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Mechanical Properties of Macro Basalt Fibre Reinforced Self-Compacted High-Performance Concrete

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Abstract. The characteristics of self-compacted high-performance concrete (SCHPC) exhibit significant differences when compared to vibrated high-performance concrete (HPC). SCHPC often encompasses a greater proportion of mineral admixtures, higher paste volumes, and reduced binder to water ratios compared to conventional HPC. The incorporation of fibres into HPC results in a substantial improvement in its mechanical characteristics. This study examined the impact of including macro basalt fibres (MBF) on the mechanical properties of SCHPC. Additionally, a comparison was made between the performance of MBF and traditional hooked steel fibres. The MBF is deemed as a type of minibar comprised of basalt fibre reinforced polymers (BFRP). The lengths of the MBF were measured to be 24mm with diameter of 0.7mm. The weight percentages of MBF incorporated into SCHPC was 25% only relative to the weight of hooked steel fibre. Hence, this study aimed to evaluate the impact of MBF on several mechanical properties of SCHPC including compressive strength, flexural strength, and tensile strength. The compressive strength and flexural strength exhibited values that demonstrate a comparable level of performance to that of hooked fibres. But the tensile strain of MBF was found to be lower than that of hooked steel fibres. At the end, promoting the use of MBF to replace steel fibre is a novel contribution toward provide durable, sustainable and corrosion free of self-compacted concrete to be used in offshore structure and coastal areas.

Keywords. Mechanical properties, macro basalt fibre (MBF), self-compacted high-performance concrete (SCHPC)

1. Introduction

Self-compacting concrete (SCC) is a variant of concrete which exhibits higher fluidity, enabling it to effortlessly flow, consolidate, and distribute within formwork, all without the requirement of external vibration. Self-compacted high-performance concrete (SCHPC) is designed with the intention of achieving elevated compressive strengths, commonly surpassing 60 MPa. A thorough comprehension of the mechanical properties of SCHPC is imperative, because of its distinct ingredients and mix proportions [1-3]. The utilization of SCHPC in the building industry is experiencing a growing trend, mostly attributed to its inherent capacity to mitigate construction

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expenses, enhance workability, and augment durability. Nevertheless, the existing body of research on the mechanical properties of SCHPC is limited, necessitating additional inquiry to comprehensively grasp its potential. In recent years, researchers have provided evidence indicating that SCHPC exhibits enhanced compressive and tensile strengths in comparison to SCC [4].

The compact microstructure of high-performance concrete (HPC) necessitates an augmentation in both compressive strength and permeability. However, it also has an adverse effect on the material's brittleness and fire resistance [5]. Fibers are commonly utilized in the reinforcement of High-Performance Concrete (HPC) with the objective of enhancing its strength and energy absorption capabilities, while also mitigating the occurrence of sudden failure. In order to impede the progression of micro-cracks and augment the toughness of HPC, the incorporation of nanomaterials such as multi-layer graphene, carbon tubes, and carbon nanofibers has proven to be efficacious [6].

The present study utilized Macro Basalt fibre (MBF) to fabricate a high-performance concrete (HPC) that is both ecologically sustainable and economically viable. It is important to acknowledge that steel fiber possesses a higher cost, lacks environmental sustainability, exhibits susceptibility to corrosion, is susceptible to the influence of magnetic and electric fields, and can pose risks to workers [7, 8]. There are no concerns regarding the heat conductivity, fire resistance, and corrosion of MBF fibers when they are enclosed within a concrete matrix [9]. However, the impact of Macro Basalt fibre (MBF) fibers on the mechanical characteristics of high-performance concrete (HPC) remains rather ambiguous, as evidenced by the subsequent literature assessment.

