THE DURABILITY ASPECTS AND BOND STRENGTH OF RUBBERCRETE CONTAINING NANO SILICA

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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CERTIFICATION OF ORIGINALITY

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

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AHMAD NUR SHAFIQ BIN AHMED NEZRI

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ABSTRACT

Crumb rubber is product from the processed waste scrap tire which is non-biodegradable and threat to environment. One of common usage of crumb rubber is production of concrete containing crumb rubber or rubbercrete. Rubbercrete contribute a lot of benefits such low density, good thermal resistivity, and high ductility. Adverse effect of rubbercrete strength of the concrete is decreased as percentage of crumb rubber added increased. This is due to physical properties of crumb rubber that repels water make the adhesion between cement and aggregate decreased. Nano silica is widely used nowadays and found can increase the compressive strength of concrete. Nanosilica works as filler in the empty spaces in the concrete particles. It acts as nucleation of the hydrated products resulting in the improvement of concrete hydration rate of the concrete proving in the high early strength of concrete containing nano silica. Thus nano silica is proven can improve the transition zone between aggregates and cement paste. Hence, in this research, we believe by adding nano silica in the rubbercrete, the nano silica will overcome the problem of decreasing in strength of rubbercrete as a matter of fact, creating a concrete that have both high ductile properties and high strength. In these studies, 0, 5, 10, 15, and 20 weights % of rubber crumbs with respect to fine aggregate is added to the concrete. The type of w/c used for the concrete containing crumb rubber is 0.41, 0.57 and 0.68 accordingly. For increasing the concrete compressive strength, 1, 3 and 5% of nano silica were introduced to the rubber containing concrete with respect to cementitios material. For the concrete containing nano silica and crumb rubber the w/c ratio used only 0.57. The mixture schemes for measuring the 28 day compressive strengths and bond strength were performed according to ACI standard. After that the durability aspect and bond strength of the concrete were tested according to BS EN 12393 and ASTM C234 1999. Result show that by adding nano silica in the concrete mixture containing crumb rubber, it counterpart the weakness of cubbercrete which low in strength. The porosity and permeability of the concrete also decrease by adding nano silica in the rubbercrete.

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CHAPTER 1
INTRODUCTION

Over time, addition of waste material in concrete is commonly used since the addition of some material brings a lot of benefits and application towards both construction industry and sustainability of the world (Batayneh, 2009). Non-biodegradable waste material such as discarded scrap tires poses environmental and health threat since even after long period of landfill treatment, unmanaged waste tire can bring a lot of harm towards environment. (Mohamed, 2009). Hence, the usage of crumb rubber from the scrap tires for the production of building material would help to decrease the threat of this waste material and also contribute in the preservation of natural resources (Bashar S. Mohamed, 2010) & (Leuzi Y, 2010).

Figure 1.1 is the example of crumb rubber used in this project. One of common usage of crumb rubber is rubbercrete. Rubbercrete contribute a lot of benefits such low density, good thermal resistivity, high sound absorption ability, high ductility and better impact resistivity (Huang, 2004)& (Mohamed, 2009). The concern of the researcher always emphasize on rubbercrete is it adverse effect on strength of the concrete such compressive and bond strength of the concrete is decrease as percentage of crumb rubber added increased. This is due to physical properties of the crumb rubber which repels water during the mixing process and entrapping air on its surfaces. The entrapped air on the surface of crumb rubber particles causes an increase in air content in the concrete mixture, producing reduction in concrete strength since the adhesion between cement paste and aggregate decreased as crumb rubber increased (Atahan, 2012).

Research found addition of nanomaterials can increase the compressive strength of concretes (Maheswaran S., 2012). This is because the nanoadditives enter the hydration reaction once they are added to the cement paste and nano silica is one or the nano material that is widely used nowadays (Li G. , 2004). Nano particles of silica work as a filler in the empty spaces in the concrete. It act as nucleation of the hydrated products resulting in the improvement of concrete hydration rate of the concrete proving in the high early strength of concrete containing nano silica. Thus nano silica is proven in improving the transition zone between aggregates and cement paste (Belkowitz, 2007).

Hence, in this research, we believe by adding nano silica in the rubbercrete, the nano silica will overcome the problem of decreasing in strength of rubbercrete as a matter of fact, creating a concrete that have both high ductile properties and high strength. In these studies, 0, 5, 10, 15, and 20 weights % of rubber crumbs with respect to fine aggregate is added to the concrete. The type of w/c used for the concrete containing crumb rubber is 0.41, 0.57 and 0.68 accordingly. For increasing the concrete compressive strength, 1, 3 and 5% of nano silica were introduced to the rubber containing concrete with respect to cementitios material. For the concrete containing nano silica and crumb rubber the w/c ratio used only 0.57. The mixture schemes for measuring the 28 day compressive strengths and bond strength were performed according to ACI standard. After that the durability aspect and bond strength of the concrete were tested according to BS EN 12390 and ASTM C234 1999

1.1 Background of study

As stated earlier, the problem of rubbercrete is the reduction of strength in the concrete as percentage of crumb rubber added increased. The study is more focusing on producing the concrete that containing nano silica and crumb rubber and strength comparison between concrete that containing nano silica and crumb rubber and the one that containing crumb rubber only

1.2 Problem Statement

Crumb rubber contributes a lot of benefits in construction and research industry. By adding crumb rubber in the concrete as a partial replacement in the fine aggregate create a concrete that have low density, good thermal resistivity, high sound absorption, increase in ductility and better impact resistivity.. Concrete that contains crumb rubber or rubbercrete also possess a disadvantages compare to normal conventional concrete. Despite decreasing in weight density which make the concrete lighter and high ductile properties, most of research indicate, the reduction in compressive strength as percentage of crumb rubber replacement increased. It is due to physical properties of crumb rubber which is repels water during the mixing process and entrapping air on its surfaces. The entrapped air in the surface of crumb rubber particles causes the decreasing on the adhesion between the cement and the aggregates thus, resulting in the reduction of strength in the concrete.

Recently nano technology is being used or considered for use in many applications and it has received increasing attention in building materials with many advantages being mentioned. Many researches underline the advantages of using nano silica in the concrete mixture. Nano silica had proven result in setting high early strength in the concrete. Nano silica also proven increases in the compressive strength and bond strength of the concrete as the percentage added is increased. The main advantages that will highlighted here is the precedence of using nano silica to improve the adhesion interface between cement and aggregates in the rubbercrete. Previous researchers have found that by the role of nano particles of silica act as fillers in the voids or empty spaces· The well dispersed nano silica act as a nucleation or crystallization centres of the hydrated products, hence increasing the hydration rate.which is believe that nano silica improved the structure of the transition zone between aggregates and paste.

Hence, in this research, we believe by adding nano silica in the rubbercrete, the nano silica will overcome the problem of decreasing in strength of rubbercrete as a matter of fact, creating a concrete that have both high ductile properties and high strength.

1.3 Objective

The main objectives of this study are:

i) To develop rubbercrete with and without nano silica
ii) To analyze the durability aspects of rubbercrete with and without nano silica
iii) To determine the mechanical properties of rubbercrete with and without nano silica

1.4 Scope of study

The scopes of study based on the objectives can be simplified as follow:

i) Prepare the aggregates, crumb rubber and nano silica.
ii) Mixing and casting of the concrete containing crumb rubber
iii) Mixing and casting of the concrete containg crumb rubber and nano silica
iv) Investigate the compressive strength and bond strength of the rubbercrete with and without nano silica
v) Investigate the durability aspects of rubbercrete with and without nano silica

1.5 Relevancy of the project

Scrap tires continue to be a nuisance to the environment hence one way to control the risk is using the material as an aggregate in concrete. Crumb rubber and rubbercrete has proved its high contribution to construction industries. The properties of rubbercrete such as low density, good thermal resistivity, better sound absorption and high ductility contribute a lot in industry. Example of crumb rubber and rubbercrete application in industry such the construction of retaining wall, embankment fills in highway and composite slab consist of crumb rubber.

Crumb rubber also widely in research studies and major concern of concrete containing crumb rubber is the drop on compressive strength of concrete as percentage of crumb rubber increased. Hence, by adding nano silica in rubbercrete, the compressive strength of rubbercrete will increased. Since properties of nano silica which is increased the strength of concrete by filling the void between the cement particles and improved the adhesion interface between the aggregate and cement, the problem in the rubbercrete will be solved in this research studies thus developing the buiding material that have high ductility and high strength yet possess many advantages properties like high termal resistivity and good sound absorption. It is conclude that, by achieved this research objective, the concrete containing crumb rubber and nano silica will bring more benefits and contribution to industry.

1.6 Feasibility of the project

The project will include 15 mix of concrete containing crumb rubber and 15 mix of concrete containing crumb rubber and nano silica. The material preparation is included fine and coarse aggregate, crumb rubber and nano silica. The material is then mixed according to specific mix design. After 28 days of curing, the specimen will be tested and the durability aspect and bond strength of the concrete is determined.

