DEVELOPMENT OF HIGH STRENGTH NANO-SILICA MODIFIED RUBBERCRETE

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ABSTRACT

Several research works have been carried out to study properties of concrete containing crumb rubber (rubbercrete) as a partial replacement to fine aggregate. Rubbercrete exhibits numerous benefits compared to conventional concrete such as lower in density, increased ductility, enhanced plastic capacity, higher toughness, higher impact resistance, better chloride penetration, lower thermal conductivity, higher noise reduction factor and better electrical resistivity. It has also been known to have better energy dissipation, durability and damping ratio. However, the main drawbacks of rubbercrete are decreasing in strengths and Young's modulus. Therefore, to improve strengths of the rubbercrete, the crumb rubber has been pre-coated with nano-silica. Results have revealed that nano-silica modified rubbercrete can be produced with high strengths due to the densification of the interfacial transition zone (ITZ) and refining pore system of the rubbercrete.

Keywords: rubbercrete, crumb rubber, nano-silica, ITZ

1. INTRODUCTION

Due to industrial revolution and continual development of the countries around the world, rising amount of vehicles on the roads has generated millions of used tires each year. According to research, there will be approximately 1.4 billion tires sold annually throughout the world and eventually they will reach their end life span and categorized as used tires (Presti, 2013). These 1.4 billion used tires produced annually subsequently require being disposed. Most of the used tires are accumulated and stored in the shops or dumped at the landfill or dumping site. The growing problem of used tires create major problem and concern for the people as it is non-biodegradable. Discarded tires pose environmental problem and health hazard. They are dangerous when caught fire; it is very hard and even impossible to extinguish the fire. It is also an ideal breeding ground for mosquitoes, flies and other disease-carrying vectors.

Many research works have been carried out on the utilization of crumb rubber on concrete. Crumb rubber is produced by shredding used tires and removing all the steels and fibres within it and variety applications of crumb rubber is being used in the construction industry to preserve natural resources and maintain the ecological balance for sustainable development (Mohammed at al., 2012). The utilization of crumb rubber as a partial replacement of fine aggregate in the concrete exhibits numerous benefits. However, the major problem of the crumb rubber concrete is the decrease of compressive strength with the increasing partial replacement of crumb rubber. Experiment done by Vadivel and Thenmozhi (2012) indicated that when the percentage of rubber replacement increases, the compressive strength of concrete will decrease. It is studied that the UPV (Ultrasonic Pulse Velocity) values of the rubbercrete decreases with the increasing percentage of crumb rubber in concrete (Mohammed et al., 2011). The natural properties of crumb rubber entrapped the air on the surface of crumb rubber as it repels water during mixing

(Mohammed et al., 2012). Besides, crumb rubber concrete has better energy dissipation capacity and ductility as compared to conventional concrete. It is recommended to be used in seismic applications (Son et al., 2011).

Most of the studies reviewed that Nano silica has great potential in improving the compressive strength of concretes. Nano sized particles have a high surface area to volume ratio, thus provides tremendous chemical reactivity and it is very reactive (Senff et al., 2012). The filler effects and pozzolanic reaction of Nano silica on concrete improved the durability and strength of the concrete. Besides, Nano size particles have a larger surface area to volume ratio that helps in speeding up the cement hydration and pozzolanic reaction (Said et al., 2012).Thus, nano-silica is added in rubbercrete to enhance the compressive strength of rubbercrete. Crumb rubber concrete exhibits low compressive strength because of the weak bonding present between cement matrix and the crumb rubber particle. With the aid of nano-silica as filler, it react with calcium hydroxide to fill the voids of C-S-H and the microstructure in concrete is improved and become denser, thus the compressive strength of the crumb rubber concrete can be highly increased (Rashad, 2014). Therefore, the main objective of this research is to identify the porosity and interfacial transition zone of rubbercrete containing nano-silica.

2. MIXTURE PROPORTIONS

Five rubbercrete dry mixtures with different nano-silica additives (0%, 1%, 2%, 3%, 4% and 5%) were prepared, cast under pressure and tested at age of 28 days. The mixtures contained 10% of crumb rubber replacement to fine aggregate by volume and amount of water equal to 8% of the total batch weight. Compressive strength, Field Emission Scanning Electron Microscopy (FESEM), and Mercury Intrusion Porosimetry (MIP) were conducted on samples from each mixture as shown in Table 1 and the mixtures proportions are shown in Table 2.