According to recent reports, concrete buildings that have been reinforced using basalt fiber reinforced polymers (BFRP) rebars have demonstrated exceptional mechanical qualities both in the short-term and over extended periods of time when exposed to marine environments [10]. The incorporation of macro basalt fibers (MBFs) derived from basalt fiber reinforced polymer (BFRP) into SCHPC is anticipated to address both the inadequate alkali resistance and brittle fracture problems concurrently. Multiple research studies have substantiated the evident improvement brought about MBF in the mechanical characteristics of conventional concrete and concrete structures, with a specific emphasis on their impact on plastic deformation [11]. The incorporation of MBF into SCHPC is anticipated to address the challenges related to durability and electrochemical corrosion that are associated with HPC including steel fibers. Additionally, this approach aims to mitigate the drawbacks of SCHPC with non-metallic fibers, such as alkali effect, brittle failure, and concerns regarding cost and flowability. Nevertheless, there is a significant dearth of research regarding the impact of MBFs on the mechanical qualities of SCHPC. Hence, this study will investigate the properties of MBF compared to hooked steel fibre in terms of compressive, flexural, and tensile strength.

2. Experimental Program

2.1. Material

The raw materials utilized to produce the SCHPC include type I ordinary Portland cement (OPC) with brand name Panda from Hume cement company Malaysia. River sand having a specific gravity of 2.65 was used. In order to achieve the desired self-compacting properties, Sika1 ViscoCrete1 – 2044 a polycarboxylate-based high range water reducing admixture (HRWRA) was used. The water-cement (w/c) ratio of 0.187 was used for all the mixes. Macro basalt fibre (MBF) shown in figure 1 is made by joining continuous basalt fibre with polymer vinylester resin matrix by pultrusion process, and then cut into separate uniform length pieces. MBF used in this research has diameter varying from 0.70 mm and length of 24mm.

Figure 1. Macro Basalt Fibre (MBF).

2.2. Mixing Ratio and Flowability

In order to attain a uniform distribution of fibers, which is crucial for achieving optimal performance in composites, the components were blended in a systematic manner. The dry components, such as cement, silica fume, and sand, were initially combined and mixed without the inclusion of water. This dry mixing process occurred for a duration of 5 minutes using a mortar mixer. Subsequently, the water was introduced into the dry mix and subjected to additional mixing for a duration of 4 minutes. Then, high-range water-reducing admixture (HRWR) was mixed for 6 minutes until blended concrete achieved the desire flowability. Finally, the inclusion of MBF into the mixture was achieved using a gradual sprinkling method throughout the mixing process. This approach was employed to ensure proper dispersion of the fiber and to prevent any undesirable agglomeration. The mixing process was extended by an additional duration of 5 minutes in order to ensure thorough dispersion of the fiber throughout the mixture. The mix proportion is shown in table 1, where used by other authors and companies to achieve UHPC. But in this study, this mix achieved only SCHPC because of using different types of material and different particle size distribution.

Table 1. Mixing proportions of SCHPC.

Mixing ratio kg/m^3	MS	MB
Cement	1114	1114
Silica Fume	169	169
Sand	1072	1072
Water	209	209
HRWR	40	40
Hooked Steel fibre	157	-
Macro basalt fibre	-	39.25

The flowability check was done with mini-conical test. Upon the removal of the filled truncated mini cone, the material undergoes a continuous flow until it attains a condition of equilibrium characterized by a flat and stable shape like a pancake. The ultimate spread diameter of the fresh paste sample is determined by calculating the average of two measurements taken in two orthogonal directions. Then, the samples were poured into moulds that had been lightly coated with oil. This was done to facilitate simple removal of the samples from the moulds. After 24h, the specimens were removed from their moulds and subsequently immersed in water for the purpose of curing, at conditions of 20° and 95% relative humidity.

2.3. Hardened Properties of SCHPC

The compressive strength test was performed on 100mm cube samples in accordance with the specifications stated in BS EN 12390-3. The compressive load of each mix was measured using a 3000kN capacity Universal Testing Machine equipped with an electronic digital screen display. The load was applied axially until the mix failed.

For the flexural strength test, a three-point bending test was conducted on the SCHPC to assess its flexural properties. The test was carried out using a 200kN capacity universal testing machine that had an integrated transducer. The transducer transmitted the test data to a computer, as shown in figure 2(a). Rectangular prisms of 500×100×25 mm was subjected to testing at the end of the curing period, adhering to the specifications outlined in ASTM C1609/ C1609 M – 10 for evaluating the flexural performance of fiber reinforced concrete beams.