CHAPTER 2
LITERATURE REVIEW

2.1 Concrete containing crumb rubber or Rubbercrete

2.1.1 Introduction to Crumb Rubber

Nowadays, in the marketplace there a lot of material research in civil engineering works have been applied and improved (Zhua, 2011).In addition, the research on the usage of the waste material has increased as well. Over time, addition of waste material in concrete is commonly used since the addition of some material brings a lot of benefits and application towards both construction industry and sustainability of the world. (Li Y. , 2008). One of the most common application of waste material in the production of building material such as rubbercrete. Non-biodegradable waste material such as discarded scrap tires poses environmental and health threat since even after long period of landfill treatment, unmanaged waste tire can bring a lot of harm towards environment. (Bashar S. Mohamed, 2010)

Hence, the application of crumb rubber from the scrap tires for the production of building material would help to decrease the threat of this waste material and also contribute in the preservation of natural resources (Mohamed, 2009). Ductility is a desirable structural property because it allows stress redistribution and provides warning of impending failure. The ductile behavior will enable the concrete material to have the capacity to deform and support flexural and tensile loads, even after initial cracking. One of the material that has been suggested as a possible replacement of mineral aggregates is rubber from used car tires. (Khaloo, 2008)

Nowadays waste tires are been processed and applied in many things especially in the construction industry. (Siringi, 2004) The properties of tires or rubber that have lightweight properties contributing a lot in the construction industry such as the construction of retaining wall, embankment fill in highway and composite slab containing crumb rubber. (Leuzi Y, 2010). Tire that have been processed has been used as lightweight fill for retaining walls to replace commonly used granular soil backfills. The addition provides some benefits like decrease the weight and decreases the lateral earth pressures acting on the retaining wall, hence reducing the cost of the retaining wall. Furthermore, for the walls that founded on weak soils, the low unit weight helps to increase stability and to avoid failure due to insufficient bearing capacity. (Sukontasukkul, 2008)

Crumb rubber is usually used as a lightweight fill in highway embankments. It has proven in various projects to be the material with the lowest cost. The low unit weight of rubber reduces driving forces and hence increases slope stability. It also reduces the weight of embankment, resulting in reducing settlement. (Azizian, 2003).

2.1.2 Properties of concrete containing crumb rubber

Rubbercrete is unique product incorporating rubber crumb from used tyres. A lot of research and studies had been conducted related the use of crumb rubber in the mixing of the concrete (Kaloush, 2004). The research in the mixture of concrete containing crumb rubber also been studied significantly since the application of crumb rubber as a part of partial replacement have been applied to both fine and coarse aggregate .Figure 2.1 show the crumb rubber that commonly used in research studies (Bashar S. Mohamed, 2010).

Figure 2.1: Crumb rubber used in research studies

One of the studies is to establish the effect of the addition of crumb rubber in size between 1 and 2 mm, as replacement of a portion of fine aggregates (sand), on the strength of concrete. Rubber was added to concrete in quantities of 5%, 10%, and 15% by volume of the mixture. Test results gathered in this research project indicated that the addition of Crumb Rubber to concrete resulted in a reduced strength as compared with that of conventional concrete. The compressive stress of the concrete decreased with the increase of the rubber content in the mix. (Kaloush, 2004). In the reinforced concrete mixture, the addition of crumb rubber changed the stress-strain relationship of concrete improving the sectional ductility of reinforced concrete, thus conclude that by adding crumb rubber the ductility of the concrete is improved. (Mohamed, 2009)

The different between the replacement of crumb rubber as part of partial replacement of the fine or coarse aggregate also give the different result in strength of the concrete. Research indicated by replaced 5% weight of crumb rubber on the coarse aggregate provide higher strength losses compare to replacement of fine aggregate. The flexibility of the concrete also improved a lot when the crumb rubber replaced the fine aggregate compare to coarse aggregate. (Ganjian, 2008)

Rubbercrete did not perform as well as normal concrete under repeated freeze-thaw cycles. It exhibited lower compressive and tensile strength than that of normal concrete but unlike normal concrete, rubberized concrete had the ability to absorb a large amount of plastic energy under compressive and tensile loads. It did not demonstrate the typical brittle failure, but rather a ductile, plastic failure mode. (Amirkhanian, 2001)

Research also found that concrete containing crumb rubber also has a better sound absorption compare to normal concrete. The test result show that noise reduction coefficients is increases as the percentage of crumb rubber replacement increases. Which means the material have lower sound reflecting ability when the sound strikes at the material; it is conclude that the sound was easily absorbed through the entrapped air on crumb rubber surface inside the rubbercrete (Bashar S. Mohamed, 2010)

Concrete containing crumb rubber also has low thermal conductivity. As the percentage of crumb rubber increases, the thermal conductivity of the concrete is decreases. According to Mohamed et al, the properties can be explained by the microstructure of concrete containing crumb rubber, the air entrapped in the crumb rubber make the concrete increasing the amount of air content. Test result show that the thermal conductivity deceases as the thermal conductivity of the air, 0.025 W m^{1} K is less than that of the concrete, 1.7 W m^{1} K. Therefore, the air voids inside the crumb rubber concrete mixture block the thermal transfer through the crumb (Bashar S. Mohamed, 2010) .

Research also found that by increasing the percentage of the crumb rubber in the concrete will decrease the slump values. Hence, it indicated that the concrete containing crumb rubber have less workability compare to the conventional concrete. According to Batayneh, despite the decrease in measured slump, observation during mixing and casting showed that increasing the crumb content in the mix still produced a workable mix in comparison with the control mix. Despite the decrease in the unit weight of the mix (due to the lower unit weight of the rubber), the unit weight remained within the accepTable range for the total aggregate volume when up to 20% crumb rubber content was used (Batayneh, 2009).

Reports indicated that there is approximately 85% reduction in compressive strength and 50% reduction in splitting tensile strength when coarse aggregate is fully replaced by coarse Crumb Rubber However, a reduction of about 65% in compressive strength and up to 50% in splitting tensile strength is observed when fine aggregate is fully replaced by fine crumb rubber. Both of these mixtures demonstrate a ductile failure and have the ability to absorb a large amount of energy under compressive and tensile loads (Li Y. , 2008).

There are also research in determine the mechanical properties of rubberized concretes with and without silica fume. Two types of tire rubber, Crumb Rubber and tire chips, were used as fine and coarse aggregate, respectively, in the production of rubberized concrete mixtures which were obtained by partially replacing the aggregate with rubber. The concretes with silica fume were produced by partial substitution of cement with silica fume at varying amounts of 5-20%. Test results indicated that there was a large reduction in the strength and modulus values with the increase in rubber content. However, the addition of silica fume into the matrix improved the mechanical properties of the rubberized concretes and diminished the rate of strength loss. (Ganjian, 2008). Table 1 indicated the conclusion of the comparison between concrete containing crumb rubber and normal concrete

Table 1: Normal Concrete VS Rubbercrete

Properties	Conventional Concrete	Crumb Rubber Concrete
Ductility	Low	High
Thermal Conduction	High	Low
Workability	High	Low
Density	High	Low
Compressive Strength	High	Low
Bond Strength	High	Low
Sound Absorption	Low	High

2.2 Concrete containing nano silica

Nano technology nowadays had been widely in the research application in the production of building materials. There is much type of nano particles that had been used in civil engineering research studies such as carbon nano tube and nano silica. The uses of nano particles are widely used because one of their properties which are 100 times smaller than the cement particles. These properties make nano particles to fill the void between the cement particles. (Mondal, 2000)

Research found addition of nanomaterials can give to the increasing of compressive strength of concretes. This is because the nanoadditives enter the hydration reaction once they are added to the cement paste. (Belkowitz, 2007)

Most of the ruptures of the concrete initially start on the area of cement paste near the aggregates. Hence, by adding nanomaterial in the mixing of concrete as partial replacement of cement paste contribute to denser structure and smoother surfaces between the cement paste and the aggregate providing a better way for force transmission. (Aly, 2011)

Nowadays, it was normal to achieved compressive strength higher than 100Mpa since by adding some of the different material than normal aggregate. Research found that by adding silica fume and superplastisizer, the compressive strength achieved is more than 100 Mpa. The research explained that the silica fume improves the microscopic texture by filling the capillary gel pores resulting in the increases of compressive strength significantly. (Zhang M.H. , 2011).

Furthermore, there also studies that do a comparison of the influence between silica fume and nano silica. The result indicated that consistency for silica fume and nano silica incorporated concrete was different. Concrete that containing nano silica makes the cement paste thicker compare to silica fume concrete as a matter of fact concrete containing nano silica also give higher compressive and bond strength value. (Amiri, 2012). Same kind of research used cement mortars also provided same kind of result proven that study of strength enhancement more depend on nano silica because the the nano scale in the silica behave not only as a filler to improve the microstructure, but also as an activator to promote pozzolanic reactions. (Belkowitz, 2007)

Concrete containing nano silica also indicated high in permeability resistance than the normal concrete (Zhang, 2010). In the studies of addition of nano silica in the fly ash cement mortars the pore analysis studies reported that permeability and pore sizes of the concrete was decreased and still the strength of the concrete is increased as percentage of nano silica added increased. (Senf, 2009)

Another research was studied for the mechanical, rheological, durability and micro structural properties of high performance self-compacting concrete containing nano silica and silica fume. The addition of nano silica alone up to 2% weight of cement improved both the compressive and split strengths by about 62% and 25% correspondingly. (Deyu Konga, 2012)

They described that the enhancement of strength was not only because of pore filling effect, but also by the accelerated cement hydration due to their higher reactivity of nano silica (Qing, 2007). Nano particles of silica work as a filler in the empty spaces in the concrete. It act as nucleation of the hydrated products resulting in the improvement of concrete hydration rate of the concrete proving in the high early strength of concrete containing nano silica. Thus nano silica is proven in improving the transition zone between aggregates and cement paste (Nik, 2012).

CHAPTER 3
METHODOLOGY

3.1 Materials

3.1.1 Fine aggregate, coarse aggregate, crumb rubber and nano silica

The processed crumb rubber mesh size 30 or No.30 (600 mm) from Ara Jaya Enterprise (Malaysia), white sand and 10 mm nominal size aggregate. Table 2 shows the sieve analysis of the fine sand aggregate. The sieve analysis is done accordance to ASTM C33. The specific gravity and water absorption test were carried out in accordance to the requirement of ASTM C127 and ASTM C128 respectively. Table 3 show several test that had been conduct and properties of Aggregate and Crumb Rubber

Table 2: Sieve analysis

Sieve Size	Percentage Passing
4.75mm	100%
2.36mm	97.3%
1.18mm	40.7%
600µm	8.0%

Preparation of crumb rubber started with shredding process that reduced the scrap tire into 100 mme50 mm. This was followed by granulation process in two stages where primary and secondary granulation further reduced the size from 50 mm to 10 mm. Separation of steel wire from the tire chips occurred after primary granulation before fed into secondary granulation. Tire chips were then grinded into smaller mesh sizes to produce crumb rubber of required gradation by cracking or grinding in rolling mills. Screens/ gravity separators and aspiration equipment were used to remove metal and fibers, respectively in the production process.

