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The Effect of Superplasticizer (SP) on the Workability and Skid Resistance of Geopolymer Concrete (GPC) Containing High Calcium Precursor (HCP)

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ABSTRACT

A superplasticizer (SP) is one of the admixtures that may be used to improve the workability of concrete. However, its effects on geopolymer concrete (GPC) have yet to be well known or published, especially regarding its skid resistance and workability performance. This research aims to study the impact of the superplasticizer on the skid resistance and workability of geopolymer concrete containing high calcium precursor (HCP) in different proportions of SP, which are 0, 0.5, 1.0, 1.5 and 2.0 % by the weight of the HCP. Seven mix designs were produced: 1 conventional concrete mix, 5 geopolymers concrete mix, and 1 bituminous cold-mix asphalt mix. Slump flow and skid resistance tests were performed in this study. A skid resistance test is achieved using a British Pendulum Tester (BPT) on a 220 mm x 220 mm x 50 mm rectangle. This study found that the effect of SP on skid resistance is insignificant. However, the skid resistance of all GPC mix designs is higher than CC and asphalt mix. The workable flow of geopolymer concrete containing HCP and 0 - 2 % SP was 118-123 mm. However, less than 2 % of SP is given an insignificant difference. The optimum mix design of GPC is mix design GPC with an added 2 % SP (M6) that gives a high workability compared to other GPC mix designs and good skid resistance of 95 BPN. This study also found that workability correlates with skid resistance. The higher the spreading width value, the smaller the skid resistance value. In other words, the higher the flowability value, the *less rough the sample surface. Hypothetically, the higher the percentage of SP, the higher the workability and the lower the skid resistance.*

Keywords: Concrete; Geopolymer; Superplasticizer; High Calcium Precursor; Skid Resistance; Workability

INTRODUCTION

Concrete combines cement, fine and coarse aggregates, and water. Because of its great strength and simplicity, it is widely used in building, columns, beams, pavements, slabs, and other load-bearing components. Since many decades ago, humanity has recognized and investigated the usage of concrete as a critical component of a global building. Acceptability is determined by the material's ability to be moulded into various forms when in the plastic state and its strength and durability once hardened. Additionally, concrete's sustainability and resilience have been cited as benefits over other building materials [1]. However, since cement is the primary binding element in concrete and has been used since ancient times, the building industry's emissions are sure to grow. The cement industry's total emissions might account for up to 8 % of worldwide emissions [2]. In 2019, Malaysia produced around 16.1 million metric tonnes of cement. It is well recognized that cement usage in the building sector is environmentally harmful due to the energy-intensive and carbon-intensive processes involved in cement manufacture. According to reports, manufacturing one tonne of Portland cement emits between 800 and 900 kilograms of carbon dioxide, whereas geopolymer emits between 150 and 200 kilograms per tonne. In the future, cement production will continue unrestrictedly, causing severe environmental damage [3].

Equally important, in recent years, the highway industry on the need to construct sustainable, long-lasting, and low-maintenance pavements has grown crucial due to environmental challenges and rising customer expectations for infrastructure availability. Design specifications permit the use of a variety of hydraulic binders, such as mixtures of cement, lime, slag, and fly ash, in conjunction with marginal, recycled, and secondary local aggregates to create a more environmentally friendly pavement solution. In order to face the challenge, it is essential to consider a number of crucial criteria in the development of excellent pavement. Designers and property owners must comprehend the required degree of serviceability of the pavement infrastructure in terms of deformation, cracking, profile, and skid resistance. For example, highway pavements must have enough skid resistance, little cracking/rutting, and sufficient ride quality for high-speed vehicle movements; they should also be low maintenance owing to the higher user cost caused by lane closures and the potential for severe safety effects. The use of concrete pavement has become a topic of conversation among highway engineers at the moment, where typically, concrete pavements are utilized for severe loads and/or subgrade conditions. This is because the usage of asphalt may lead to deformation under slow-moving or stopped cars [4].