The Japan Society of Civil Engineers (JSCE) developed the direct tensile test for self-compacted concrete, which used in this study to do the tensile strength test. The size of the sample and the arrangement of the test are illustrated in figure 2b. A 200kN capacity Universal Testing Machine (UTM) was utilized, which was connected to a computer equipped with an inbuilt data logger. The UTM recorded the load and displacement as a direct tensile load was steadily delivered to the specimen at a rate of 0.15 mm/s until the sample failed.

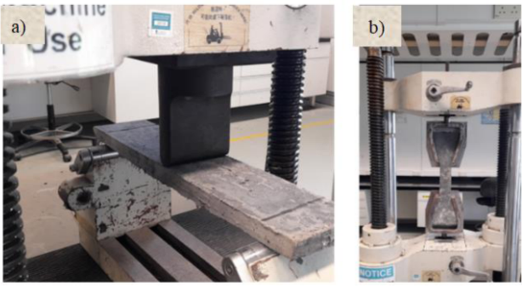

Figure 2. (a) Flexural strength test (b) Tensile strength test.

3. Results and Discussions

3.1. Flowability

The properties of the fresh SCHPC were determined using the EFRANCE standard. The desired slump-flow diameter of the mixture can be determined from the test results. For the mini-slump flow test, the needed value for the EFRANCE of flow table should fall between the range of 240-260mm spread diameters [12]. Similarly, for the analysis of V-funnel, the flow duration should be between 7 and 11 seconds. The slump flow test of SCHPC reached up to 26mm for d_1 [12]. To calculate the slump flow test, Equation 1 is used. Hence, $\Gamma_{p/m}$ was 5.71, where d_1 was 26 and d_2 was 25.8.

$$\Gamma_{p/m} = (\frac{d}{d_0})^2 - 1 \tag{1}$$

where

$$d = \frac{d_1 + d_2}{2} \tag{2}$$

3.2. Hardened Properties

The impact of varying levels of macro basalt fibre on the compressive strength of self-compacting high-performance concrete (SCHPC) resulted in a rise in the compressive strength of the specimens, as shown in figure 3. The compressive strength of the control group, which did not contain any fibres, after 28 days was 89.21 MPa. The specimens containing 0.25% MBF content had compressive strengths of 94.01MPa. The values exhibited an increase of 5.1% compared to the control samples. Furthermore, the use of MBFs effectively restricted the development and spread of microcracks, resulting in a notable improvement in compressive strength. On the other hand, the specimens containing 2% hooked steel fibres, in contrast, demonstrated compressive strengths of 97.91MPa. Where the result exhibited an increase of 8.9% compared to the control samples.

Flexural Strength is investigated by testing SCHPC casted into concrete prisms under three-point load. The test was performed after 28 days of curing age. From the result shown in figure 4, it can be seen that macro basalt fibre mix (MB) achieved flexural strength almost similar to hooked steel fibre Mix (MS) with 2.6% difference between them. This evidence shows the ability of MBF to replace steel fibre in SCHPC. On the other hand, deflection of MB was less than MS by 21.7% that is because of using hooked steel fibre instead of straight steel fibre for comparison. Hence further study is recommended to further investigation the comparison of MBF to straight steel fibre.

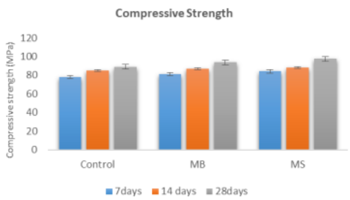

Figure 3. Compressive strength of SCHPC.

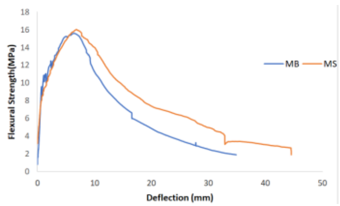

Figure 4. Flexural strength Behavior of the samples.