Table 3: Properties of Aggregate and Crumb Rubber

Properties	Fine Aggregate	Coarse aggregate	Crumb Rubber
Specific gravity	2.68	2.65	0.65
Moisture content	16.7	0.94	1.15
Bulk density	15.84 kN/m^3	-	-
Water absorption	4.45	1.14	-

3.1.2 Cementitious and Nano silica

Ordinary Portland Cement (OPC) Type I conform to the requirement of ASTM C150-04 was used in the producing of the concrete mixture. The chemical composition of Portland cement used and Nano silica had been shown in Table 4. Figure 1 show the figure of nano silica that been used in this research.

Figure 1: Nano silica

Table 4: Chemical composition of portland cement and Nano silica

Chemical Composition (%)	Portland Cement	Nano Silica
CaO	61.43	-
SiO_2	20.77	99.8
Al_2O_3	5.55	-
Fe_2O_3	3.35	-
MgO	2.49	-
SO_3	2.49	-
K_20	0.77	-
Na_2O	0.19	-
Loss on Ignition	2.2	-
SiO_2 + Al_2O_3 + Fe_2O_3	29.37	-
Specific Gravity	3.06	-
Average Diameter	180	15
Blaine fineness (m^2/kg)	325	200000
Density	2.22	2.12

3.2 Method and mix design.

In these studies 15 trial mixes at three level of water cement ratio (w/c) 0.41, 0.57 and 0.68 accordingly with, 0, 5, 10, 15, and 20 weights % of rubber crumbs with respect to fine aggregate is added to the concrete. Only 5 best mixes have selected for futher studies in addition of nano silica for increasing the concrete compressive strength. 15 mixes of 1, 3 and 5% of nano silica were introduced to the rubber containing concrete with respect to cementitios material and 5, 10, 15, and 20 weights % of rubber crumbs respect to fine aggregate is used. For the concrete containing nano silica and crumb rubber the w/c ratio is 0.57. Thus, total 30 mixes different mixtures were prepared, cast and tested for compressive and bond strength of the concrete. The mixture schemes for measuring the 28 day compressive strengths and bond strength were performed according to ACI standard. Table 5 show the mixture proportioning that indicated in details the mixture of the concrete containing crumb rubber and Table 6 show the details mixture of the concrete containing crumb rubber and nano silica. It should be noted that the following codes are used in Table 6.

1-C: stands for conventional (plain) concrete.

2-CR: stands for crumb rubber.

3-NS: stands for nano silica.

For example, C is indicative of plain concrete; CR5 of concrete containing 5% crumb rubber;

NS 1 of concrete containing 1% nano silica; CRNS15-3 of concrete containing 15% crumb rubber and 3% nano silica.

Table 5: Mix proportion of concrete containing crumb rubber

Mix No	w/c	Crumb Rubber		Cement (Kg/m^3)	Fine (kg/m^3)	Coarse (kg/m^3)	Water
		%	kg/m^3				
1	0.41	0	0	592.68	775.96	673.35	243
2	0.41	5	16.41	592.68	698.37	673.35	243
3	0.41	10	24.62	592.68	659.57	673.35	243
4	0.41	15	32.83	592.68	620.77	673.35	243
5	0.41	20	49.24	592.68	543.18	673.35	243
6	0.57	0	0	426.32	750.65	750.65	243
7	0.57	5	18.3	426.32	748.53	750.65	243
8	0.57	10	27.45	426.32	735.28	750.65	243
9	0.57	15	36.6	426.32	692.03	750.65	243
10	0.57	20	54.9	426.32	605.53	750.65	243
11	0.68	0	0	357.35	901.96	782.69	243
12	0.68	5	19.08	357.35	811.76	782.69	243
13	0.68	10	28.62	357.35	766.67	782.69	243
14	0.68	15	38.16	357.35	721.57	782.69	243
15	0.68	20	57.24	357.35	631.37	782.69	243

Table 6: Mix proportion of concrete containing crumb rubber and nano silica

Mix No	w/c	Crumb Rubber		Cement (Kg/m^3)	Fine (Kg/m^3)	Coarse (Kg/m^3)	Water	Nano Silica (Kg/m^3)
		%	(Kg/m^3)					
NS-1	0.57	0	0	426.32	750.65	750.65	243	4.26
CRNS-5-1	0.57	5	18.3	426.32	748.53	750.65	243	4.26
CRNS-10-1	0.57	10	27.45	426.32	735.28	750.65	243	4.26
CRNS-15-1	0.57	15	36.6	426.32	692.03	750.65	243	4.26
CRNS-20-1	0.57	20	54.9	426.32	605.53	750.65	243	4.26
NS-3	0.57	0	0	426.32	750.65	750.65	243	12.48
CRNS-5-3	0.57	5	18.3	426.32	748.53	750.65	243	12.48
CRNS-10-3	0.57	10	27.45	426.32	735.28	750.65	243	12.48
CRNS-15-3	0.57	15	36.6	426.32	692.03	750.65	243	12.48
CRNS-20-3	0.57	20	54.9	426.32	605.53	750.65	243	12.48
NS-5	0.57	0	0	426.32	750.65	750.65	243	21.32
CRNS-5-5	0.57	5	18.3	426.32	748.53	750.65	243	21.32
CRNS-10-5	0.57	10	27.45	426.32	735.28	750.65	243	21.32
CRNS-15-5	0.57	15	36.6	426.32	692.03	750.65	243	21.32
CRNS-20-5	0.57	20	54.9	426.32	605.53	750.65	243	21.32

3.3 Preparation of test specimen

The batches were prepared and cured following ASTM C192. At the completion of mixing, the concrete was deposited in a wheel barrow, remixed by shovel until it appeared uniform. Then slump test was carried out following ASTM C143. Table 7 shows the total number and size of the test specimens as well as adopted Standard test methods for the studies in this research.

Table 7: Specimen details and standards

Test	Dimension	Number	Standards
Compressive strength	100mmX100mm	90	BS EN 12390
Bond Strength Test	100mm D & 200mm high	90	ASTM C 234 1999
Porosity	4mm diameter	10	ASTM C 642
Permeability	55mm D & 100mm high	10	

The compressive strength test specimens were prepared in accordance with the requirements of the BS EN 12390. Figure 2 shows the specimen preparation picture.

The materials for the block making were initially compacted three times manually using a hammer and of approximately equal depth. Then compaction was carried out by using compression machine; a compression force at a rate of 600 kN min ^{1} is applied for 1 min to compact the material in the mold. Test specimens were removed from the mold after 24 h and subjected to 28 days water curing. Figure 3 shows the specimen prepared for the compression strength test.

Figure 2: Specimen preparation picture

Figure 3: Specimen prepared for compressive strength test

The pull out test or bond strength test specimen is prepared according to ASTM C234 1999 by pouring the concrete material in cylinder size 100mm diameter and 200mm high while a steel rebar was positioned vertically at its center and held in place 100mm from above by protruding into an indentation at the center of the bottom inside surface of the mold. The mild steel rebar was size 12, length 26 cm, and diameter 12mm, and 0.888 kg/m mass per unit length, 113 cross sectional area crossed spiral surface deformations of pitch 2.6 cm and protruded height 0.1 cm. After the pouring of the concrete mix, compaction was carried out by using compression machine; a compression force at a rate of 600 kN min ^{1} is applied for 1 min to compact the material in the mold. Test specimens were removed from the mold after 24 h and subjected to 28 days water curing. Figure 4 show the specimen prepared for the bond strength test.

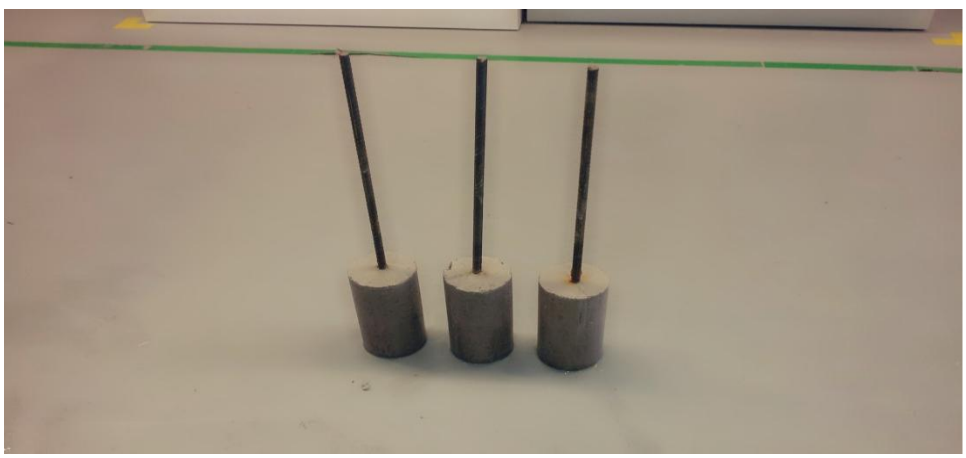

Figure 4: Specimen prepared for bond strength test

There is no standard method for measuring permeability of the concrete neither from ASTM guideline nor BS standard. The permeability equipment conforming to IS was used in the study and the testing specimen was prepared according to the manual and requirement of the permeability testing machine. The specimen required is cylinder with 55mm in diameter and 100mm high. Test specimens were coring from the slab mold and subjected to 28 days water curing. Figure 5 below shown the specimen that been used for permeability testing.