Table 1: The test, standards, sample dimension and number

Test	Standard	Dimension	Number of samples / mixture
Cube compressive strength	BS EN 12390-3	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	-	10 mm x 10 mm x 5 mm	1

Table 2: Mixture proportion by ratio per rubbercrete mixture

	Cementitious Materials			Aggregates		
Mixture reference	Cement	Fly ash	Nano Silica	Fine	Crumb rubber	Coarse Aggregate
NS0 CR10	0.85	0.15	0	1.8	0.2	1
NS1 CR10	0.85	0.15	0.0085	1.8	0.2	1
NS2 CR10	0.85	0.15	0.017	1.8	0.2	1
NS3 CR10	0.85	0.15	0.0255	1.8	0.2	1
NS4 CR10	0.85	0.15	0.034	1.8	0.2	1
NS5 CR10	0.85	0.15	0.425	1.8	0.2	1

3. TEST RESULTS AND ANALYSIS

Compressive stress, porosity, total pore volume and interfacial transition zone (ITZ) thickness were determined at age of 28 days and shown in Table 3.

Table 3: Rubbercrete test results

Mixture reference	Compressive strength, MPa	Porosity, %	Total pore volume, mm^3/gm	Interfacial transition zone, micron
NS0 CR10	23	15	48.6	2.9
NS1 CR10	35	12	44.2	2.2
NS2 CR10	37	7.5	33.1	2.1
NS3 CR10	38	6	27.1	1.4
NS4 CR10	42	5.5	25.9	1.4
NS5 CR10	45	2	1.6	1.1

As shown in Table 3, the compressive strength of hardened rubbercrete increased as the amount of nano silica (NS) has been increased. Adding 5% NS (NS5 CR10) leads to increasing in the compressive strength by 182% in comparison to mixture without NS (NS0 CR10). This improving in the compressive strength is attributed to the effect of nano-silica in the rubbercrete mixtures. As it is known, hardened concrete has three phases: hardened cement phase, coarse aggregate phase and interfacial transition zone (ITZ) between the between the aforementioned phases. However, ITZ is a porous phase and as the ITZ's thickness increases, the bonding between the cement paste and aggregate decreases and consequently the compressive strength decreases. In addition, in rubbercrete mixtures, another two phases are existed which are: crumb rubber phase and the ITZ between the hardened cement paste and crumb rubber particles. Crumb rubber (CR) is a hydrophobic material which repels water and entrap air on it surface which lead even to weaker ITZ between cement paste and CR. The reason of the weaker strength is explained by the stress concentrations at the ITZs which lead to forming of micro cracks which subsequently followed by failure. Therefore, to enhance the compressive strength of rubbercrete, ITZs have to be densified, in other words; enhancing bonding between aggregates and cement paste. Adding NS to rubbercrete has lead to improve significantly the compressive strength. This is due to chemical reactivity of the NS with Ordinary cement. Whereas, NS react with $Ca(OH)_2$ (hydration product of Ordinary cement) in the pore system and ITZs to produce C-S-H gel which is responsible on strength. This leads to densifying of ITZs and eventually increasing the compressive strength as shown in Table 3 and Figures 1 to 5.