Besides, referring to The Fourth Industrial Revolution (IR 4.0), industries in this era need to be more sensitive to using natural resources, reducing waste, and taking care of the environment [5]. Therefore, various mitigations have been proposed to overcome the problem. Several researchers have conducted investigations to reduce emissions in line with building structural improvements. Concerning this issue, several attempts are being made to limit the use of cement or to replace it with sustainable materials, such as by-product cementitious or pozzolanic material utilizing geopolymer technology. Geopolymer is an environmentally friendly cementitious material, and its development may help minimize carbon dioxide emissions produced by the cement industry development. Geopolymer may be manufactured using natural and waste materials as primary raw materials through an alkali or acid activation process. Fly ash, silica fume, metakaolin, glass powder, and steel slag are all common raw materials in geopolymer concrete. Since the early 1980s, geopolymer materials have been regarded as a viable alternative to Ordinary Portland Cement (OPC) owing to their low carbon footprint and performance benefits [6].

Furthermore, geopolymerisation can be define as the process of producing geopolymers at low temperatures by chemical interactions between different aluminosilicate oxides and silicates under highly alkaline conditions, resulting in polymeric SiOAlO linkages that occur in producing the geopolymer concrete [7]. According to the notion described, the primary components of geopolymer are aluminosilicate and an alkaline solution, commonly known as an alkali activator. Aluminosilicate sources need to possess a high concentration of silicon (Si) and aluminum (Al), which may be derived from GGBS, fly ash, metakaolin, rice husk, and many more [8]. In addition, a previous study found that geopolymer materials exhibit superior mechanical qualities and various superior features, such as fire resistance, skid resistance, and corrosion resistance. However, a study found that geopolymer concrete degrades the flowability and workability, but the strength remains increased [9].

Despite the current availability of research on geopolymer concrete, studies on the use of admixtures to improve the workability and performance of geopolymer concrete still need to be more restricted. Stated in a study that geopolymer concrete needs water and superplasticizers (SP) to enhance its workability and maintain strength. Talking about workability, a superplasticizer (SP) is among the admixtures that can improve the workability of concrete. superplasticizers (SP), also called "high-range water reducers," are additives used to make high-strength concrete with high workability. Plasticizers are chemical compounds that make it possible for concrete to be made with about 15 % less water. superplasticizers make it possible to reduce the amount of water by 30 % or more without intruding on the concrete's workability. Besides, superplasticizer's purpose is to improve the dispersion of cement particles. The dispersion permits cement to have a greater surface area for hydration, which advances at a faster pace in the first phases. In addition, it has been claimed that superplasticizers may increase the strength of concrete by drastically reducing the water-cement ratio without impairing its workability [9]. Additionally, admixtures known as superplasticizers are frequently employed in the concrete industry to produce liquid and high-strength concrete. A superplasticizer's dispersion capacity in a cement paste depends on the adsorption of superplasticizers on the cement particle surface. This adsorption is aided by electrostatic adsorption between negatively charged functional groups in the superplasticizers and positively charged sites on the surface of the cement. Once superplasticizer molecules have been adsorbed onto cement particles, electrostatic repulsion or steric hindrance acts to separate the particles. Figure 1 depicts a schematic illustration of electrostatic repulsion and steric hindrance. However, the application of superplasticizer in geopolymer concrete, its influence on its workability of it, and its performance on skid resistance require additional study [10].

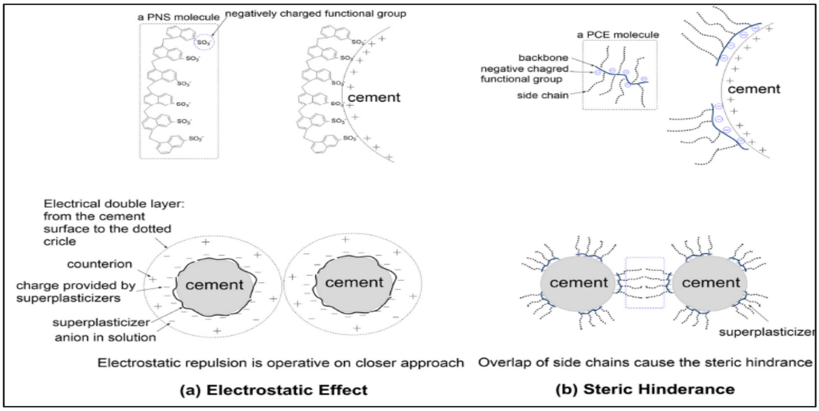

Figure 1: Schematic illustration of electrostatic repulsion and steric hindrance [10]