Figure 5: Specimen for permeability test

The specimen that was prepared for porosity testing is a small part of the 100X100X100 mm cube that had been casted. The cube was prepared based on the compressive strength standard procedure which is BS EN 12390. The specimen for porosity testing was chipped off from the cube specimen. Size of the specimen used was approximately 4mm in diameter size. The procedure of preparation followed is according to ASTM C 642. Figure 6 below show the specimen used for porosity testing.

Figure 6: Specimen for porosity test

3.4 Experiment procedure

The compressive strength for the 30 mixtures was determined using cube specimens. The test was carried out at 28-days using ELE compression 2000kN machine in accordance with the requirements of the BS EN 12390. Figure 7 shows ELE machine that had been used to test the specimen. A constant rate of 0.2 N/mm^2 loading was applied when testing conducted. The machine will give the maximum axial load applied on the specimen. The results were taken as average value of compressive strength from three cube of the same mixture.

Figure 7: ELE Machine for compressive strength

Pull out test was conducted to determined bond strength of the concrete for the 30 mixtures. The test was carried out at 28-days using Universal Testing Machine (UTM) 1000kN in accordance with the requirements of the ASTM C 234 1999. Speed of loading is 0.367 kN/s. Figure 8 shows UTM machine that had been used to test the specimen. From the machine the breaking load or the maximum loading applied to pull out the rebar from the concrete specimen will be given. From the result given, bond strength of the concrete will be calculated as equation 1 below.

$$\boldsymbol{\tau = \frac{F}{\pi \times D \times L}} \qquad \text{Equation 1}$$

Where:

τ = Bond strength of the concrete

F = Breaking load applied

D = Diameter of rebar used (mm)

L = Depth of rebar penetration

π = Pi

Figure 8: UTM Machine for pull out test

Permeability of concrete for 30 mixtures was determined by using Metest machine Figure 9 below show the machine that been used to determine the coefficient of permeability.

Figure 9: Apparatus for permeability testing

The permeability tester used was a tester with two layouts which is the pressure chamber and an air compressor supplying water to the test sample under required pressure. . The test cell made from a metal safely can withstand a pressure up to 2.0 MPa. The inner dimension of the cell was 115mm whereas the size of the specimen was kept as 100mm. The hose pipe from the air compressor was connected to the stem and air was admitted at a pressure about 0.5 MPa into the specimen

. The water was allowed to flow through the specimen at the pressure of 0.8-1 MPa. The test was carried out at the room temperature. The coefficient of permeability was calculated by using Darcy’s formula, which is applicable at steady state flow condition. The coefficient of permeability of a test specimen was calculated from the rate of inflow by using equation 2 which is based on Darcy’s Law,

$$K = \frac{Q}{A \times H / l \times T}$$ Equation 2

Where:

K = Coefficient of permeability in m/sec

Q = Quantity of water

A = Area of surface of specimen exposed to water flow

H = Water head causing flow

l = Dimension high of specimen

T = Time

Porosity testing is done according to ASTM C 642 1990. Mercury porosity Thermo Pascal 40 series machine was used to determine the porosity of the concrete. The specimen prepared was approxiately 4mm diameter is size. The porosity of the specimen is given by the machine after the test is done. Figure 10 show the machine that was used to determine the porosity of the concrete.

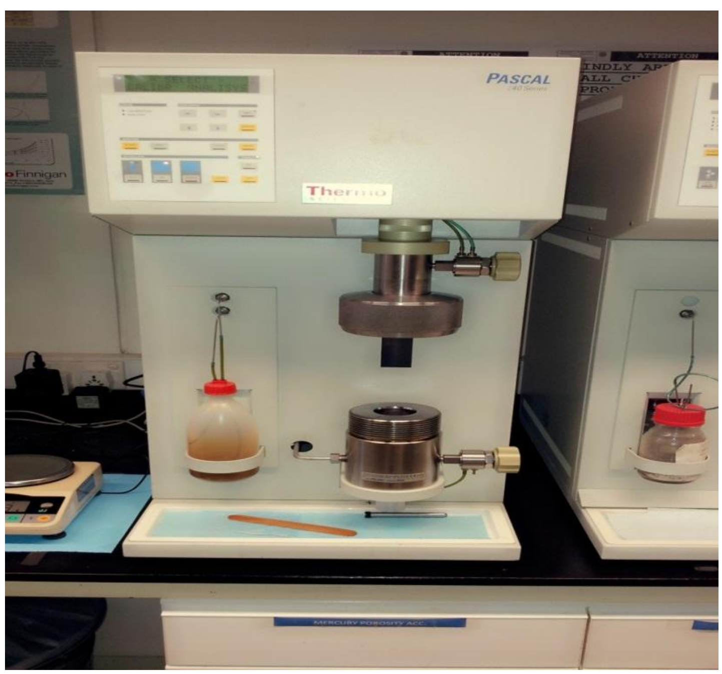

Figure 10: Pascal machine for porosity test

CHAPTER 4
RESULT AND DISCUSSION

4.1 Compressive strength and bond strength

The experimental results were summarized in Table 8 and Table 9. Table 9 indicated the result of 15 trial concrete mixes that containing crumb rubber only in as shown in Table 5. Table 9 summarize both experimental result of concrete containing crumb rubber and concrete containing nano silica and crumb rubber using same w/c ratio which is 0.57. The clear comparison between the two different types of concrete should be seen in this Table. It should be noted that the following codes are used in Table 9.

1-C: stands for conventional (plain) concrete.

2-CR: stands for crumb rubber.

3-NS: stands for nano silica.

For example, C is indicative of plain concrete; CR5 of concrete containing 5% crumb rubber;

NS 1 of concrete containing 1% nano silica; CRNS15-3 of concrete containing 15% crumb rubber and 3% nano silica.

Table 8: Compressive and bond strength of concrete containing crumb rubber

Mix No	w/c	Crumb Rubber		Compressive strength(N/mm^2)	Bond Strength(N/mm^2)
		%	kg/m3		
1	0.41	0	0	43.6	11.78
2	0.41	5	16.41	38.4	10.93
3	0.41	10	24.62	33.1	9.63
4	0.41	15	32.83	25.6	9.31
5	0.41	20	49.24	21.7	8.12
6	0.57	0	0	37.6	11.62
7	0.57	5	18.3	32.8	10.69
8	0.57	10	27.45	26.3	9.71
9	0.57	15	36.6	22.1	9.10
10	0.57	20	54.9	19.3	7.72
11	0.68	0	0	32.3	10.61
12	0.68	5	19.08	28.7	10.53
13	0.68	10	28.62	22.2	9.13
14	0.68	15	38.16	19.1	8.73
15	0.68	20	57.24	16.7	7.48

In these studies 15 trial mixes at three level of water cement ratio (w/c) 0.41, 0.57 and 0.68 accordingly with, 0, 5, 10, 15, and 20 weights % of rubber crumbs with respect to fine aggregate is added to the concrete. Figure 11 and 12 indicated that the result of the compressive strength of the mixture by using three different w/c ration. The mixture that using 0.57 were chosen for further enhancement by nano silica because of its advantages in terms of workability and strength. Workability of the mixture is also important since by adding nano silica, the setting time of the mixture will be early

Based on the graph from figure 11 and 12, we can see the compressive strength and bond strength of concrete decrease as w/c ratio increase. As the water cement ratio (w/c) increases the workability of the concrete also increases. According to Ken Hover, w/c ratio is directly related to the volume of the empty pore spaces in concrete. Correspondingly, the volume of cement in concrete related directly to the solid volume of the concrete. Water cement ratio is therefore a measure of the void volume relative to the solid volume of concrete and its strength increased as the void volume goes down. Hence, the higher w/c ratio, the higher void volume in concrete thus resulting in reducing in compressive strength. However, too low w/c ratio of the concrete might have caused concrete mixtures possess low in workability hence the mixture is hard to compact properly in the formwork.

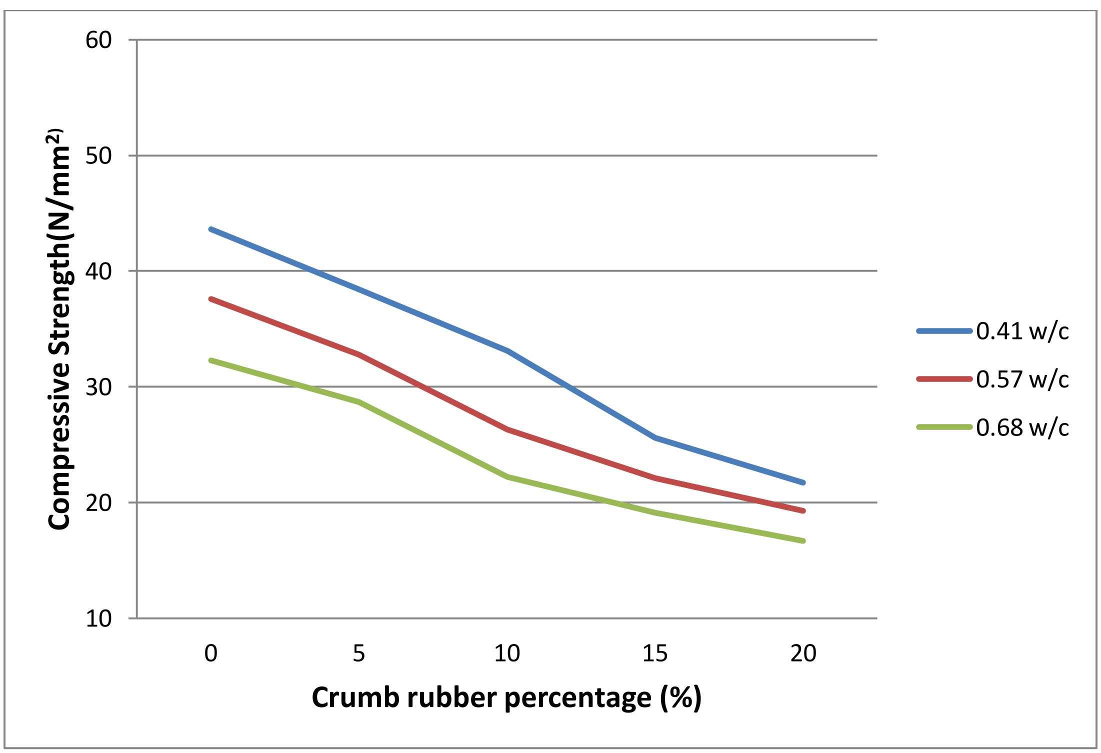

Figure 11: Compressive strength of concrete containing crumb rubber graph.

