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Enhancement of High Strength Concrete Performance By Utilising Nano Waste Paper Sludge Ash

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ABSTRACT

High strength concrete (HSC) is an amazing breakthrough in the history of construction material. Due to its high strength, durability, and economic value, it has been used in large-scale construction with a unique structure design not achievable by conventional concrete. However, HSC uses a high amount of cement powder which contributes to its overall strength. However, it will require high cement consumption and increases carbon dioxide emission. Waste paper sludge ash (WPSA) is utilised in cement and has improved concrete properties. Nano engineered WPSA might further enhance HSC capabilities. This research focused on the physical and fresh properties of HSC with partial replacement of nano-engineered WPSA to cement through experimental investigation. The HSC produced in this research has a targeted strength of more than 40MPa with a fixed water-cement ratio of 0.2. The WPSA was oven-dried and was sieved to a particle size of 212 micrometers. Then, it was milled until a nano-size particle is obtained. The nano WPSA is used to replace cement in the HSC mix with a replacement percentage of 1%, 3%, 5%, 7%, and 10%. The new properties of the concrete were measured by conducting the flow table test, and the physical property was determined by conducting the compressive test. Compressive tests were conducted for 1, 3, 7, 14, and 28 days with a cube sample size of 50mm x 50mm x 50mm. This research shows that 1% of nano WPSA replacement tends to improve the compressive strength *of the HSC concrete by 10.7% compared to the control sample. On the other hand, the 1% replacement of nano WPSA in HSC did not affect the concrete's workability compared to the control sample. The conventional HSC properties were improved with less usage of cement with the use of WPSA.*

Keywords: high strength concrete, nano waste paper sludge ash, workability, compressive strength

INTRODUCTION

High strength concrete (HSC) discovery has vastly benefited the construction industry in building unique designs and requires less raw material. HSC has high mechanical properties such as compressive strength [1] that could cater to more loading than conventional concrete. The mix proportion of HSC typically comprises binders, mineral admixtures, aggregates, chemical admixtures with a small quantity of water. This leads to a very low water-cement ratio, and this would produce denser concrete. According to [2], HSC is also expressed as concrete with compressive strength of up to 40 to 100 MPa.

HSC is known for its low water-cement ratio, which gives higher strength and durability. However, HSC development has been growing rapidly these days. HSC has been innovated to produce more durable and ductile concrete [3–5]. HSC has also been innovated by the incorporation of waste materials such as recycled concrete aggregate (RCA) [6, 7], and palm oil fuel ash (POFA) [8].

Based on [9], concrete is only considered green if it consists of more than one cement alternative or recycled waste materials, or the production and manufacturing process is environmentally friendly or possesses high performance and excellent durability. Waste material with pozzolanic properties can be used to replace cement or used as an additive in HSC to improve concrete properties [10–14].

In this research, WPSA is used due to its abundance. According to [13], the Malaysian newsprint production mill produces around 280,000 tonnes of newsprint daily. Europe produces about 11 million tonnes of paper wastes annually [15]. At the same time, Italy produced 60kg of ash from 6×10^5 tonnes of paper sludge [16].

WPSA's main minerals are aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), and calcium oxide (CaO). It has cement-like properties when added with water [17]. According to [17], WPSA can enhance cement hydration and also has the ability to undergo its own hydration. A study by [18] revealed that 5% of WPSA was the optimum percentage that produces the best compressive strength of concrete. Other than that, WPSA has also been used in the production of low-sulfate masonry [19]. WPSA has also been used in geopolymers due to its main constituent elements. WPSA tends to enhance the mechanical strength of fly ash-based geopolymer, and the inclusion of WPSA in the geopolymer mortar tends to positively affect the geopolymerisation process [20]. On the other hand, WPSA is also used as an alternative to commercial Limes or Cements for clay stabilisation [21].

Several studies in the past show that nanomaterial tends to improve concrete properties. Nanomaterials produce denser concrete by acting as ultra-fillers [22]. The addition of nano-silica in concrete leads to better bonding between aggregate and concrete and results in enhanced toughness, shear, tensile, and flexural strength [23]. Nano-silica promoted more nucleation in the hydration process and improved the strength of concrete [22]. Other than that, nano alumina may act as extra cover, and it tends to improve the protection of concrete in the marine environment [22]. This study investigates the incorporation of nano WPSA on the performance of HSC.

EXPERIMENTAL DETAILS

Material Preparation

The material used in this study is the Ordinary Portland Cement, with a grade of 42.5. The cement chemical properties are obtained using X-ray Diffraction (XRF), as shown in Table 2 in the result section. The engineered mineral admixtures (i.e., WPSA) were obtained from the

Malaysian Newsprint Industries in Mentakab, Pahang. The raw WPSA chemical properties are also obtained through XRF and are shown in Table 2. The sand and gravel were obtained from the Faculty of Civil Engineering concrete laboratory. The sand and gravel were screened with 5mm and 10mm sieves, respectively. The sand acts as fillers, whereas gravel acts as larger fillers. Tap water was used without further purification. MasterGlenium ACE 8538 superplasticizer by BASF Malaysia was the chemical admixture. This superplasticizer is used due to the low water-cement ratio of HSC.