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Therefore, this study focuses on the effect of the superplasticizer on the skid resistance and workability of geopolymer concrete containing high calcium precursor (HCP). Hence, to evaluate the skid resistance of surface geopolymer concrete, British Pendulum Number (BPN) testing is conducted for this investigation in terms of pendulum value. The test is conducted on the dry surface of 7 different mix designs: one conventional concrete mix design, one asphalt mix design, and five geopolymers concrete mix designs with different percentages of superplasticizer after being cured at ambient temperature for 1, 3, and 28 days. At the same time, the workability study is conducted by a flowability test to measure the flowable/spreading width of the mix design. Lastly, the skid resistance and flowability of the mix design is compared, and the optimal mix design is analyzed.

EXPERIMENTAL DETAILS

Different rates according to the weight of the glenium superplasticizer used in this study were 0 % (M2), 0.5 % (M3), 1.0 % (M4), 1.5 % (M5), & 2.0 % (M6). While, the weight of the high calcium precursor (HCP) and alkali-activator solution (a mixture of Natrium Hydroxide and Sodium Silicate with a ratio of 2:5) was 1240 g for all five mixes. Next, this study required a conventional concrete sample (M1) with the similar ratio as M2 and a cold mix asphalt mix design (M7) for comparison purposes. This study is designed in two stages which are the study of fresh and hardened concrete.

Slump flow and British Pendulum Number (BPN) tests were conducted to achieve the objectives of this study.

Materials

In this study, seven types of mixed designs were made. M1 is a mixture of conventional concrete that uses Ordinary Portland Cement (OPC), sand, gravel (5-10 mm) and water as ingredients. M2 to M6 is a mixture of geopolymer concrete that uses high calcium precursor (HCP), alkaline activator (a mixture of sodium hydroxide and sodium silicate), sand, and gravel as the main ingredients, along with the addition of a different percentage of glenium superplasticizer (SP). The glenium superplasticizer used in this study is a new generation superplasticiser for concrete containing polycarboxylate ether (PCE) polymers, designed for optimal use in regular grades of concrete in ready-mix industry and it is chloride free. Table 1 shows the characteristics of glenium superplasticizer used in this study. The last mix design is an asphalt mix design with the usage of bituminous cold-mix patching material that has an aggregate size of 9 mm and a binder content of 4-6 % binder content. This study used the high calcium precursor (HCP) as a binder in geopolymer concrete (GPC). This HCP is the latest product produced by Innovative Construction Material Research Group (INCOM), using the nano participation process of calcium carbonate (nPCC) extracted from the carbonation process released by natural oil and gas industries. The chemical composition of the high calcium precursor (HCP) is shown in Table 2.

Table 1: Characteristics of glenium superplasticizer

Aspects	Light Yellow Liquid
Relative Density	1.08 ± 0.01 at 25 °C
pH	≥6
Chloride Ion Content	< 0.2 %

Table 2: Chemical composition of HCP

Chemical Composition	HCP (%)
CaO	72.00
SiO_2	15.00
Al_2O_3	4.30
Fe_2O_3	3.96
SO_3	2.00
K_2O	1.08
MgO	1.30
Others	0.35

Mix Design

Seven mixed combinations of the sample were made. One sample is a conventional concrete (M1-CC) sample. The other five samples were geopolymer concrete (GPC) containing high calcium precursor (HCP) with added different rates of Glenium Superplasticizer (SP), which are 0 % (M2), 0.5 % (M3), 1.0 % (M4), 1.5 % (M5), & 2.0 % (M6), and a sample of asphalt (M7). Every combination mix requires three samples each, to test at different curing times of 1, 3, and 28 days. Hence, 57 sample sizes 220 mm x 220 mm x 50 mm were prepared in this study. The ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) is 2.5 for all GPC mix designs. While the water-to-binder ratio for both CC and GPC mix design is 0.75, with a ratio of binder to both aggregates of 1:2:2. Slump flow (BS EN 12350-8) and British pendulum test (BPT) (ASTM E303-9) were conducted to achieve the objectives of this study. Table 3 shows the mixed combination of this study.