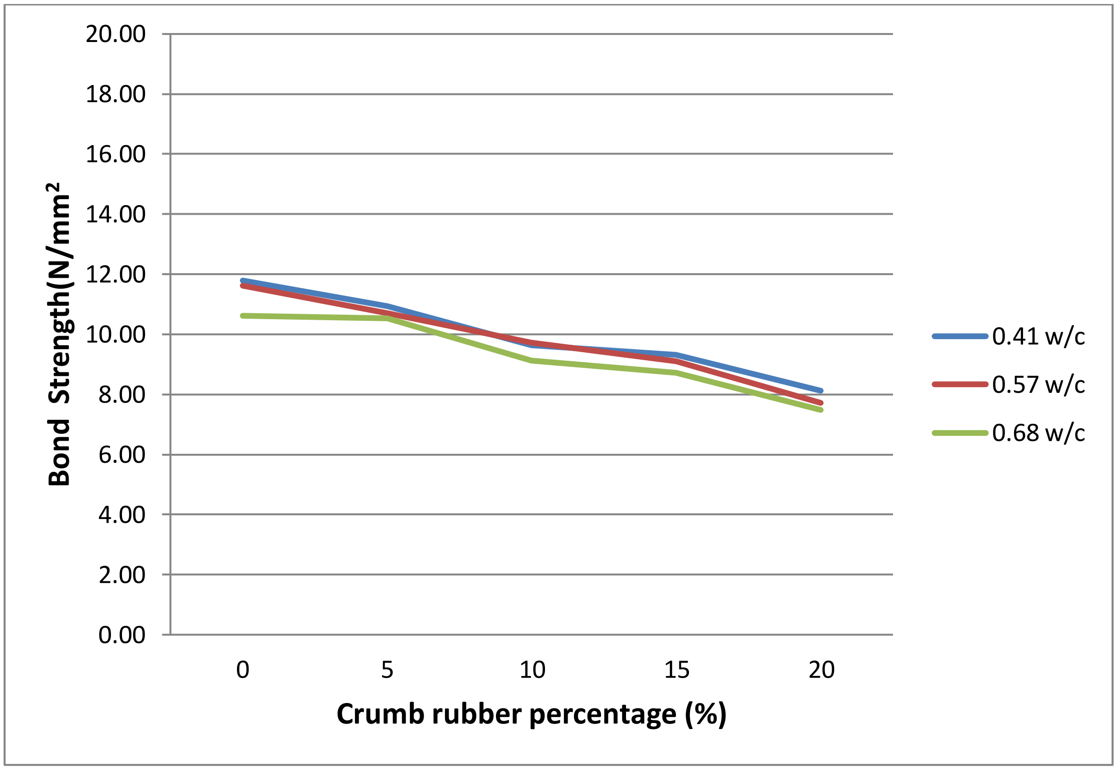

Figure 12: Bond strength of concrete containing crumb rubber

The compressive strength and bond strength of the concrete also decreased as the percentage of the crumb rubber replacement is increased. This is due to the properties of the crumb rubber itself. The properties of crumb rubber are it repels water during the mixing process and entrapping air on its surfaces. The entrapped air on the surfaces of the crumb rubber particles causes an increase in air content in the concrete mixture. Besides that, as the crumb rubber content in the mixture increased, the adhesion bonding between the cement paste and the aggregated decreased. Both of this reason is the main aspect in the reduction of strength of concrete as the percentage of the crumb rubber increased.

Table 9: Compressive and bond strength of concrete containing crumb rubber and nano silica

Mix No	w/c	Crumb Rubber		Compressive strength (N/mm^2)	Bond Strength(N/mm^2)
		%	kg/m3		
NS-1	0.57	0	0	43.4	13.35
CRNS-5-1	0.57	5	18.3	38.8	12.39
CRNS-10-1	0.57	10	27.45	32.4	10.77
CRNS-15-1	0.57	15	36.6	31.2	9.68
CRNS-20-1	0.57	20	54.9	27.7	5.65
NS-3	0.57	0	0	49.4	14.65
CRNS-5-3	0.57	5	18.3	42.6	12.84
CRNS-10-3	0.57	10	27.45	38.3	10.53
CRNS-15-3	0.57	15	36.6	35.55	9.90
CRNS-20-3	0.57	20	54.9	29.6	9.60
NS-5	0.57	0	0	51.2	15.57
CRNS-5-5	0.57	5	18.3	48.1	14.70
CRNS-10-5	0.57	10	27.45	41.3	11.44
CRNS-15-5	0.57	15	36.6	36.9	11.04
CRNS-20-5	0.57	20	54.9	31.8	10.45

In order to investigate the effect of nano silica on 28- day compressive and bond strength, 1,3 and 5 weight % of nano silica were added to specimens containing 5, 10 and 15% crumb rubber adopting 0.57 w/c ratio. The mix proportion of the mixture is based on the Table 6. The reason of choosing 0.57 of w/c ratio is because of its advantages in terms of strength and workability of concrete. Figure 13 and 14 shows the relationship of strength of the concrete related to the amount of crumb rubber and nano silica added in the mixture of the concrete.

Based on the result on table 9, it can be seen that both of compressive strength and bond strength of the concrete increases with nano silica addition for example, NS-1 is the control specimen without addition of crumb rubber. From Table 8, it can be seen that same concrete mixing with the same w/c ratio obtained 37.9 N/mm^2 of compressive strength and 11.62 N/mm^2 of bond strength respectively. It can be seen as 1% of nano silica is replaced as a partial replacement of cementious material, the compressive strength and bond strength of the concrete is improved by 10-15% which is 43.4 N/mm^2 for the compressive strength and 13.35 N/mm^2 for the bond strength of the concrete.

The relationship between strength and crumb rubber percentage of the concrete containing crumb rubber and nano silica can be seen from Figure 13 and Figure 14. The graph show multiple line of graph indicated different percentage of nano silica used in the concrete. Based on the graph, it can be seen that, by increase the amount of nano silica in concrete mixture. The strength of the concrete also improves. Even though increase in percentage of crumb rubber still decrease the strength of concrete. The strength of concrete with nano silica still has better strength than concrete without nano silica.

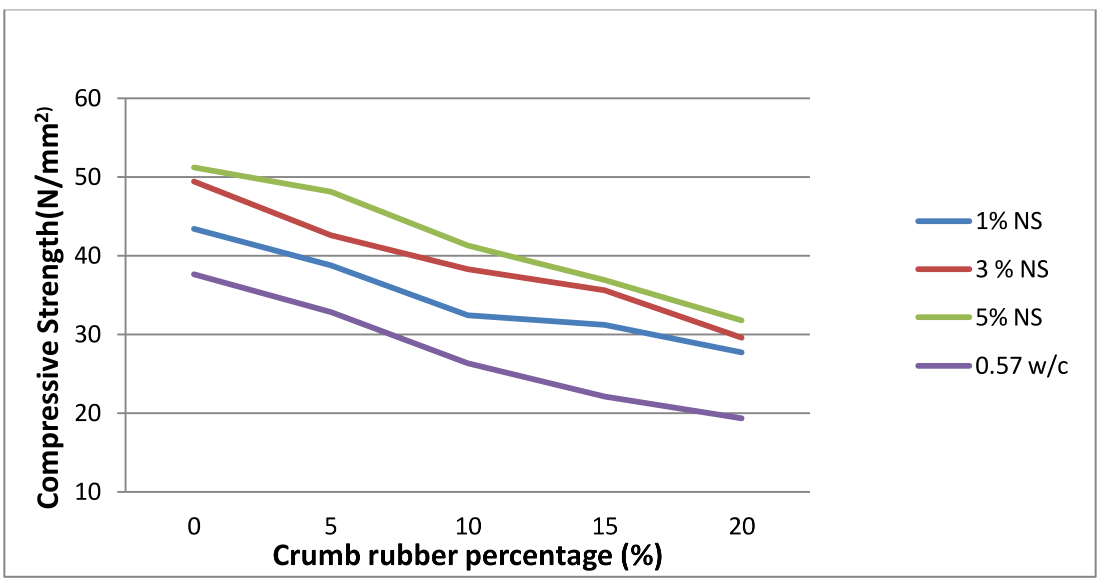

Figure 13: Compressive strength of concrete containing crumb rubber and nano silica

