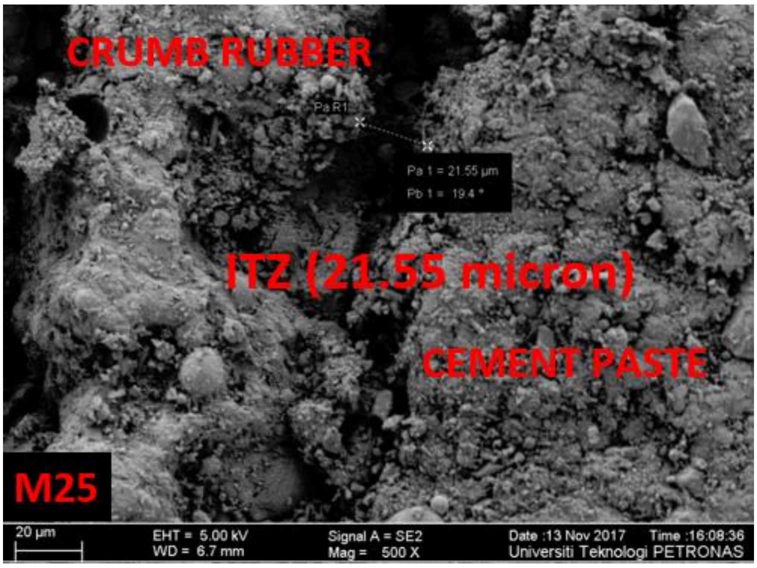

Figure 4.11 Microstructure of M25

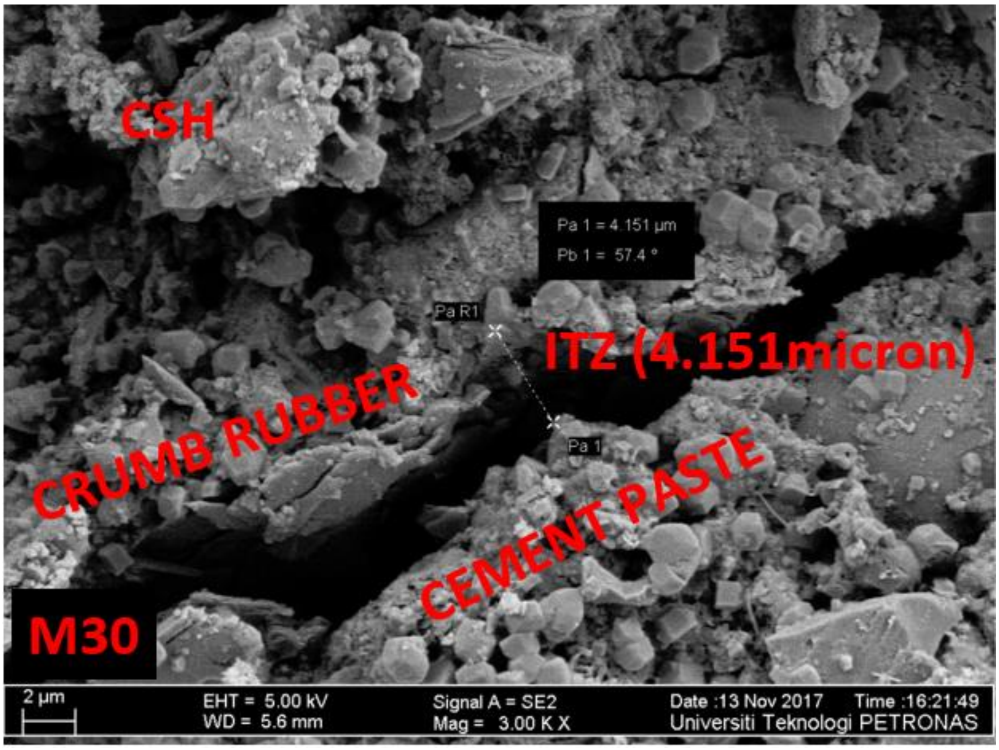

Figure 4.12 Microstructure of M30

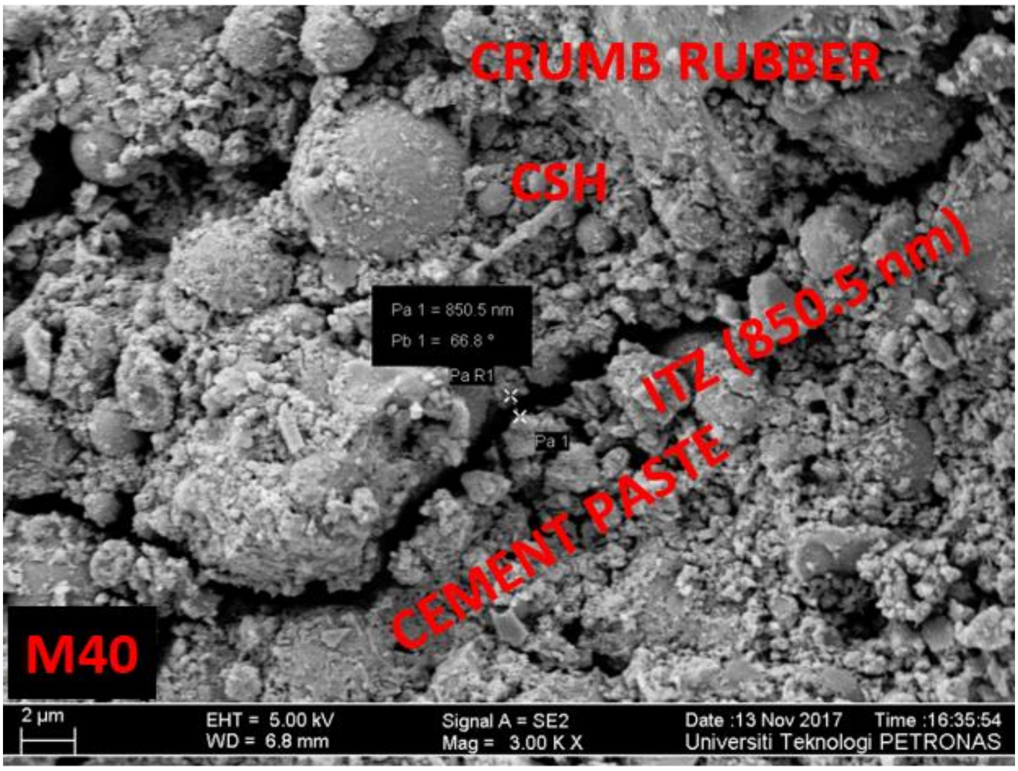

Figure 4.13 Microstructure of M40

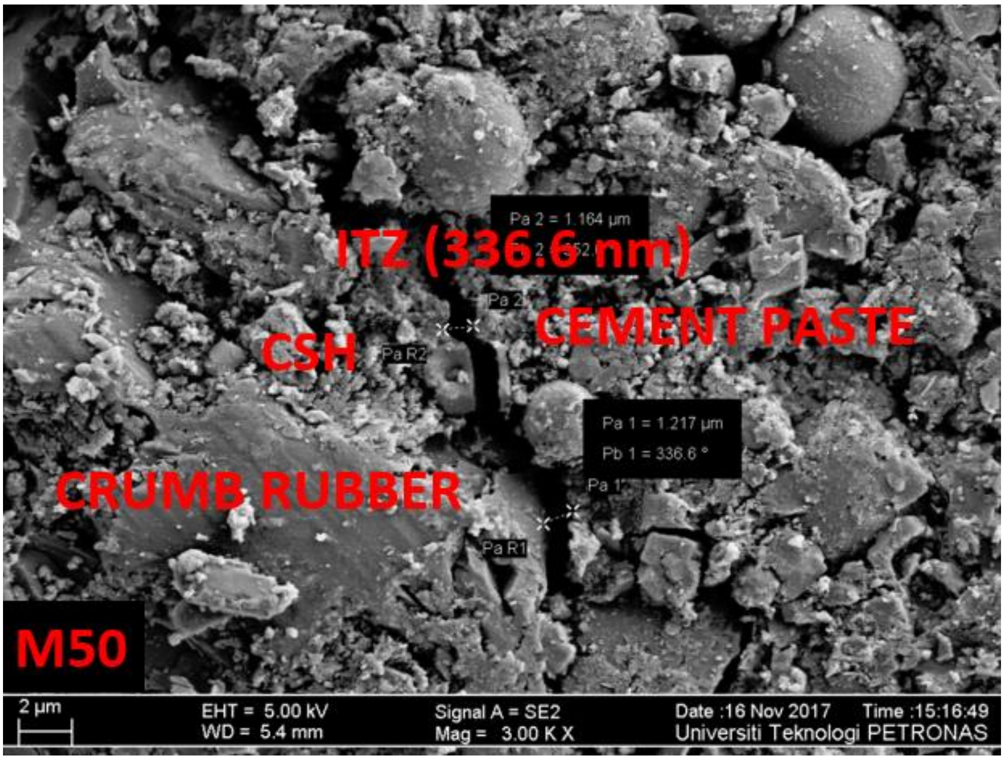

Figure 4.14 Microstructure of M50

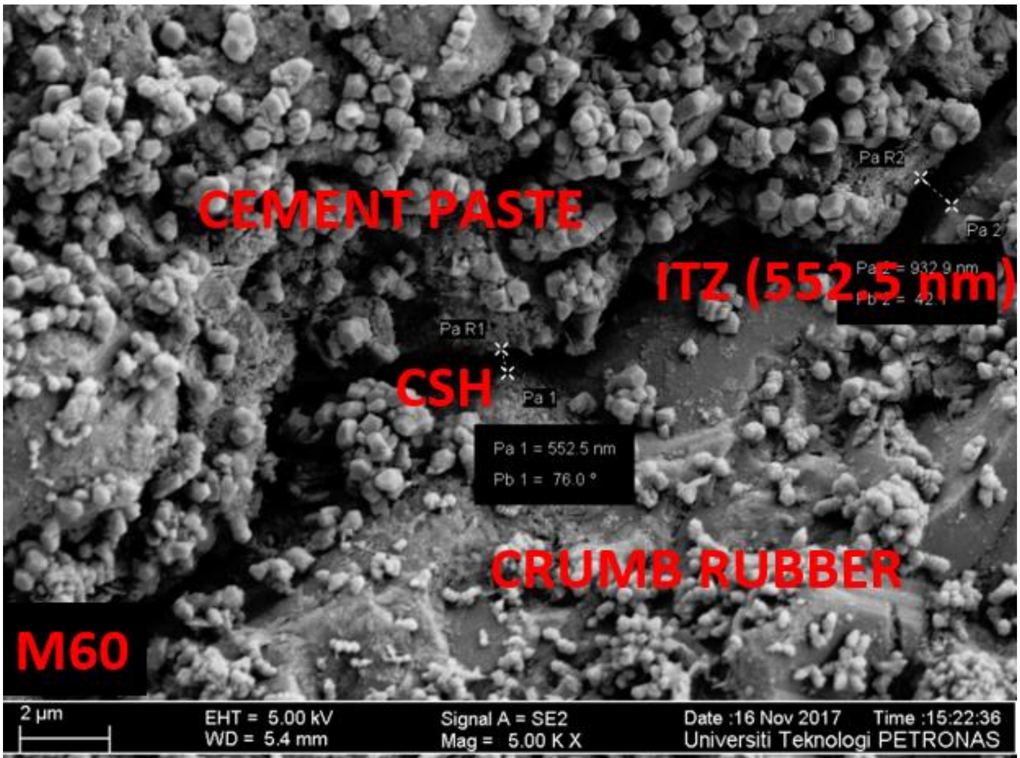

Figure 4.15 Microstructure of M60

4.3 Mercury Intrusion Porosimetry (MIP)

The mercury intrusion porosimetry (MIP) test was carried to examine the effect of NS physiochemical activity in CRC.NS has the ability to fill in pores including nano sized pore such as gel pore and capillary pores in CRC which result in refinement of pore structures. Basically, capillary pores with size range from 100nm to 1 μm is formed when excessive water during mixing evaporates from hardened CRC.Meanwhile, gel pores is formed when water evaporates from C-S-H gels which is a product of hydration process during curing of the concrete which can have diameter below 3 nm (Mohammed, Awang, San Wong & Nhavene, 2016). Figure 4.16-4.21 shows the graph of cumulative pore volumes against pore diameters for 6 CRC mixtures. The cumulative pore volume is shown by the blue curve, whereas range of pore diameter is indicated by the red line. Basically, CRC porosity level increases when CR content in CRC also increase. The outcome of this study is similar with result of the previous research (Mohammed et al., 2016).