The tensile characteristics of SCHPC were assessed using the direct tensile method developed by the Japan Society of Civil Engineers (JSCE). In order to attain good tensile strength characteristics, it is necessary to customize SCHPC so that the matrix, fibre, and fiber-matrix interface together contribute to the propagation of microcracks. The data shown in figure 5 indicates that the tensile strength of MBF was reduced by only 12.9%. Furthermore, the tensile strain MS was 52.6% higher than MBF. This lower Tensile behavior of MBF is because the amount used of Macro basalt fibre (MBF) in this study was only 25% of the total weight of hooked steel fibre. Hence, further study is recommended to optimize the percentage of MBF to be incorporated into SCHPC.

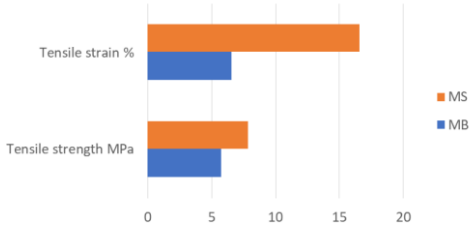

Figure 5. Tensile strength Behavior of the samples.

4. Conclusion

In conclusion, this study examined the impact of including macro basalt fibre (MBF) on the mechanical properties of self-compacted high-performance concrete (SCHPC). Moreover, a comparison was made between the performance of MBF and traditional hooked steel fibres to further understand the behavior of MBF. From the results, a novel MBF has the potential ability to replace steel fibre in SCHPC. Where the compressive strength of MS is only 3.9% higher than MB. Moreover, the flexural and tensile strength differences of MF were only 2.6% and 12.9% lower than MS, respectively. On the other hand, the tensile stain of MB was lower than MS by 52.6%. This lower tensile behavior of MBF was because the amount used of Macro basalt fibre (MBF) in this study was only 25% of the total weight of hooked steel fibre.

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References

[1] Zende AA, et al. Mechanical properties of high-strength self-compacting concrete. ACS Omega. 2023.
[2] Alraeeini AS and Nikbakht E. Corrosion effect on the flexural behaviour of concrete filled steel tubulars with single and double skins using engineered cementitious composite. Structures. 2022; 44: 1680-1694.
[3] Alraeeini AS, Nikbakht E and Gunawan L. Behavior of double and single square steel tube alloy composite subjected to bending. 2022 7th International Conference on Electric Vehicular Technology (ICEVT), 2022; p. 161-164.
[4] Smarzewski P. Fresh and mechanical properties of high-performance self-compacting concrete containing ground granulated blast furnace slag and polypropylene fibres. Applied Sciences. 2023; 13(3): 1975.

[5] Kodur V. Spalling in high strength concrete exposed to fire: Concerns, causes, critical parameters and cures. Advanced Technology in Structural Engineering. 2000: 1-9.

[6] Cui K and Chang J. Hydration, reinforcing mechanism, and macro performance of multi-layer graphene-modified cement composites. Journal of Building Engineering. 2022; 57:104880.

[7] Senaratne S, Gerace D, Mirza O, Tam VW and Kang WH. The costs and benefits of combining recycled aggregate with steel fibres as a sustainable, structural material. Journal of Cleaner Production. 2016; 112:2318-2327.

[8] Alraeeini AS, Nikbakht E and Ismail MC. Square steel tube impressed current corrosion rate in term of linear polarization resistance (LPR) method. The International Conference on Architecture and Civil Engineering (ICACE2020), Springer, 2021; p. 123-130.

[9] Bhat T, Chevali V, Liu X, Feih S and Mouritz A. Fire structural resistance of basalt fibre composite. Composites Part A: Applied Science and Manufacturing. 2015; 71: 107-115.

[10] Liu S, Wang X, Ali YM, Su C and Wu Z. Flexural behavior and design of under-reinforced concrete beams with BFRP and steel bars. Engineering Structures. 2022; 263: 114386.

[11] Adhikari S. Mechanical and structural characterization of mini-bar reinforced concrete beams. The University of Akron, 2013.

[12] EFNARC S. Guidelines for Self-compacting Concrete. London, UK: Association House. 2002; 32: 34.