Table 1: Design Mix

Designation	Material					
	Cement (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	Water (m3)	Chemical Admixture (kg)	Mineral Admixture (kg)
HSC	1000	800	433	200	16	-
NW1	990	800	433	200	16	10
NW3	970	800	433	200	16	30
NW5	950	800	433	200	16	50
NW7	930	800	433	200	16	70
NW10	900	800	433	200	16	100

Sample Preparation

Preparation of Mineral Admixtures

The raw WPSA was oven-dried for 24 hours, sieved to a consistent 212mm particle size, and then milled with a planetary ball mill to obtain nano-sized particles. The rotation speed was set at 200 rpm, and zirconia balls with a diameter of 10mm were used. The balls were mixed with the powder at a weight ratio of 1 ball to 10 WPSA powder. The ball mill was stopped, and the powder sample was mixed with ultra-pure water for analysis with a particle size analyzer (i.e., zetasizer). The analysis is conducted for every interval of milling until nano-size WPSA is obtained. The smallest particle size of WPSA obtained is 351nm after 150 minutes of milling.

Preparation of Concrete Sample

The concrete in this study is of grade 40. The samples in this study consist of control concrete samples with 1%, 3%, 5%, 7%, and 10% nano WPSA replacement to the weight of cement (Table 1). Cement powder and nano WPSA were mixed in the mixer. Then, tap water was mix with a superplasticizer and poured into the mixer. Due to the low water-cement ratio, the superplasticizer was allowed to react with the mixture to ensure the paste properly mix and form a consistent paste. After that, the consistent paste was blended with sand and then gravel. After a few minutes of mixing, the mixture was prepared for flow table test, and the rest was poured in a mold.

Flow Table Test

Flow table test was used to assess the fresh concrete workability according to ASTM C 230-97. The workability of concrete with increasing replacement percentage of nano WPSA to cement weight was recorded.

Compressive Strength

All 72 hardened concrete cube samples with similar dimensions (50mm x 50mm x 50mm) were prepared for the compressive test. The cubes have undergone curing using tap water at room temperature in a curing pond for 28 days. Three cubes of different mix designation were conducted for compressive tests on days 1, 3, 7, 14, and 28. A compression machine in the Faculty of Civil Engineering concrete laboratory was used to conduct this test. This test is conducted in compliance with ASTM C109.

RESULT AND DISCUSSION

Chemical Properties of Cement and WPSA

The chemical properties of cement and WPSA used in this research are obtained by using XRF and are shown in Table 2.

Table 2: Chemical Compositions (% w/w) of WPSA and Cement

Components	Composition (%)	
	WPSA	Cement
MgO	10.15	1.27
Al_2O_3	11.50	2.56
SiO_2	< LOD	15.05
P_2O_5	9.47	0.06
SO_3	4.43	2.90
K_2O	13.59	0.41
CaO	37.75	72.17
TiO_2	0.89	0.12
MnO	0.61	0.06
Fe_2O_3	11.54	4.00

Flow Table Test

Figure 1 shows the flow behavior of HSC incorporated with different content of nano WPSA. As the replacement percentage of nano WPSA to cement increases, the flow diameter seems to decrease slightly. Both NW0 and NW1 have a similar diameter of 250mm, whereas NW3 was 249mm. All NW5, NW7, and NW10 have a similar diameter of 248mm. This is probably due to the presence of a superplasticizer. Even though the water-cement ratio is low, the concrete seems to have improved workability from the inclusion of a superplasticizer. Since a small difference of flow was observed between the control sample with the others, another set of data was analyzed.