Pore volume increment is due to hydrophobic nature in CR that repels water and trap air during mixing of the CRC.The causes the CRC to have more pores as it hardened (Mohammed et al., 2016). Nevertheless, reduction in pore volume can be due to the high compaction effort during making of CRC as it prevents the air entrainment during mixing and aid in densifying the conrete. As shown in the graph of cumulative pore volumes, the pore size is in the range of 10 to 100,000 nm. The NS addition in the CRC mixture increased gradually from M20 to M60.When the NS inclusion increases, the cumulative pore volume decreases. As shown in Figure 4.2.2, The highest nanosilica content was in M60 which is 5%. Hence, the cumulative pore volume of M60 which is 5.5mm^3/g, is the lowest volume compared to other mix. This is mainly due to properties of NS that can increase the pozzolanic reaction between hydroxide from cement and silicon dioxide from NS which produce more C-S-H gel that can densify and reduce the ITZ thickness which eventually result in more refined microstrucre of CRC (Mohammed et al., 2016).

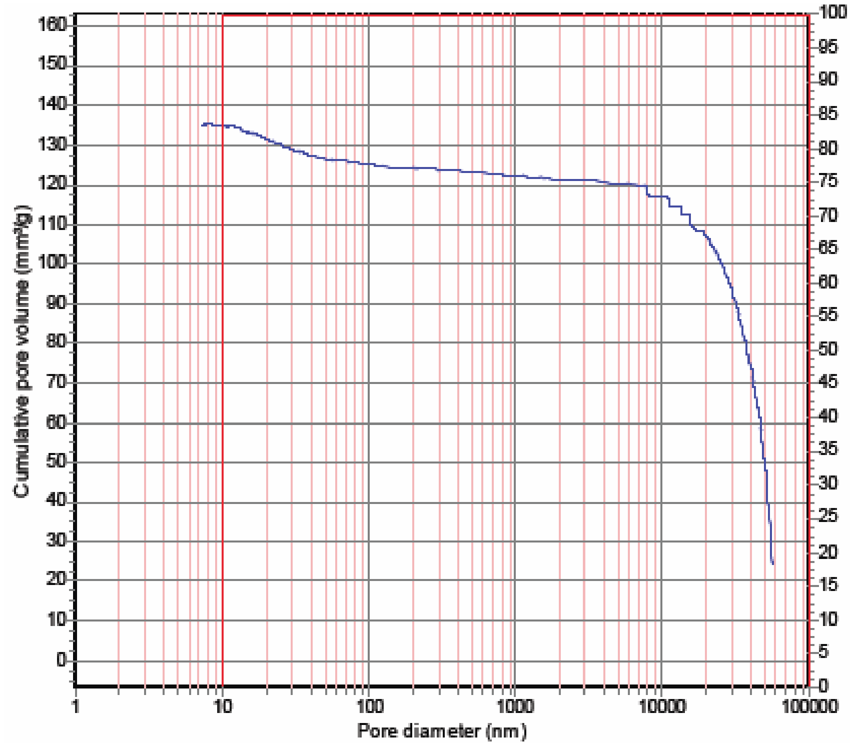

Figure 4.16 Pore size distribution of M20

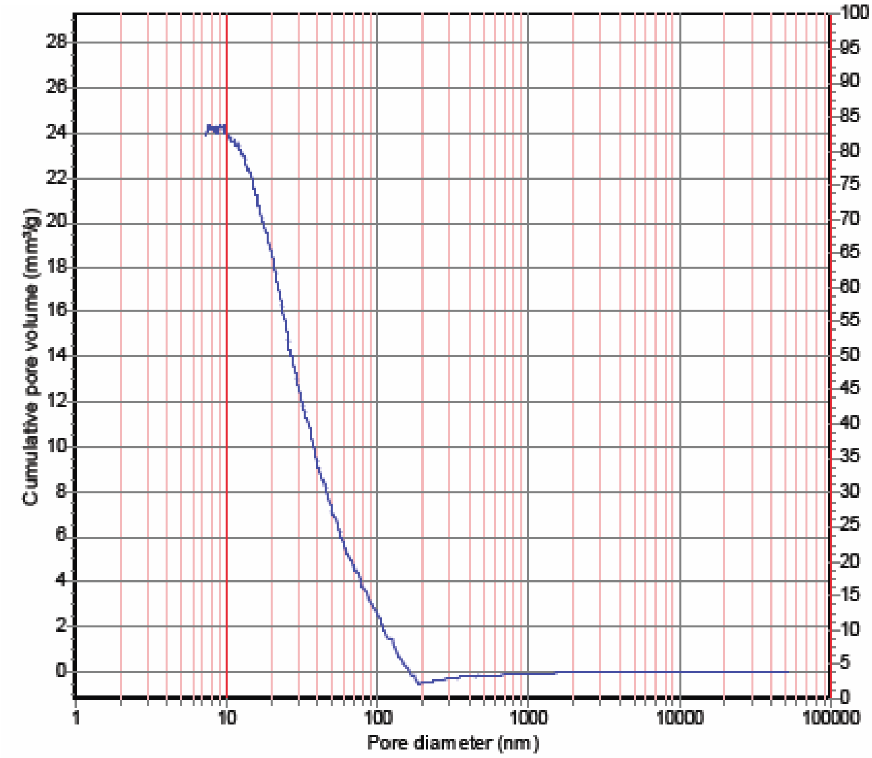

Figure 4.17 Pore size distribution of M25

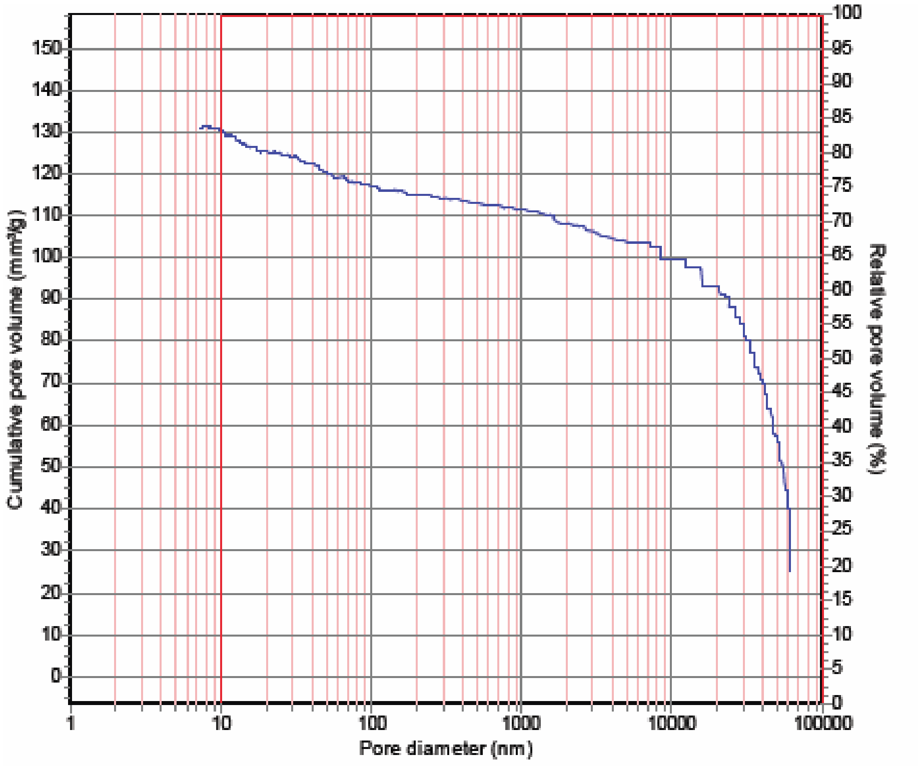

Figure 4.18 Pore size distribution of M30

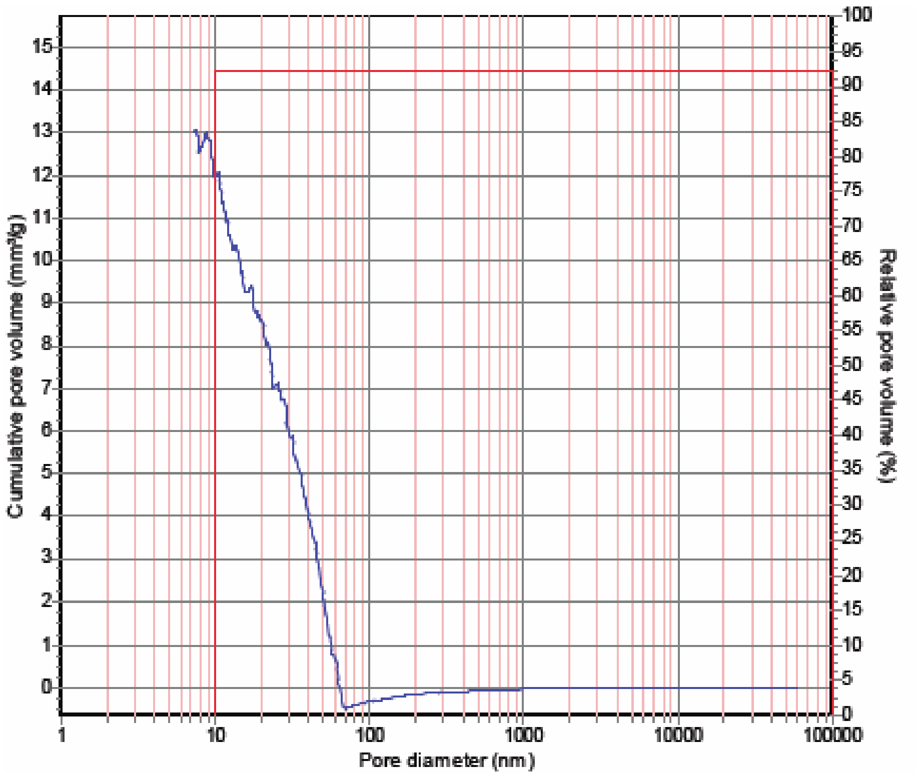

Figure 4.19 Pore size distribution of M40

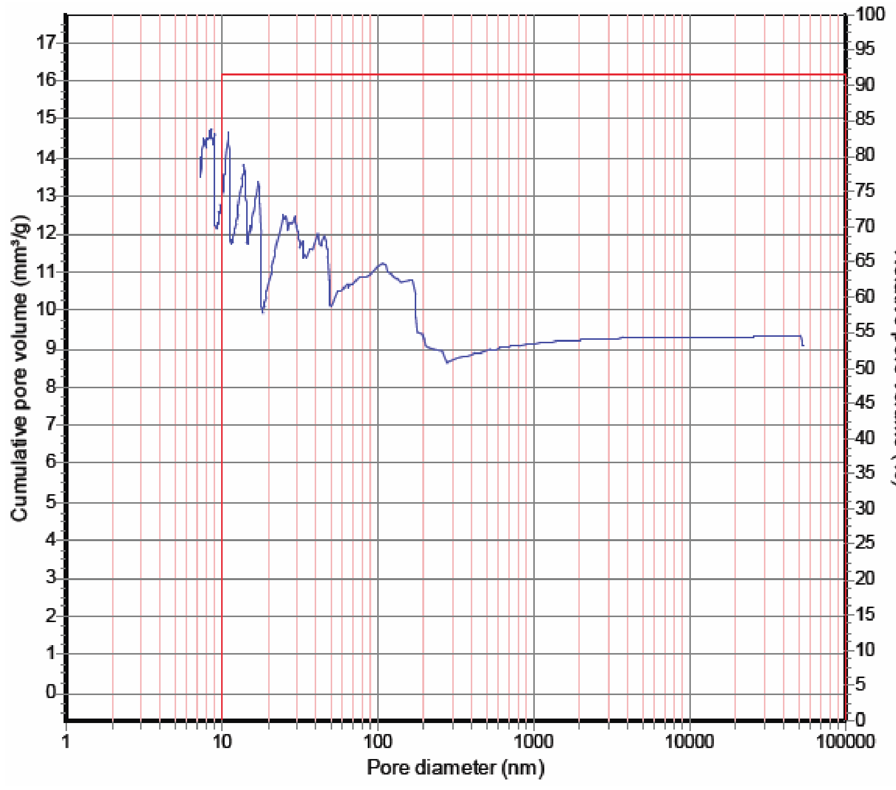

Figure 4.20 Pore size distribution of M50

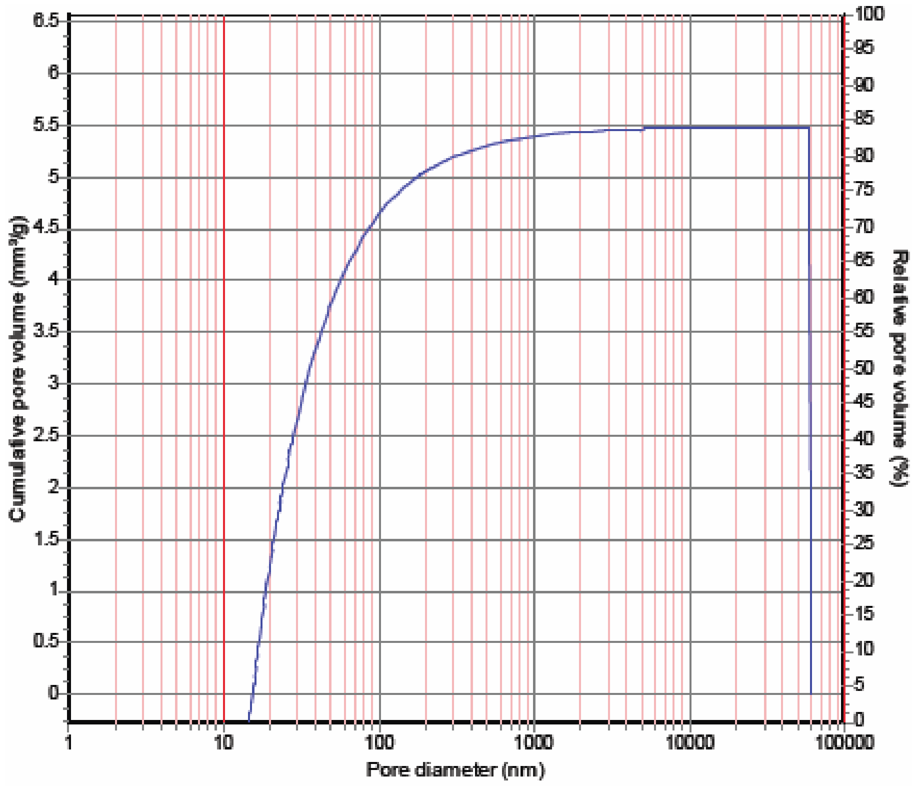

Figure 4.21 Pore size distribution of M60

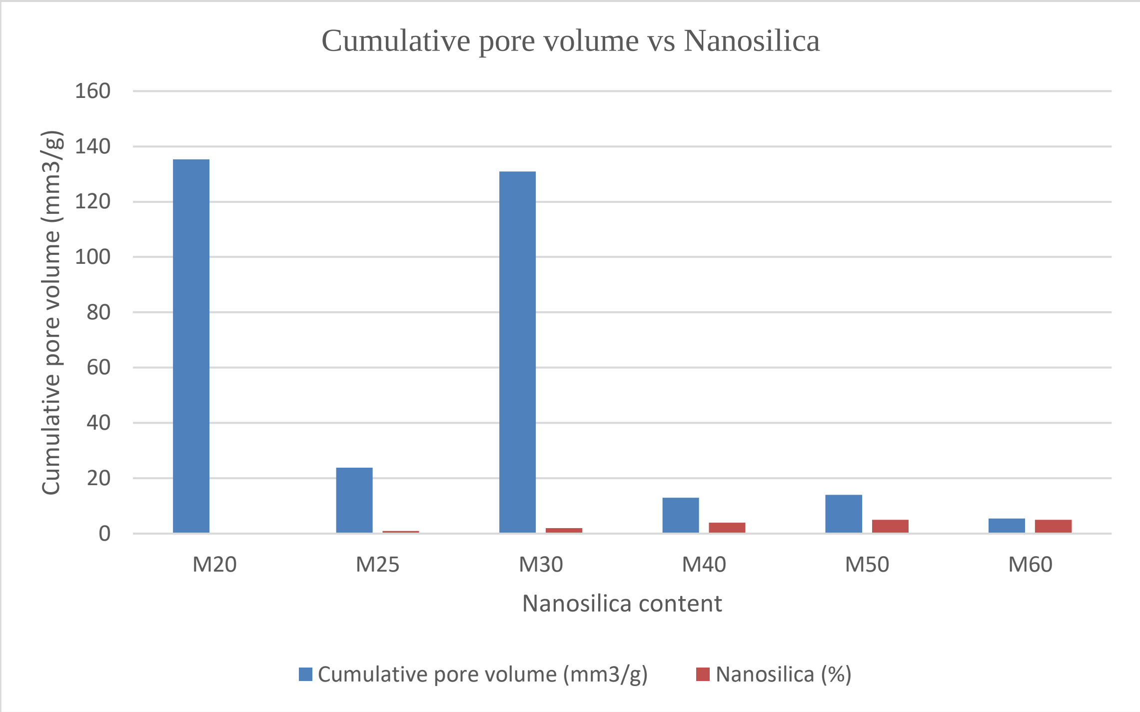

Figure 4.22 Graph of cumulative pore volume against nanosilica content

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Summary

The study was conducted to evaluate the pore structures and abrasion of crumb rubber concrete with using four different variables which is crumb rubber, nanosilica, fly ash and water/cement ratio. Total of 30 mixture with different proportions was used to determine the optimum mix design based on the compressive strength result. Further six mixtures of different proportion of crumb rubber, nanosilica, fly ash and water/cement ration was obtained by using RSM based on the compressive strength result to study the pore structures and abrasion of crumb rubber concrete. Basically, pore structure and abrasion of crumb rubber concrete were evaluated through experiment such as Cantabro Abrasion test, Field Emission Scanning Electron Microscope (FESEM) test and Mercury Intrusion Porosimetry (MIP).