Table 3: Mix Design Proportion

MIX DESIGN	HCP (kg/m^3)	OPC (kg/m^3)	FILGAP (kg/m^3)	WATER (kg/m^3)	SAND (kg/m^3)	GRAVEL (kg/m^3)	SP
(%)							
M1-CC (control)	-	660	-	496	-	1320	-
M2-GPC (0 % SP)	660	-	496	-	1320	1320	0
M3-GPC (0.5 % SP)	660	-	496	-	1320	1320	0.5
M4-GPC (1 % SP)	660	-	496	-	1320	1320	1.0
M5-GPC (1.5 % SP)	660	-	496	-	1320	1320	1.5
M6-GPC (2 % SP)	660	-	496	-	1320	1320	2.0
M7-ASPHALT	1320 (kg/m^3) of Bituminous Cold-Mix Patching Material						

Testing Method

Workability Test

To determine the workability of the geopolymer concrete, experiments on its slump flow are required in accordance with the standard of BS EN 12350-8. This test was undertaken to see how superplasticizer (SP) affects the diameter of concrete spread in mm. The equipment used was a 300 mm tall cone with 200 mm base, as shown in Figure 2. The procedure for conducting this test is shown in Figure 3.

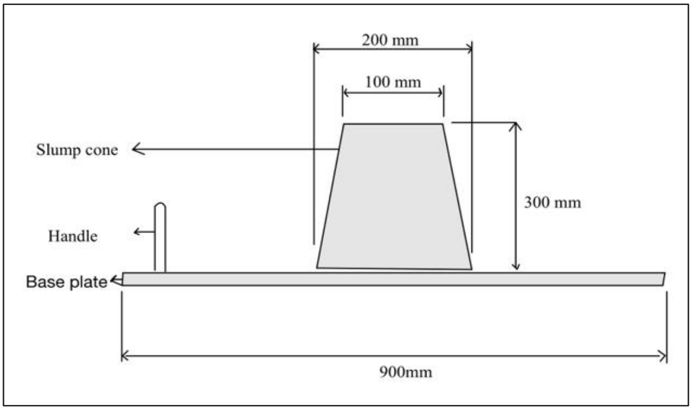

Figure 2: Schematic Diagram of Slump Flow Test Equipment

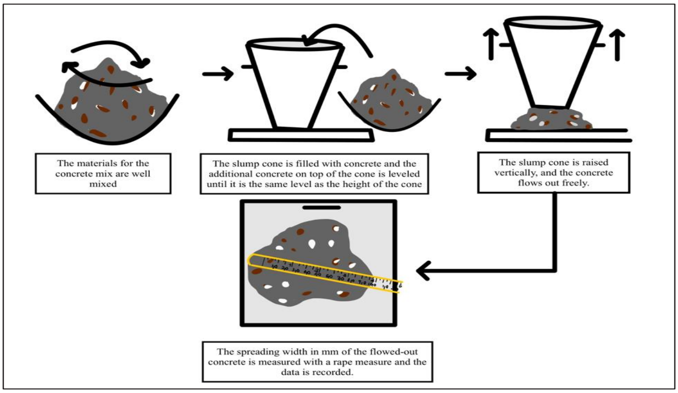

Figure 3: Schematic Diagram for Slump Flow Test Procedure

Skid Resistance Test

Test of skid resistance was conducted by using British Pendulum measurement in accordance with ASTM E303-93. Three (3) data from each sample were collected, and the average of the data was calculated and recorded as a result. This test is to measure the friction on the surface of the sample by sliding a rubber slider mounted at the end of the pendulum arm over a short patch. The measured value is written as British Pendulum Numbers (BPN).