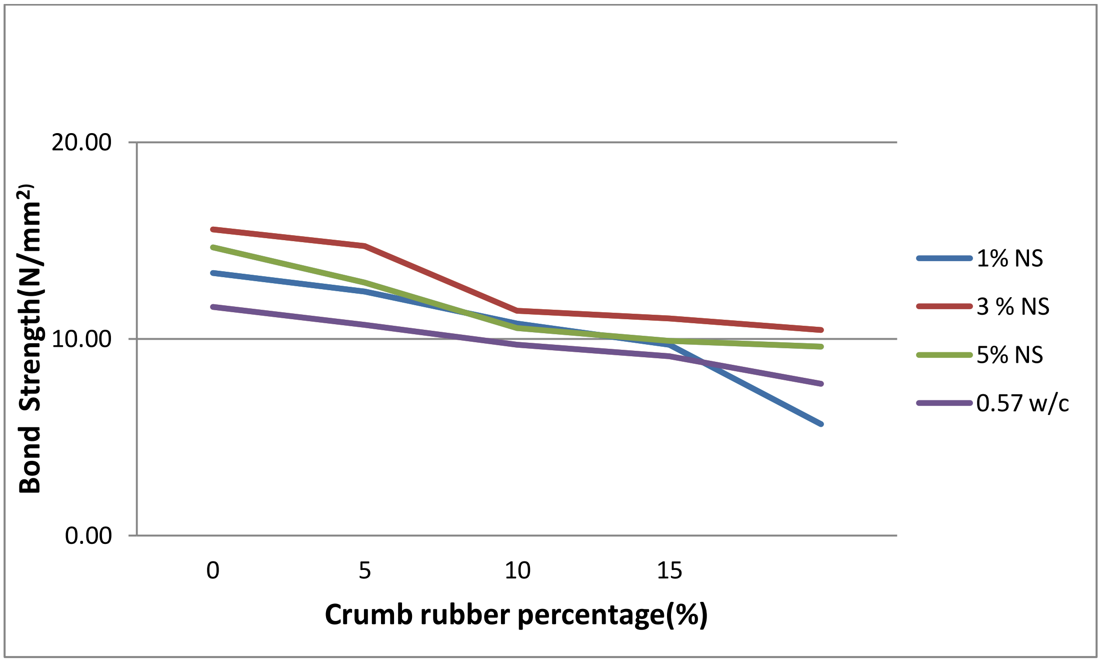

Figure 14: Bond strength of concrete containing crumb rubber and nano silica graph.

. The reason is that the nano silica act as filler to the nanometric voids in cement particles and so producing a denser structure. This results in the increment of concrete strength. The increase in strength of the concrete in the presence of nano silica arises from the high pozzolanic activity of nano silica. It seems that these nano particles provide a large surfaces area on which high pozzolanic activity occurs and nano silica particles react with calcium hydroxide from cement hydration reaction and form calcium silica gel. This process is the main contribution to the improvement of concrete strength.

However, by adding rubbercrete that contain 5% of nano silica has only slightly changes compare to the rubbercrete that contain 3% of nano silica. This is due to case of using nano silica in concrete, water shortage occurs which reduces the fluidity of the concrete. Hence, the slump of concrete decreases, and the concrete in the mold does not compact properly. This is the reason why 5% addition of nano silica does not contribute a lot in improvement of concrete strength.

4.2 Porosity and permeability

The result for porosity and permeability of the concrete was shown in Table 10 below. Specimen of concrete containing crumb rubber without addition of nano silica and specimen of concrete containing crumb rubber and nano silica with 1% and 3% of nano silica is been tested for both porosity and permeability of the concrete. The test is to analyze the relationship of compressive strength and durability aspect of the concrete as percentage of nano silica and crumb rubber increased. The entire specimen that been tested adopt same water cement ratio which is 0.57.

Table 10: Porosity and permeability results of concrete containing crumb rubber and nano silica

Mix	w/c	Crumb Rubber		Compressive strength(N/mm^2)	Porosity (%)	Permeability (cm/s)
		%	kg/m3			
NS-1	0.57	0	0	43.4	15	0.57
CRNS-5-1	0.57	5	18.3	38.8	17	0.63
CRNS-10-1	0.57	10	27.45	32.4	19	0.71
CRNS-15-1	0.57	15	36.6	31.2	20	0.74
CRNS-20-1	0.57	20	54.9	27.7	21	0.77
NS-3	0.57	0	0	49.4	14	0.51
CRNS-5-3	0.57	5	18.3	42.6	16	0.61
CRNS-10-3	0.57	10	27.45	38.3	17	0.67
CRNS-15-3	0.57	15	36.6	35.55	18	0.72
CRNS-20-3	0.57	20	54.9	29.6	21	0.75
NS-5	0.57	0	0	51.2	13	0.46
CRNS-5-5	0.57	5	18.3	48.1	15	0.53
CRNS-10-5	0.57	10	27.45	41.3	17	0.63
CRNS-15-5	0.57	15	36.6	36.9	18	0.67
CRNS-20-5	0.57	20	54.9	31.8	20	0.72

Table 11: Porosity and permeability result of concrete containing crumb rubber

Mix	w/c	Crumb Rubber		Compressive strength(N/mm^2)	Porosity (%)	Permeability (cm/s)
		%	kg/m3			
6	0.57	0	0	37.6	17	0.65
7	0.57	5	18.3	32.8	19	0.76
8	0.57	10	27.45	26.3	20	0.84
9	0.57	15	36.6	22.1	23	0.88
10	0.57	20	54.9	19.3	25	0.91

Based on the result, it can be seen that as crumb rubber percentage increase, the permeability and porosity of the concrete also increased. By adding nano silica in the rubbercrete mixture, it can be seen that concrete that contain nano silica have lower porosity and permeability compare to the rubbercrete without nano silica for example both of concrete that contain 5% of crumb rubber percentage which is mix 7 and CRNS-5-1. Based on the result mix 7 obtain 19% of concrete porosity and 0.65 cm/s coefficient of permeability whether mix CRNS-5-1 achieved 17% of porosity and 0.63 cm/s coefficient of permeability.

The permeability and porosity resistant also increase as the percentage of nano silica added as shown in result in Table 10. It can be seen as example mix CRNS-5-1 compare to CRNS-5-3. Both of mixtures have same w/c ratio and percentage of crumb rubber content. CRNS-5-1 acquired 17% of porosity and 0.63 cm/s permeability of the concrete while CRNS-5-3 obtained 16% of porosity and 0.61 cm/s permeability of the concrete.

The relationship among porosity, permeability and concrete compressive strength was discussed in Figure 15 until Figure 22. In the graph from the figure, the result of both compressive strength and durability aspect of the concrete can be seen..

Based on the result obtained, it can be seen as the porosity of the concrete increased the compressive strength of the concrete decrease. The same happen with permeability of the concrete. Permeability of the concrete is inversely proportional to compressive strength. By adding crumb rubber in the concrete mixture, the voids in the concrete tend to increase. This is due to the properties of crumb rubber which entrapped air on its surfaces. The entrapped air on the surface of crumb rubber particles causes an increase in air content in the concrete mixture. Figure 15 and Figure 16 show the relationship between compressive strength and durability of concrete that contain crumb rubber only.

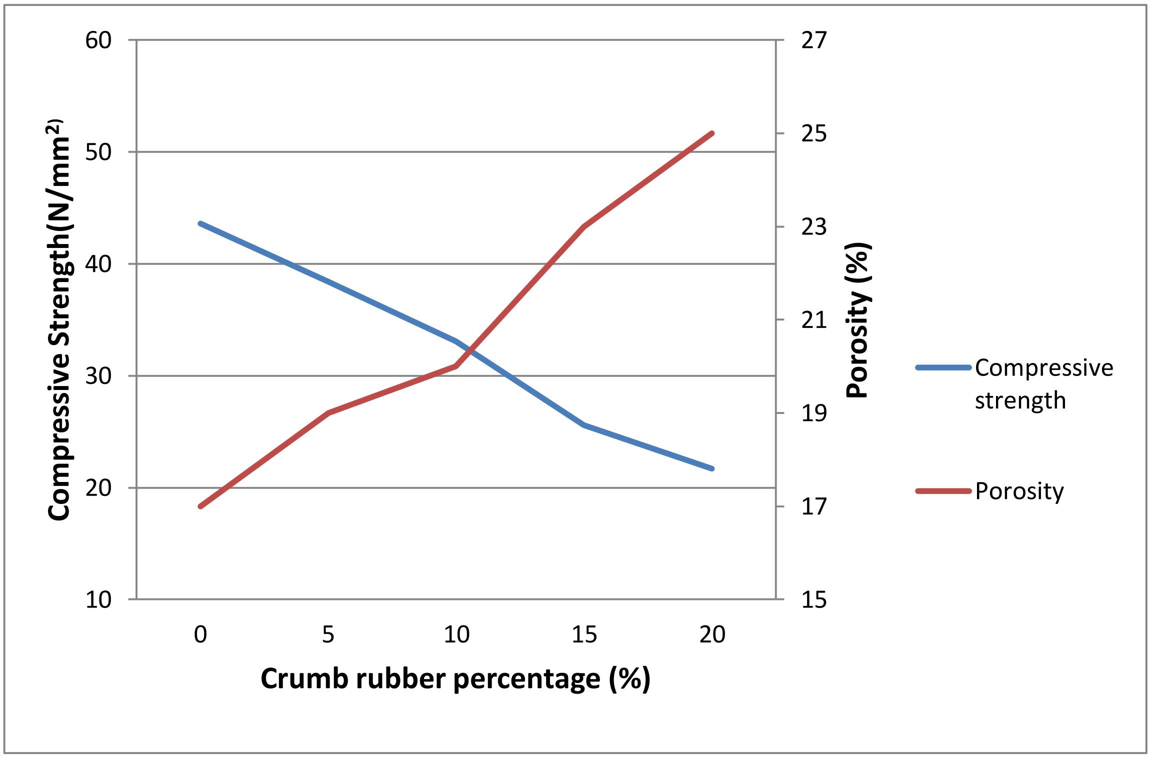

Figure 15: Relationship of compressive strength and porosity of concrete containing crumb rubber