5.2 Conclusion

Based on the experimental result and discussion, the following conclusion can be made:

1. The optimized mix design for crumb rubber concrete was obtained successfully using the RSM.

2. The abrasion resistance of the crumb rubber increases with nanosilica addition along with reduction of crumb rubber replacement to fine aggregate, low water/cement ratio and low fly ash content

3. Addition of nanosilica proven to refine and densify the crumb rubber concrete, reduce thickness of ITZ of the crumb rubber concrete.

4. Pore structures of crumb rubber concrete improves significantly when inclusion of nanosilica is high while crumb rubber, fly ash and w/c ratio is lower in the mixture. Cumulative pore volume decreases gradually when the addition of nanosilica increases.

5.3 Recommendation

After a detailed experimental study within the set scope and comprehensive work on CRC, the following recommendations will help as a potential future research:

1. Study the effect of additional superplasticizer into crumb rubber concrete.

2. Examine the effect of using Class C Fly Ash as partial replacement to fine aggregate in crumb rubber concrete.

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APPENDICES

APPENDIX A

MATERIALS USED FOR CRUMB RUBBER CONCRETE

Figure A.1 Fine Aggregate

Figure A.2 Coarse Aggregate

Figure A.3 Portland Cement

Figure A.4 Crumb Rubber

Figure A.5 Fly Ash

Figure A.6 Nanosilica

Figure A.7 Water

Figure A.8 Superplasticizer

APPENDIX B

SIEVE ANALYSIS RESULT

Table B.1: Sieve Analysis Results for Coarse Aggregates

Sieve size (mm)	Weight of sieve (kg)	Sieve + weight of coarse aggregate (kg)	Weight retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Total Passing (%)
13.2	1.077	1.077	0	0.00	0.00	100.00
9.5	1.079	1.083	0.004	0.13	0.13	99.87
No.4 (4.75)	1.172	3.097	1.925	64.17	64.30	35.70
No.8(2.36)	1.085	2.015	0.93	31.00	95.30	4.70
No.16(1.18)	0.951	1.077	0.126	4.20	99.50	0.50
Pan	0.735	0.75	0.015	0.50	100.00	0.00
Total	6.099	9.099	3	100.00		

Table B.2: Sieve Analysis Results for Fine Aggregates

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
No.8(2.36)	0.443	0.443	0	0.00	0.00	100.00
No.16(1.18)	0.337	0.337	0	0.00	0.00	100.00
No.30(0.6)	0.384	2.244	1.86	92.95	92.95	7.05
No.50(0.3)	0.338	0.477	0.139	6.95	99.90	0.10
No.100(0.15)	0.256	0.258	0.002	0.10	100.00	0.00
0.063	0.249	0.249	0	0.00	100.00	0.00
Pan	0.365	0.365	0	0.00	100.00	0.00
Total	2.751	4.752	2.001	100.00		

Table B.3: Sieve Analysis Results 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
No.8(2.36)	1.11	1.85	0.74	37.00	37.00	63.00
No.16(1.18)	0.97	2.01	1.04	52.00	89.00	11.00
No.30(0.6)	0.9	1.12	0.22	11.00	100.00	0.00
No.50(0.3)	0.79	0.79	0	0.00	100.00	0.00
No.100(0.15)	0.827	0.827	0	0.00	100.00	0.00
0.063	0.802	0.802	0	0.00	100.00	0.00
Pan	0.744	0.744	0	0.00	100.00	0.00
Total	7.349	9.349	2	100.00		

APPENDIX C

SLUMP TEST RESULT

Table C.1 Slump test result of trial mix.

Mix	Slump (mm)	SP value (%)	Mix	Slump (mm)	SP value (%)
1	100	2.52	16	100	1.53
2	90	1.10	17	100	2.78
3	100	0.94	18	85	0.99
4	95	1.25	19	82	1.10
5	89	1.12	20	75	0.11
6	82	0.88	21	80	1.12
7	93	2.85	22	100	0.61
8	98	2.63	23	100	1.82
9	85	0.28	24	100	0.26
10	85	0.39	25	90	1.12
11	80	1.64	26	81	0.66
12	100	1.21	27	80	0.64
13	90	0.31	28	85	0.57
14	77	0.48	29	100	0.75
15	100	0.22	30	75	0.20