RESULTS & DISCUSSION

Skid Resistance

Development of Skid Resistance of All Mix Designs

Figure 4 and Figure 5 are a line graph and bar chart of the average results for the development of skid resistance. Each mix design has 3 data on curing: 1 day, 3 days, and 28 days. Referring to the diagrams, visually, the development of skid resistance for each mix design has a less significant increase when compared to the BPN value on the first day of curing until curing on the 28th day. As for the comparison between geopolymer concrete, the sample with a high SP value (M6) has a lower BPN value compared to the geopolymer concrete mix design with 0 % SP. Hypothetically, the data for this study shows that superplasticizer in geopolymer concrete does not significantly affect the development of skid resistance. However, the data shows that geopolymer concrete has a more significant difference in the development of skid resistance compared to conventional concrete and cold-mix asphalt. The previous study [11] found that the polymerization reaction in geopolymer concrete considerably impacts the rigid pavement's contact area. The reaction produced calcium aluminosilicate hydrates (C-A-S-H) in little gels. It filled the cement paste's voids and contributed to the expansion of the contact area, enhancing friction. However, there is limited study on the effect of superplasticizers on the development of skid resistance.

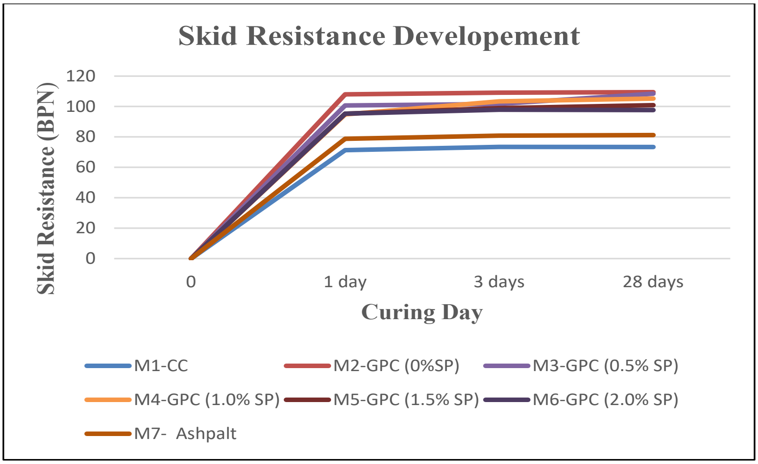

Figure 4: Line Graph of Skid Resistance Development

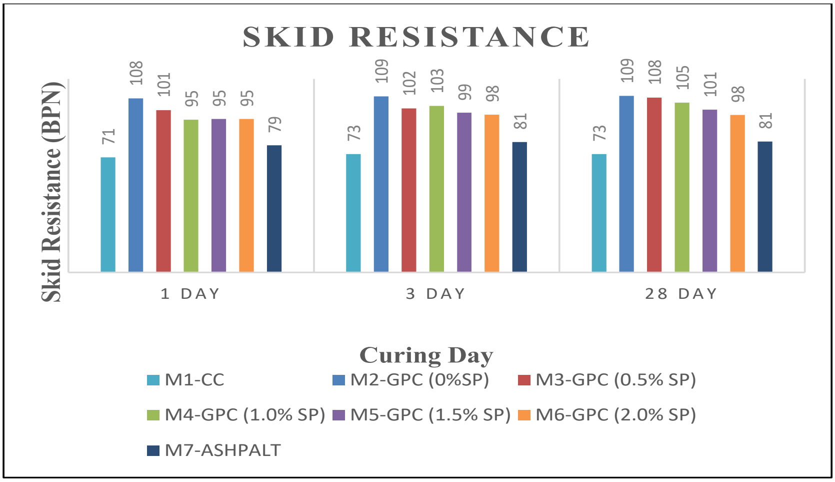

Figure 5: Bar Chart of Skid Resistance Development

Skid Resistance Development of Geopolymer Concrete at Early and Later Age

Figure 6 shows a bar chart of the average skid resistance value for all samples at an early age after 1 day of curing. Referring to the diagram below, visually, the geopolymer concrete design with 0 % SP (M2) recorded the highest value after 1 day of curing, which was 108 BPN. Meanwhile, the lowest BPN value for this study was the conventional concrete mix design (M1), which recorded a value of 71. On the contrary, geopolymer concrete with the use of superplasticizer 1 % (M4), 1.5 % (M5) and 2 % (M6) of the weight of the binder shows the lowest value record among other geopolymer concrete designs with a record of 95 BPN. Hypothetically, skid resistance at the early age of geopolymer concrete decreases when the percentage of superplasticizer use increases. The second, skid resistance for geopolymer concrete, was higher than conventional concrete. Meanwhile, the asphalt design has a skid resistance value that is the same as conventional concrete but slightly higher than conventional concrete.