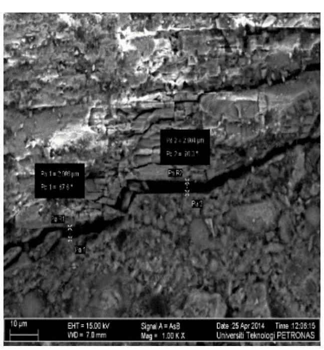

Figure 1: FESEM for NS0 CR10

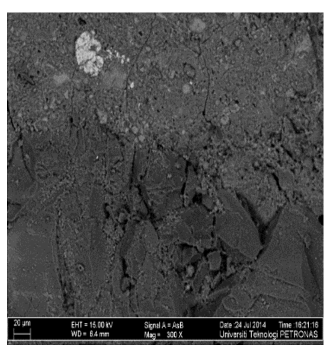

Figure 2: FESEM for NS1 CR10

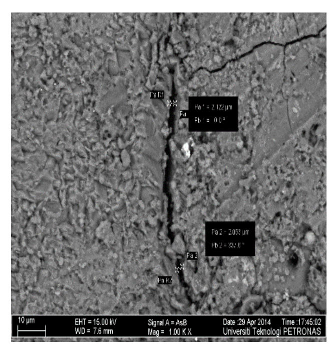

Figure 3: FESEM for NS2 CR10

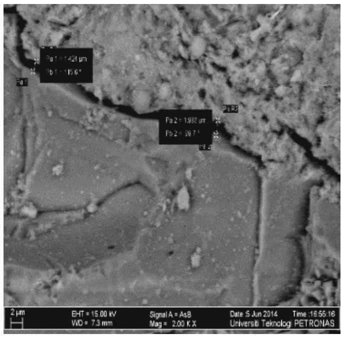

Figure 4: FESEM for NS4 CR10

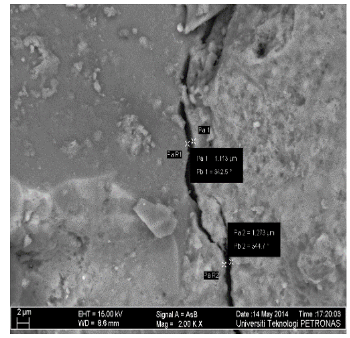

Figure 5: FESEM for NS5 CR10

Another effect of NS is physical due to its fill-ability. Whereas, NS will fill up the nano-voids in the ITZ which lead to densifying the ITZs and also filling up the pore system of the hardened cement paste in the rubbercrete which leads to decreasing the total pore volume as shown in Table 3 and Figures 6-11. Filling up the pores, in other words, is modifying the rubbercrete micro structure by densifying it and refining the pore system which in turn help in improving the rubbercrete strength and also reduce its porosity. For example, cumulative pore volume has been decreased from 49 mm^3/g (NS0 CR10) to 1.65 mm^3/g (NS5 CR10), while percentage of relative pore volume for 100 nm pore diameter has been increased from 53% (NS0 CR10) to 67% (NS5 CR10).