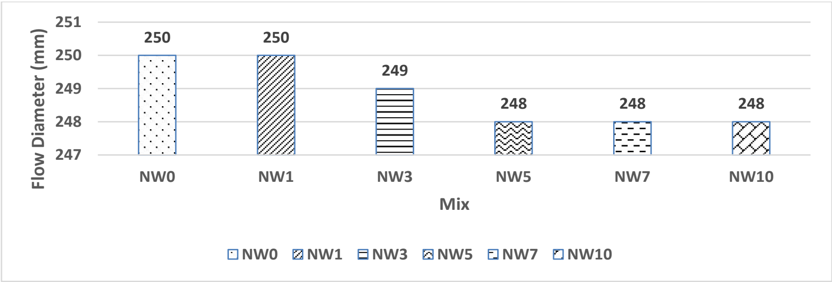

Figure 1: Flow Diameter (mm) of HSC With Nano WPSA Replacement to Cement Weight

Figure 2 shows the relationship between the mixing capability of HSC pastes with increasing replacement percentage of nano WPSA to cement. Although all samples have almost similar flow diameters, the mixing times for each mix to form a consistent paste were different. Due to the low water-cement ratio, ordinary Portland cement and nano WPSA were blended before mixing with tap water and superplasticizer to form a paste. As the replacement percentage of nano WPSA to cement increases, the mixing time was also increased. NW0 and NW1 tend to form paste around 30 seconds after tap water and superplasticizer were poured into the mix. Whereas NW3, NW5, and NW7 formed paste at 186, 248, and 307 seconds, respectively. NW10 took up to 598 seconds of mixing to form a consistent paste. The higher nano WPSA in cement caused a longer time for the mix to form a consistent paste. This could be due to the higher ability of WPSA to absorb water than cement particles [24, 25]. Therefore, WPSA particles and the superplasticizer might have absorbed more water than the cement particle, resulting in a slow reaction. The lack of water caused a longer mixing time for the cement to form a consistent paste. The high CaO content in cement powder may contribute to faster hydration and setting time. However, when the nano WPSA replaces a part of the cement, less CaO content caused a lower hydration rate and longer time for the cement to set. It can be concluded that the flow was not affected by nano WPSA replacement percentage. However, it can affect the mixing time. Thus, concrete with a longer mixing time is not efficient to be produced for large-scale use.

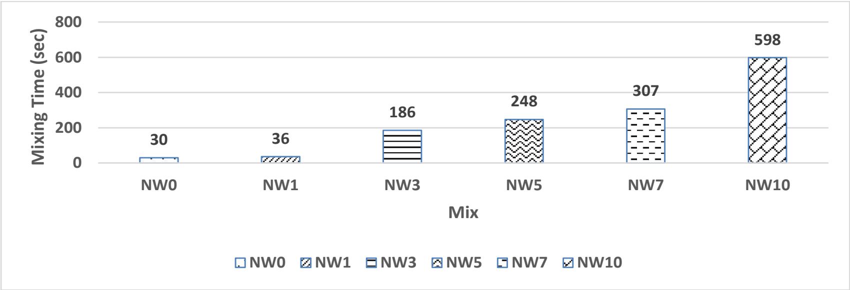

Figure 2: Mixing Time of HSC With Nano WPSA Replacement to Cement Weight to Form Consistent Paste

Compressive Strength Test

Figure 3 shows the effect of nano WPSA on the compressive strength of HSC on days 1, 3, 7, 14, and 28. As observed, NW1 has the highest compressive strength on day 28, followed by NW5, NW10, HSC, NW7, and NW3. All mixes show an increment of compressive strength. As the replacement percentage of nano WPSA increases, there is a slight fluctuation in compressive strength. At 1% replacement, the strength tends to improve drastically. However, at 3% replacement, the compressive strength diminished by 18% compared to NW0. Nevertheless, the strength improved again at 5% replacement. At 7% replacement, the compressive strength was lower than the 5% replacement. At 10% replacement, the compressive strength once again increased. This fluctuation is probably due to the agglomeration of nano WPSA particles inside the mix caused by milling. This shows that cement replaced by nano WPSA in HSC improved the compressive strength but at an optimum amount. This is also proven by [24–27], where all concrete compressive strength decreased as WPSA replacement increased. This was probably due to the lack of CaO in the system resulting in a reduction in compressive strength. Therefore, it is concluded that 1% is the best replacement percentage of nano WPSA to cement in HSC.

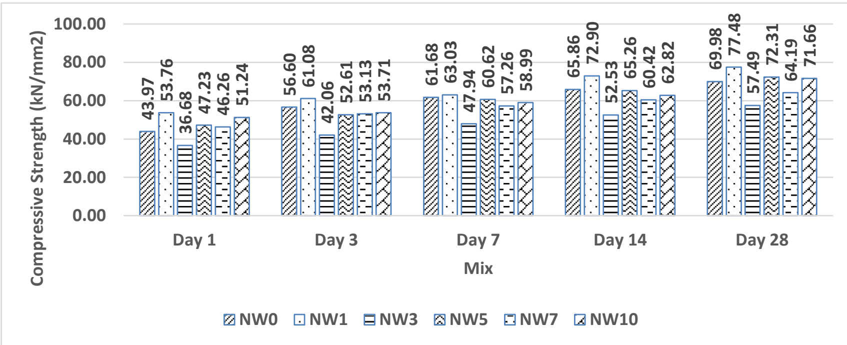

Figure 3: Compressive Strength Development of HSC With Nano WPSA Replacement to Cement Weight

CONCLUSION

This study stresses the strength and new properties of HSC incorporated with waste paper sludge ash (WPSA) through experimental investigation. Based on the discoveries of this study, it was concluded that the use of nano WPSA could improve the strength performance of HSC at a certain amount of cement replacement. 1% nano WPSA replacement to cement produced the best strength in HSC, and it does not hinder the flow. Nano WPSA replacement percentage of more than 1% has similar or lesser compressive strength with HSC despite almost the same flowability. However, regardless of the flowability, HSC with 1% nano WPSA replacement has the same paste mixing time with HSC, which is noticeably lesser than those with higher nano WPSA replacement percentages. This mixing time plays an essential role in the efficiency of production, especially on a large scale. Therefore, HSC with 1% nano WPSA replacement to cement produces the best compressive strength and flowability and the most efficient HSC to be produced compared to the others.

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