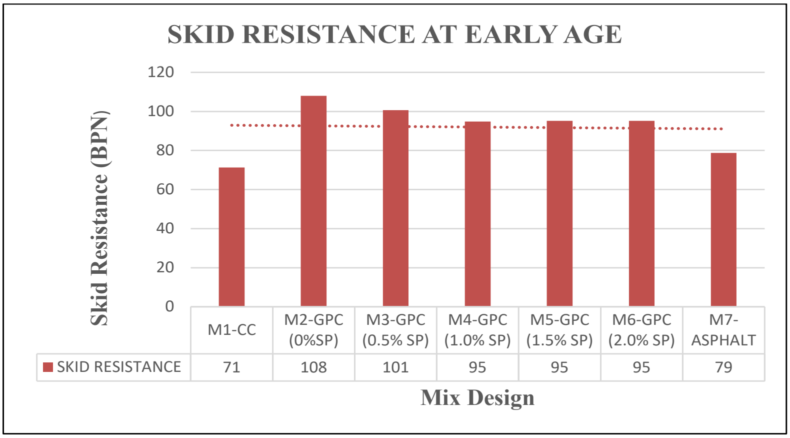

Figure 6: Bar Chart of Skid Resistance at Early Age (1 Day Curing)

Figure 7 shows a bar chart of skid resistance for all mix designs on day 28. Visually, the M1 mixed design has the lowest skid resistance value. The skid resistance for the designs of the five geopolymer concrete mixes shows values that have less significant differences. The highest skid resistance value for geopolymer concrete design is the design without a superplasticizer which is M2. In comparison, the lowest is the M6 design, where the numerical difference between the two is 10 %. The bar chart in Figure 7 clearly shows that the design of all GPC leads to the value of skid resistance compared to normal concrete and asphalt. Meanwhile, it can also be seen that the higher the use of SP in the GPC, the lower the skid resistance value.

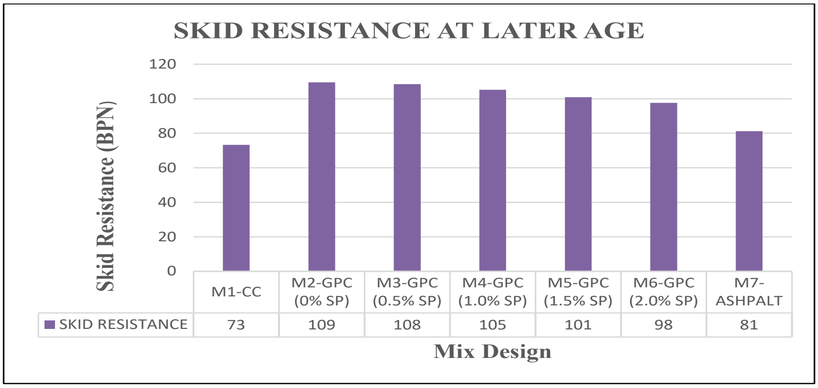

Figure 7: Bar Chart of Skid Resistance at Later Age (28 Days Curing)

Workability

Effect of Superplasticizer on Workability of Geopolymer Concrete

The bar comparison chart in Figure 8 results in the analysis of the workability of geopolymer concrete with a high calcium precursor with different percentages of superplasticizer content for the 5 samples. It can be seen that the highest spread width is mixing design 6 (M6) with a 2 % superplasticizer. This mixed design provides a spreading width of 123 mm. In contrast, the lowest value for this study is 118 mm. This value was obtained from mix design 2 (M2) and mix design 3 (M3), which use 0 % and 0.5 % superplasticizer, respectively, in the geopolymer concrete mix. Nevertheless, the difference in spreading width for all the varied designs is insignificant. In contrast, numerically, only a 4 % difference in spreading width was recorded between the mixture that used the lowest and highest superplasticizer percentage. Therefore, using a superplasticizer in geopolymer concrete has less influence on the employability of geopolymer concrete with a rate of not more than 2 % of the weight of the binder. The workability of geopolymer concrete can be enhanced by utilizing SP with 3-7 % mass of binder. However, there is no discernible change when using SP with less than 3 % mass of binder [12].