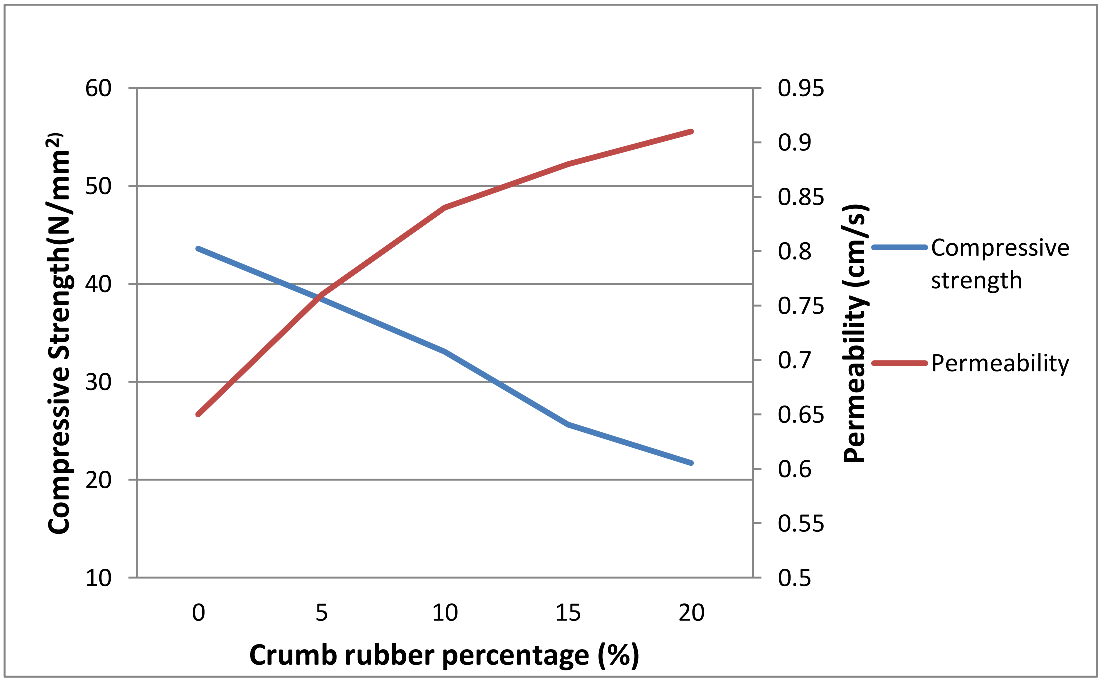

Figure 16: Relationship of compressive strength and permeability of concrete containing crumb rubber

According to Mohamed, reduction of strength in concrete containing crumb rubber is due to the increasing of void content in the specimen. The void content is related to porosity and permeability of concrete since higher void content means higher in permeability and porosity of the concrete also higher void content in the concrete resulting in low strength of concrete

In order to improve the strength of the concrete containing crumb rubber, nano silica is added in the concrete mixture. 1%, 3% and 5% of nano silica is added as partial replacement of cement material is added in the concrete containing crumb rubber. Figure 17 until Figure 22 show the relationship between the compressive strength of the concrete related to both porosity and permeability of the concrete that contain 1%, 3% and 5% of nano silica.

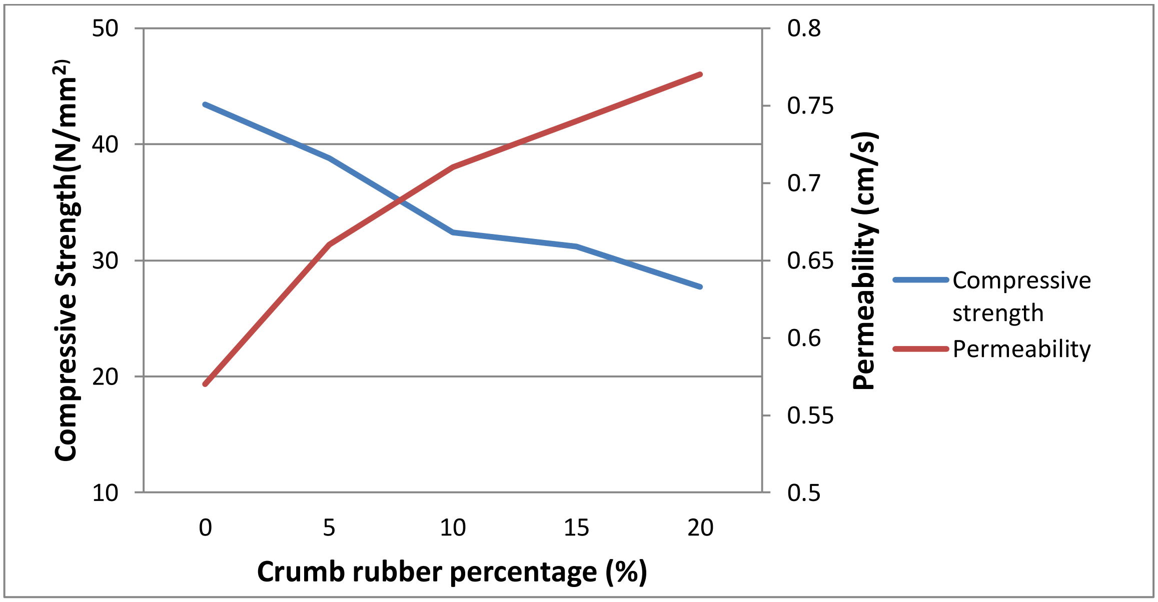

Figure 17: Relationship of compressive strength and permeability of concrete containing crumb rubber and nano silica (1%)

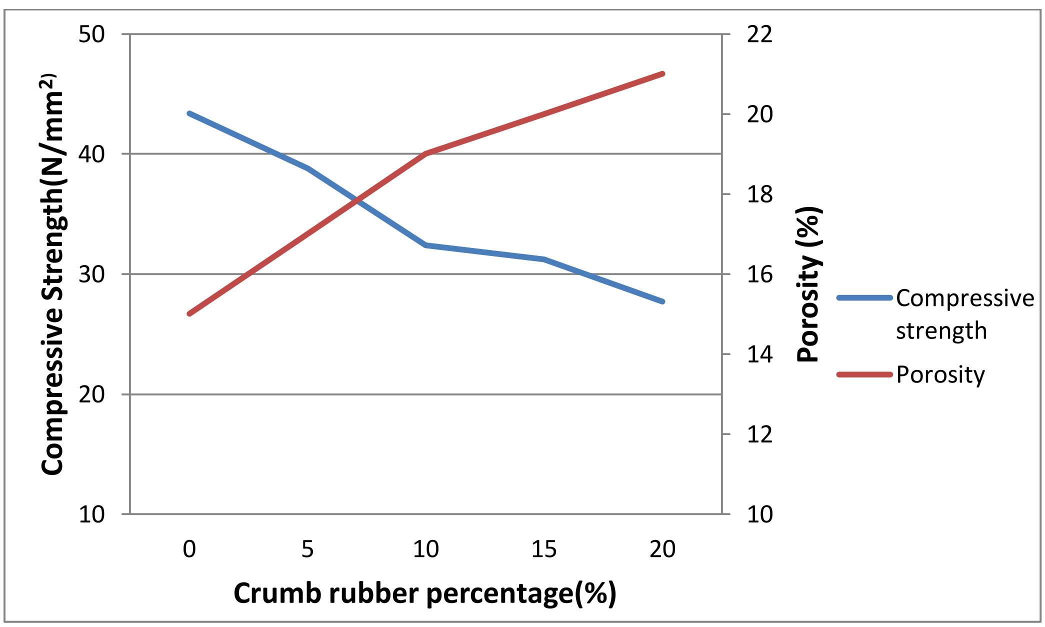

Figure 18: Relationship of compressive strength and porosity of concrete containing crumb rubber and nano silica (1%)

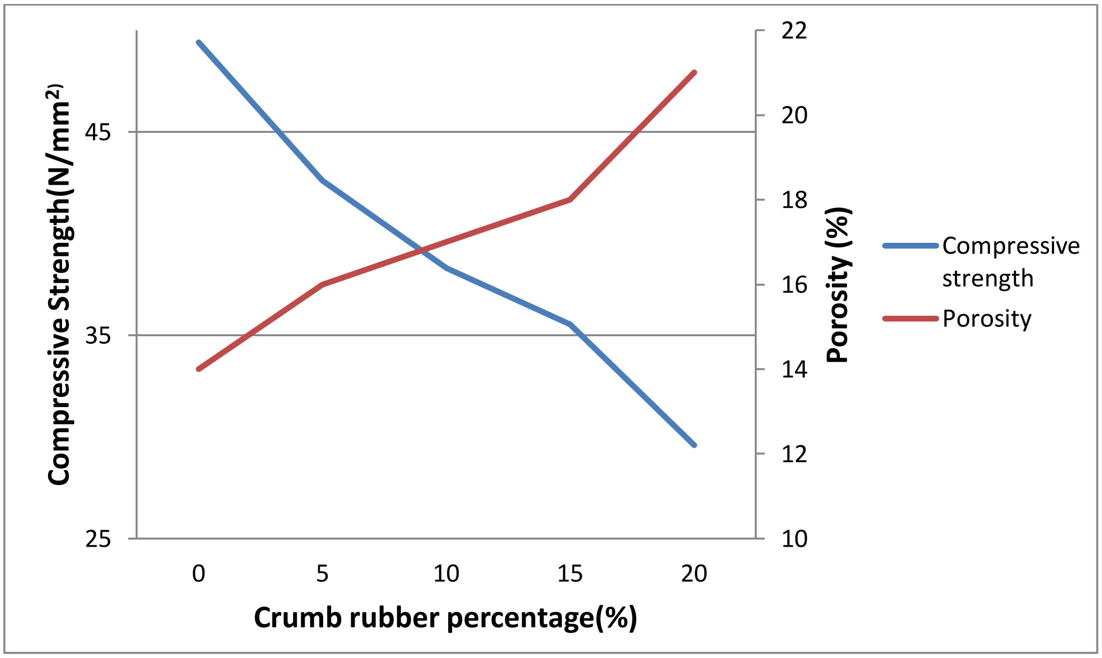

Figure 19: Relationship of compressive strength and porosity of concrete containing crumb rubber and nano silica (3%)