APPENDIX D

RSM OPTIMIZED MIXTURES

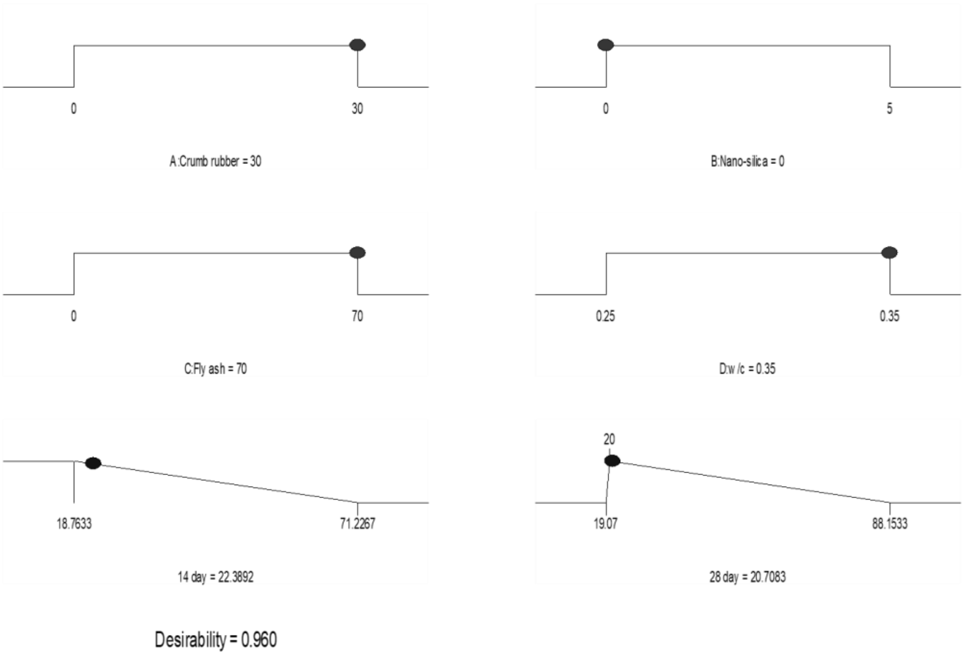

Figure D.1 Mix design for M20

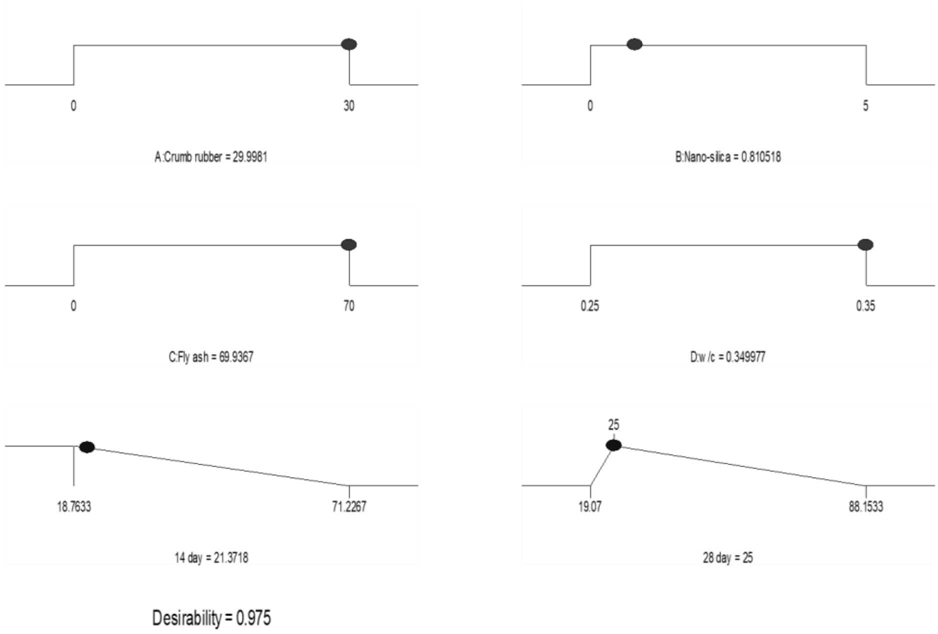

Figure D.2 Mix design for M25

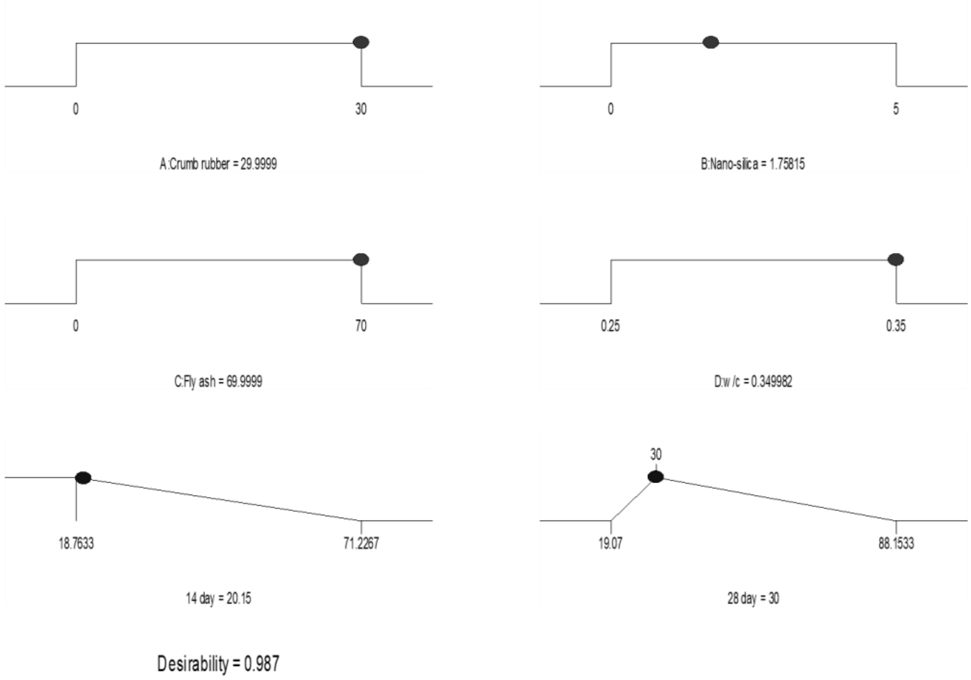