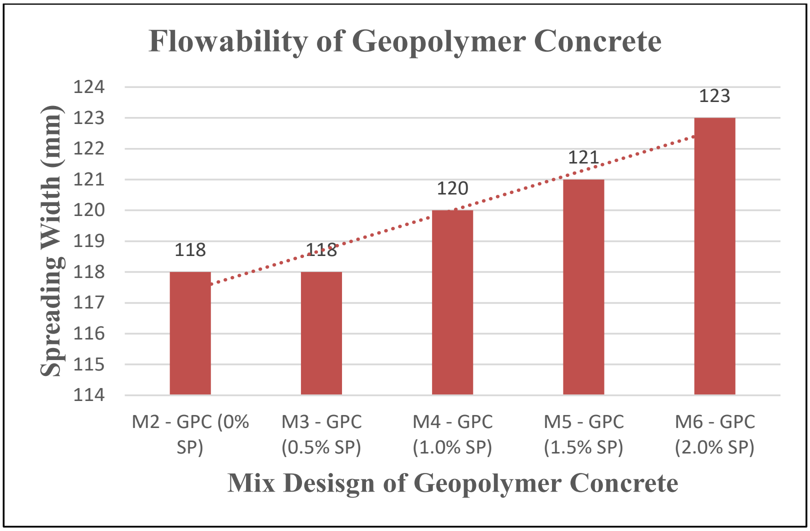

Figure 8: Flowability of Geopolymer Concrete

Effect of High Calcium Precursor (HCP) on Workability

As shown in Figure 9, geopolymer concrete has very low flowability without the use of a superplasticizer. The bar chart shows a significant difference in the flowability of geopolymer concrete with 0 % SP (M2-GPC) when compared to conventional concrete (M1-CC). The average data for M2 shows a low spreading width value with an average record of 118 mm, while M1 has a common spreading value for concrete with an average record value of 530 mm. This can also be analyzed during the mixing process of M2, where the texture is sticky and non-free flowing. Thus, handling and compacting this mixture is slightly stiff as the mixture is quickly hardened. A previous study [13] also observed that the calcium ion produced by the reaction supplements the hydration product together with the geopolymeric reaction, which may accelerate the hardening process. In addition, other researchers' research on the use of high calcium fibre content in GPC [14] found that both porosity and critical pore size decreased as high calcium fibre content increased. With the addition of the high calcium fibre, the geopolymer grouting material became more homogeneous and denser. This is also connected to the fact that the flowability of geopolymer concrete containing an increased quantity of calcium precursor is decreased.

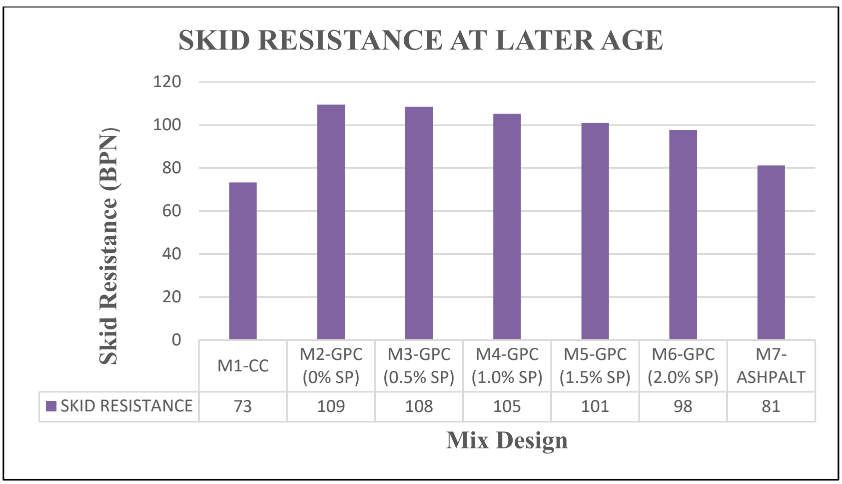

Figure 9: Flowability of Different Type of Concrete

Figure 10 shows a linear correlation between flowability and skid resistance for all geopolymer concrete mix designs. Referring to the figure, the relationship between skid flowability and skid resistance is that the higher the concrete flowability, the lower the skid resistance recorded. The diagram shows a high R-squared value of 0.9735. It can indicate more variability in this study.