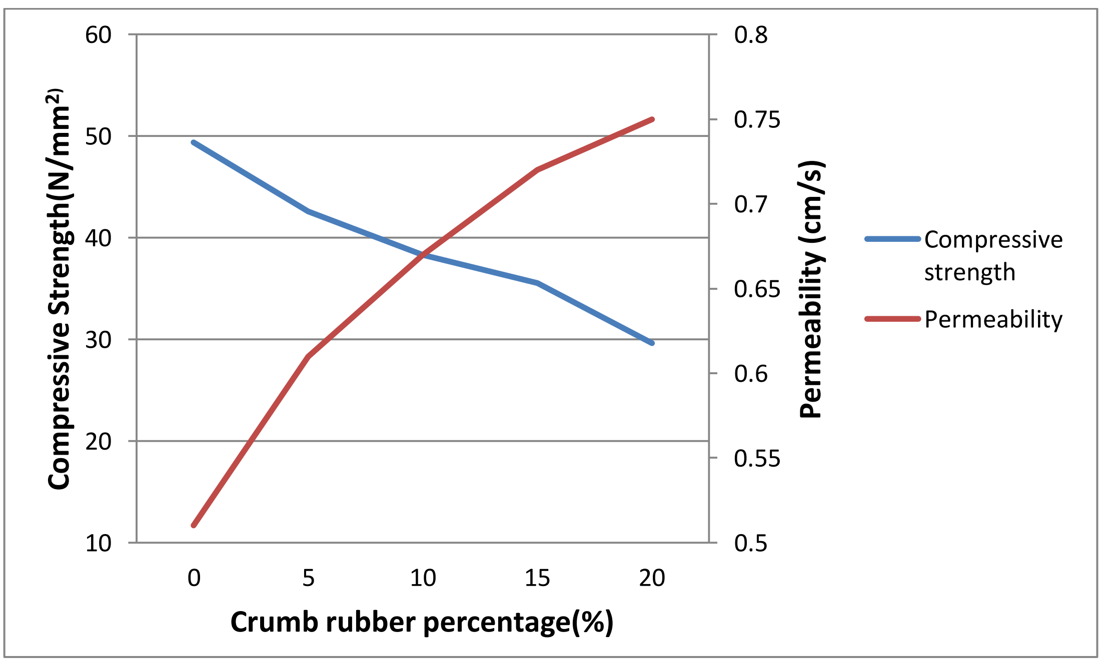

Figure 20: Relationship of compressive strength and permeability of concrete containing crumb rubber and nano silica (3%)

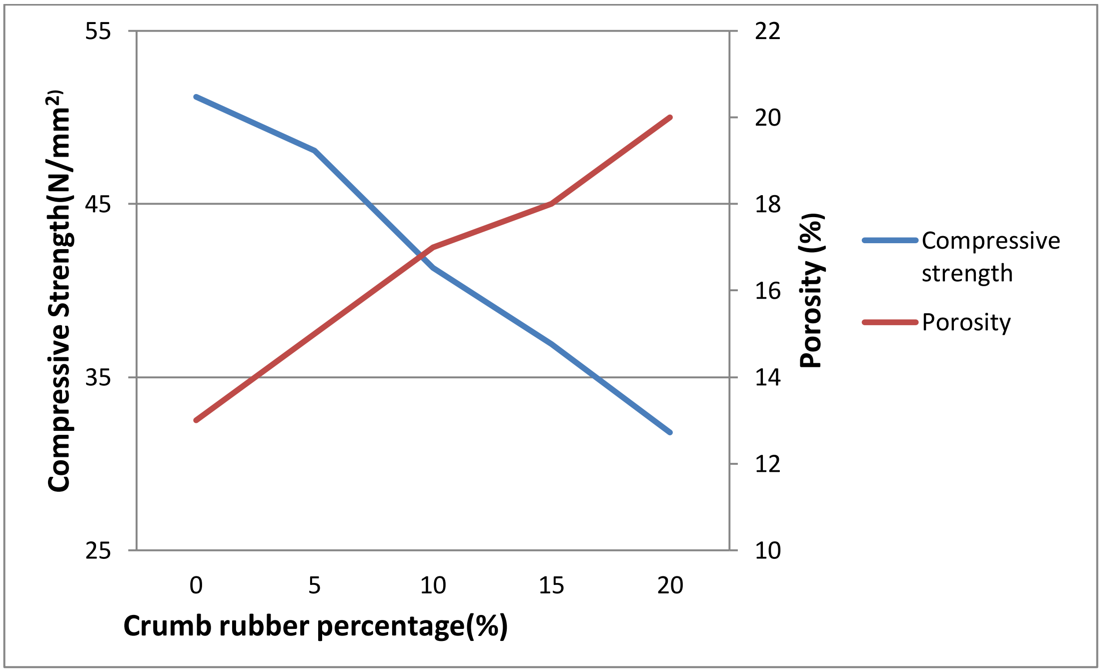

Figure 21: Relationship of compressive strength and porosity of concrete containing crumb rubber and nano silica (5%)

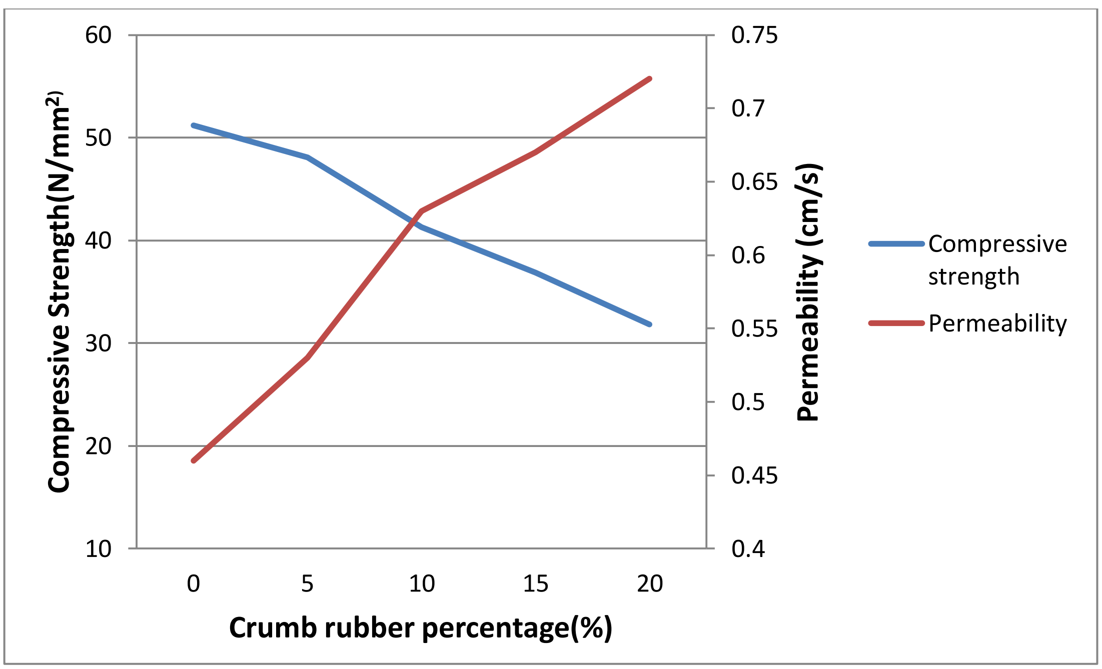

Figure 22: Relationship of compressive strength and permeability of concrete containing crumb rubber and nano silica (5%)

Based on the result, both permeability and porosity of the specimen is decreasing. This might be due to nano silica that acts as filler in the void of the concrete mixture. Properties of nano silica are the size of the particles which is 100 times smaller than the cement particles. These properties make nano particles to fill the void between the cement particles. Hence, by filling the void in the concrete mixture, the nano silica counterpart the void that entrapped by the crumb rubber thus decreases the void content in the concrete.

Porosity and permeability is depending on the void content in the concrete. Hence, if the void content in the concrete is increased, both of porosity and permeability will increased too. Another factor that affects the permeability and porosity of the concrete is compressive strength. It can be clearly see that compressive strength decreased as the porosity and permeability of the concrete increased. These are main factor that had to be considered in order to obtain the good concrete specimen.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The 28 day compressive strength and bond strength of the specimens increased by addition of nano silica to concrete containing crumb rubber. This happens because of filling capability of nano silica fine particles as well as good adhesion between the rubber and the cement paste.

Addition of 1, 3 and 5% nano silica to concrete containing crumb rubber specimens results in the increase of 28 day compressive strength in comparison with those which only contain crumb rubber. The reason of this increase is that nano materials can fill the nano voids and provide a denser structure, thus overcome the problem of crumb rubber containing concrete on the compressive strength

The porosity and permeability of the concrete increased as the percentage of crumb rubber increased. This is due to properties of crumb rubber that entrapped air on its surfaces. By adding nano silica in the mixture, porosity and permeability of the concrete is decreased. Nano silica acts as filler that fill the void in the concrete. This indicates that this type of concrete have high energy absorption yet possess high strength since both of crumb rubber concrete and nano silica concrete is combined.

Other result and behavior of concrete containing nano silica is decreasing of slump value compare to concrete containing crumb rubber. This is due water shortage occurs which reduces the workability of the final concrete resulting improper compaction of concrete in the mold. The suggestion to compensate the problem is by adding plasticizers in the concrete mixing or increase the w/c use in order to allow the concrete to have more high fluidity and workability properties.

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