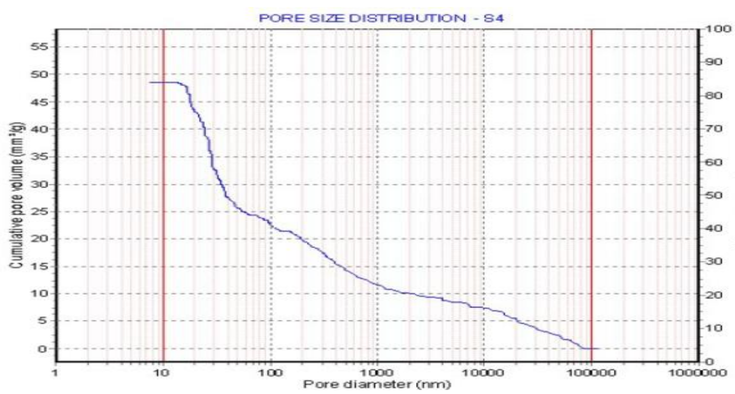

Figure 6: Pore size distribution for NS0 CR10

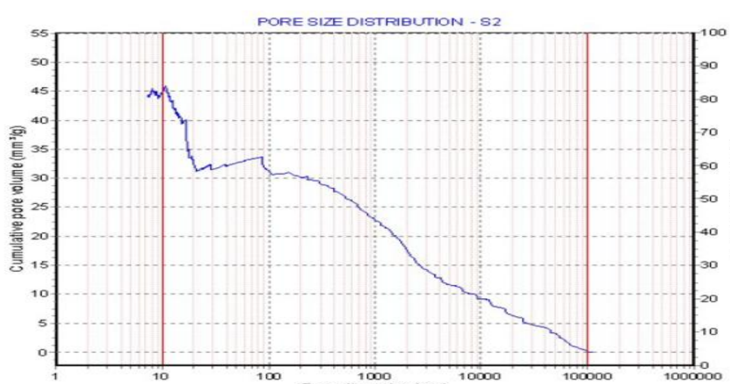

Figure 7: Pore size distribution for NS1 CR10

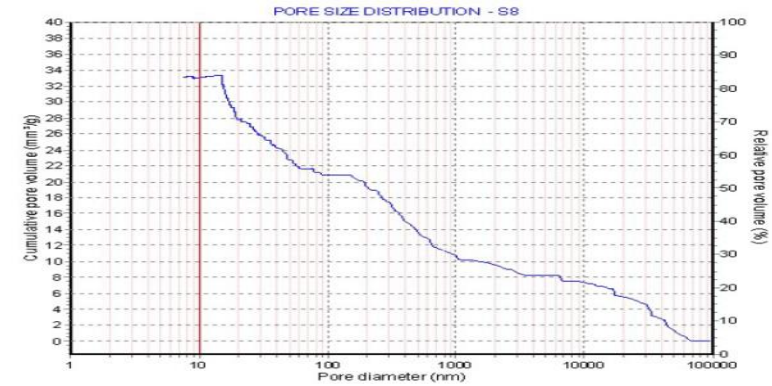

Figure 8: Pore size distribution for NS2 CR10

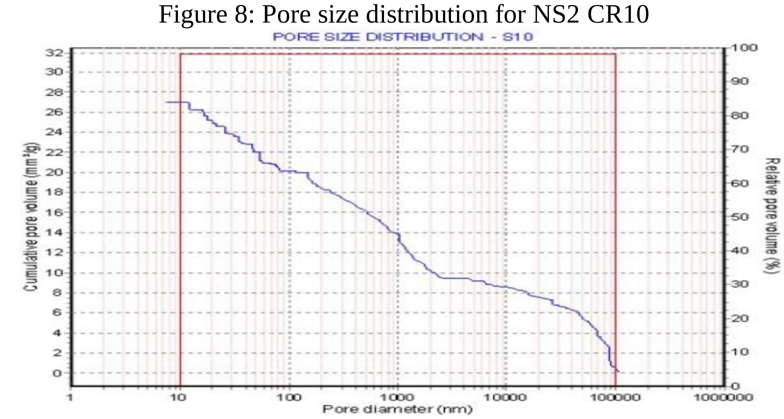

Figure 9: Pore size distribution for NS3 CR10

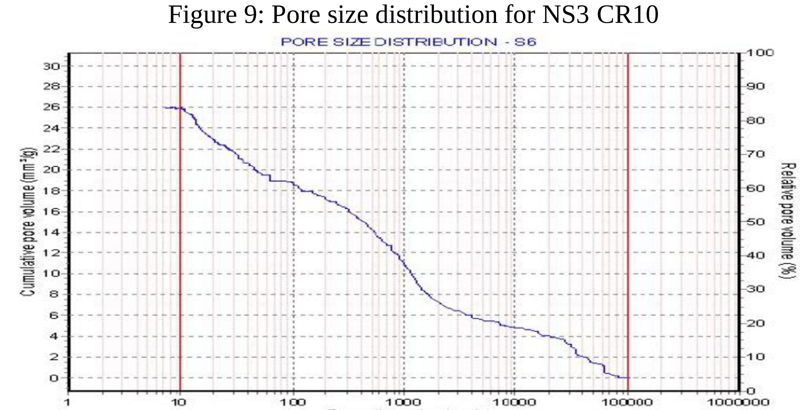

Figure 10: Pore size distribution for NS4 CR10

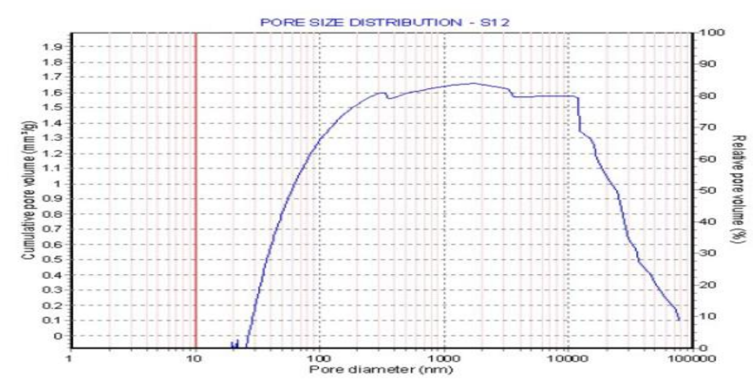

Figure 11: Pore size distribution for NS5 CR10

4. CONCLUSION

Rubbercrete has many advantages in comparison with the conventional concrete. However, it is usage in the construction industry has been limited due to its poor compressive strength. Therefore, producing rubbercrete with good strength, and without additional cement, will lead to better consideration of rubbercrete in the construction industry. Using of nano-silica in rubbercrete mixtures has lead to improving the strength due to the physicochemical. Whereas, through chemical effect, nano-silica reacts with $Ca(OH)_2$ to produce C-S-H gel which responsible for strength and through physical effect, the nano particles have filled up nano voids and also pores in the hardened cement paste. Both effects of nano-silica has led to modify the microstructure of the rubbercrete and subsequently increasing the compressive strength.

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