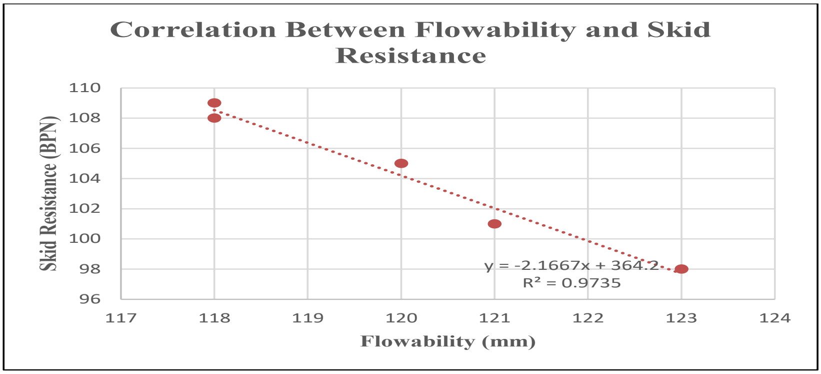

Figure 10: Line Graph of Correlation Between Flowability and Skid Resistance

Hypothetically, this study shows that flowability correlates with skid resistance. The higher the spreading width value, the smaller the skid resistance value. In other words, the higher the flowability value, the less rough the surface of a sample. There is limited study on the correlation between these two performances. However, it can be supported by the relationship between the influence of flowability and the strength related to skid resistance. This result, following previous research [12], [15], stated that the hypothesis in their research indicates a rise in the workability of geopolymer concrete, resulting in greater compressive strength. In addition, high-strength pavement, such as rigid pavement, has a high skid resistance value compared to low-strength pavement, such as flexible pavement. The optimum geopolymer concrete mix design was M6 with a 2 % superplasticizer (SP) admixture. This is because M6 has an acceptable flowability and skid resistance value of 123 mm and 98 BPN, respectively, compared to other geopolymer concrete mix designs.

CONCLUSION

In summary, the goal of this study was to improve the workability of the geopolymer concrete as well as its influence on skid resistance. As a result, the mixed design needed to be modified, and an analysis was conducted to determine the ideal percentage of SP to use. Based on this study, certain conclusions can be made based on the data and analysis:

Improvements in the workability of the concrete could be achieved by adding water or a superplasticizer (SP). However, less than 2 % of SP is given an insignificant significance difference.

The superplasticizer has almost no influence against the skid resistance for geopolymer concrete, and it has a slightly significant difference in skid resistance value.

The highest skid resistance obtained on the mixture of 0 % superplasticizer (M2) and the lowest skid resistance obtained on the mixture of conventional concrete (M1) with a numerical difference of 33 %.

The optimum geopolymer concrete mix design is M6 with a 2 % superplasticizer (SP) admixture. This is because M6 has an acceptable flowability and skid resistance value of 123 mm and 98BPN, respectively.

Workability correlates with skid resistance. The higher the spreading width value, the smaller the skid resistance value. In other words, the higher the flowability value, the less rough the surface of a sample.

Geopolymer concrete has a more significant difference in the development of skid resistance compared to conventional concrete and asphalt.

Surface characteristics and material used can affect the skid resistance. An admixture of SP has no significant effect on skid resistance.

RECOMMENDATION

Improvements can be made to ensure continuity to this study. some other things/properties can be taken into account to answer some questions about the need to use superplasticizer in this study and its effect on the workability of concrete and skid resistance. Some recommendations can be considered among them are:

The use of superplasticizer more than 2 % of the weight of the binder should be used to see a significant change in the workability of geopolymer concrete containing high calcium precursor (HCP).

Reduces the alkaline activator ratio or makes the alkaline activator ratio a variable in the study to check on the workability of geopolymer concrete.

Testing on the other type of properties, such as the setting time of the geopolymer concrete, as the mixing process is much more difficult than conventional concrete where geopolymer concrete requires a short setting time than other mix design.

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