Figure D.3 Mix design for M30

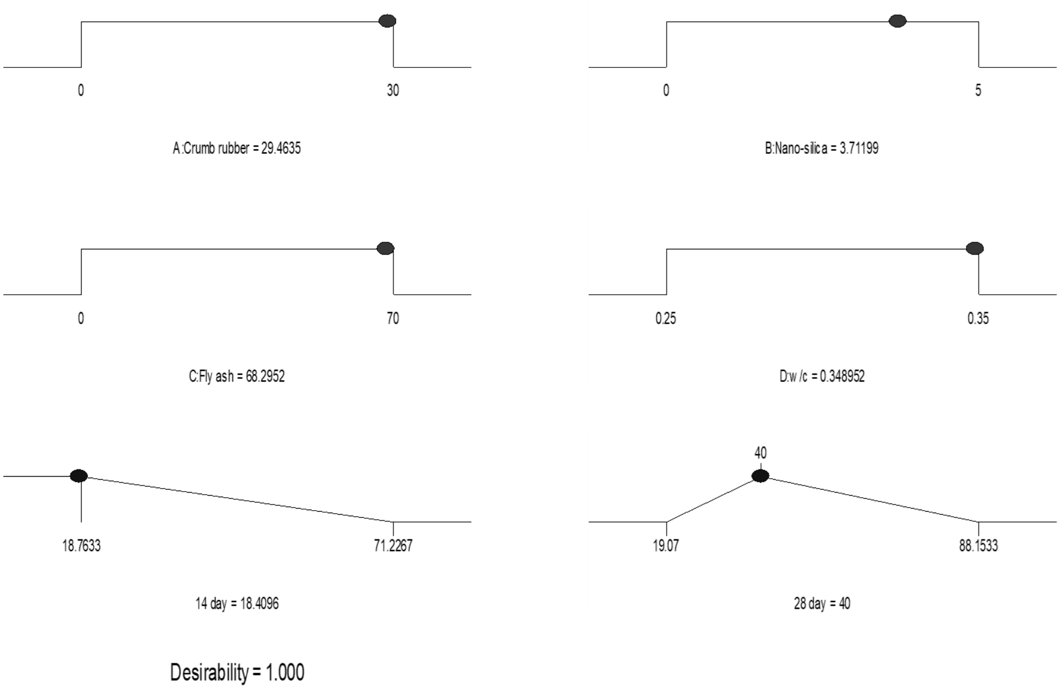

Figure D.4 Mix design for M40

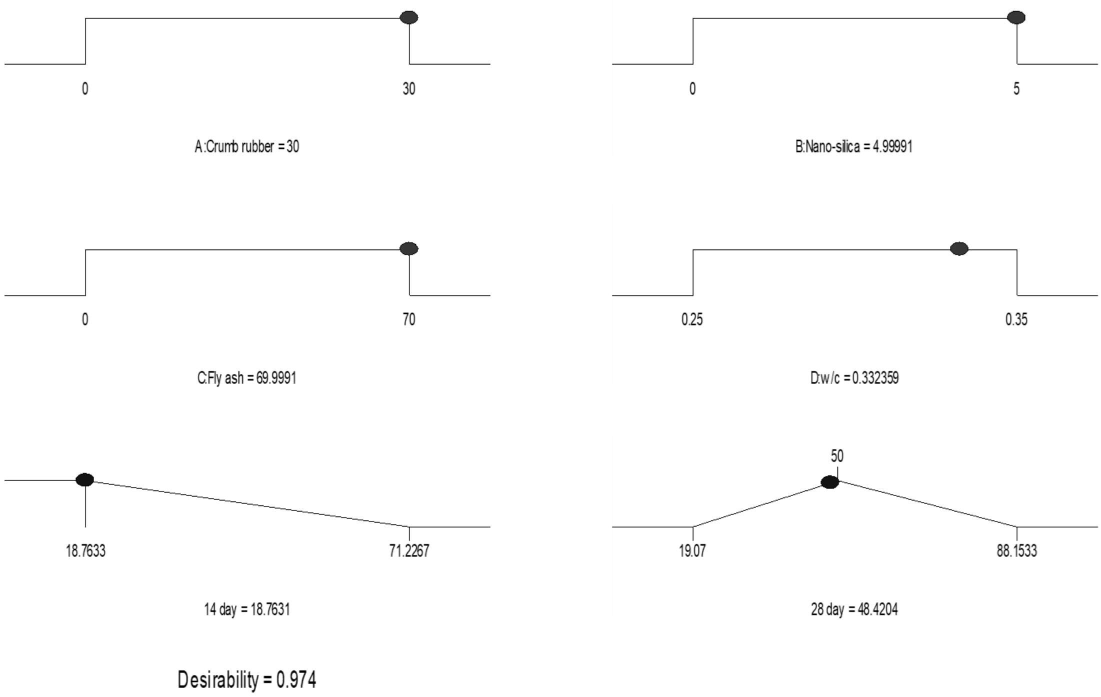

Figure D.5 Mix design for M50

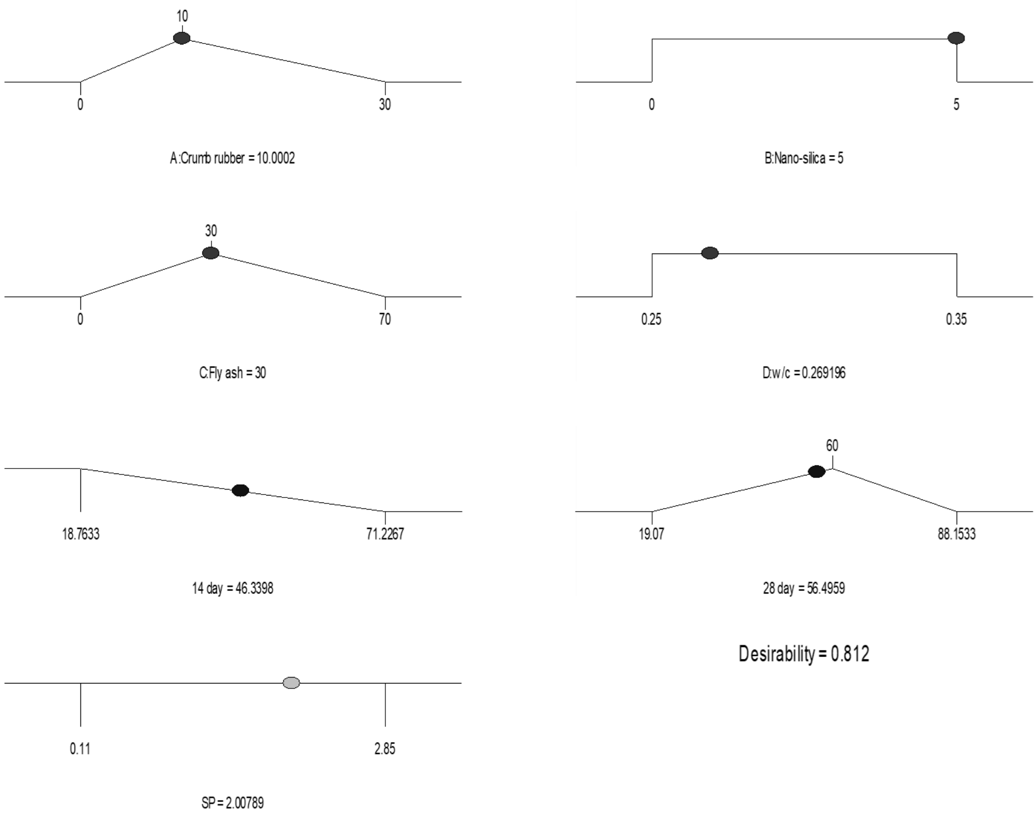

Figure D.6 Mix design for M60