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The properties of chopped basalt fibre reinforced self-compacting concrete

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HIGHLIGHTS

- We studied utilization of different amount and length of basalt fibre in SCC.
- Effect of basalt fibre on the fresh and hardened properties of SCC was investigated.
- The addition of basalt fibre in SCC decreases the workability.
- Utilization of basalt fibre improves the mechanical properties of SCC.
- The optimum values of fibre content and length were determined using RSM.

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ABSTRACT

The use of basalt fibre in the production of self-compacting concrete (SCC) has been studied to identify how the fresh and hardened properties of SCC are affected by the addition of fibre. The basalt fibres of 3, 6, 12 and 24 mm in length are incorporated into the SCC mixtures as 0%, 0.1%, 0.3% and 0.5% of concrete volume. After the progression of flow diameter, T_{500} flow time and V-funnel time tests on the fresh SCC, the tests of compressive strength, flexural strength, splitting tensile strength, rapid chloride permeability and water penetration have been conducted to identify the hardened properties of SCC produced with basalt fibre. The response surface method is employed in the conducted multi objective optimization analysis considering the maximisation of the compressive, flexural and splitting tensile strength parameters while minimising the response criterion of rapid chloride permeability and water penetration depth. The results reveal that the use of basalt fibre decreases the workability but improves the mechanical properties of SCC. The highest flexural and splitting tensile strength results are obtained from the concrete mixtures incorporated with the content of 0.5% fibre having the length of 24 mm. Whereas, the highest compressive strength result is obtained from the mixtures containing the fibre content of 0.1% for the utilised fibre lengths of 12 mm and 24 mm. The optimum volume fraction and length of basalt fibre are determined as 0.49% and 21.12 mm considering the optimized strength and permeability based durability properties of SCC.

1. Introduction

Since the limited amount of short fibre addition into the fresh concrete during the mixing process increases the toughness of concrete [1], many researches [2–5] reveal that the incorporation of steel, polymer, glass and carbon fibres into concrete significantly improves the material properties such as the tensile, flexural, impact, fatigue and abrasion strength characteristics. The increase in the toughness of concrete and in the reduction of the size and amount of defects subsequently improve the performance of the concrete by remedying its brittle behaviour that mostly provokes the low values of properties such as tensile strength, ductility and energy absorption.

Basalt fibre is relatively a new type of inorganic fibre that is produced by environmentally friendly melting process of volcanic rocks in non-hazardous manner [6–8]. Although the production process of basalt fibre is similar to that of glass fibre, it consumes less energy and misses out the additives. In this sense, basalt fibre is of advantageous in terms of the cost than that of glass or carbon fibres [8–10]. Additionally, basalt fibre is an alternative

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reinforcement material for concrete compared to other fibres such as glass, carbon or aramid owing to the several advantages of higher graded material properties on its modulus, strength, thermal and chemical resistance [7,8,11–16].

Ma et al. [17] has conducted a laboratory study on the concrete incorporated with pre-soaked basalt fibre in various lengths (10, 20 and 30 mm) and dosages (3, 5 and 7 kg/m^3). It is revealed that the increase in content and length of basalt fibre reduces the workability of concrete [17]. The effect of basalt fibre utilisation with the various ratios (0–0.5%) on the workability of concrete has also been investigated by Borhan [18] who concluded that the increase in the percentage of fibre volume leads to a reduction in the slump value of concrete. Singaravadivelan et al. [19] states that the slump of concrete mixture produced with different basalt fibre contents decreases while the fibre content is increased. The reduction in the workability of concrete is attributed to the large fibre surface area and the high utilisation content of fibres that absorb more cement paste to wrap around. This subsequently constitutes a reduction in the water cement ratio and the increase in viscosity of mixture that finally leads to the loss of slump [4,20,21].

Arivalagan [22] underlines that the compressive strength of concrete incorporated with basalt fibre is higher than the compressive strength of the control concrete. Borhan [18] also states that the compressive strength of concrete is increased by the increment in the content of basalt fibre utilised up to the incorporation of 0.3% and this enhancement gradually decreases by the further increase of this ratio. The effect of basalt fibre lengths on the compressive strength of concrete has been studied by Palchik [23] who states that the concrete incorporated with basalt fibre having the lengths of 12 and 24 mm lead to increase the compressive strength as 58% and 25%, respectively. However, Ma et al. [17] highlights that the variation in content and length of pre-soaked basalt fibre does not induce an increase at the compressive strength of concrete. Jun and Ye [24] point out that the maximum compressive strength value is achieved for the basalt fibre utilisation of 0.1%.

Considering the tensile strength variation, Ma et al. [17] has also investigated the effect of different lengths of basalt fibre (10, 20 and 30 mm) on the tensile strength of concrete. It is stated that the increase in the length of pre-soaked basalt fibre causes a rise in the tensile strength value and the highest tensile strength is achieved by the use of basalt fibre having the length of 30 mm. Budkonstruktsiya [25] has investigated the effect of basalt fibre on the tensile strength of concrete using the fibre lengths of 12, 24 and 50 mm with the amount of 1–3%. It is underlined that the higher tensile strength values are achieved for the fibre length of 12 mm and the utilisation of 1–2%. It is also highlighted that an insignificant difference is observed between the tensile strength values of concrete mixes having the fibre lengths of 24 and 50 mm [25]. Ketan and Kulkarni [26] however point out that the addition of 1% basalt fibre reduces the tensile strength of concrete. Chen [27] states that the utilisation of basalt fibre increases the 28 days tensile strength of concrete about 19%.

The effect of basalt fibre utilisation on the flexural strength of the concrete has been investigated by Jun and Ye [24] using the fibre having the length of 30 mm and the incorporated fibre amount of 0.1–0.35%. The drawn conclusions include that the flexural strength of concrete increases with the rising amount of fibre addition and the maximum value of flexural strength is obtained in the case of 0.3% basalt fibre utilisation. However, Ketan and Kulkarni [26] state that 1% basalt fibre addition to concrete reduces the flexural strength. Al-Baijat [28] concludes that the increase in the amount of basalt fibre utilisation leads to higher flexural strength of the concrete.

The availability of surplus raw materials and the low production cost of basalt fibre increase its widespread utilisation as a concrete reinforcement material. This popular attracted reference has brought about the need to fully identify the effect of basalt fibre utilisation in the mechanical properties of concrete. In this sense, many researchers [18,20,29] have investigated this issue in the current literature and highlighted that the incorporating amount of basalt fibre up to approximately 0.3–0.5% by volume provides beneficial results. However, this outcome and the utilised fibre content differ notably in terms of the type of concrete produced [30].

Mohamed and Al-Hawat [31] investigated influence of fly ash and basalt fibre on strength and chloride penetration resistance of SCC. It was stated that addition of basalt fibre (varying range of 1–2%) to the SCC mixture incorporated with 40% fly ash improves chloride penetration resistance of SCC compared to the mixture without basalt fibre.

In the study conducted by Paulraj et al. [32], the behaviour of SCC produced with basalt fibre was investigated using the fibre amounts ranging from 0.6% to 2.0%. It was stated that the addition of fibre into SCC increases the 28-day splitting tensile and flexural strength by 5% to 50% and 30% to 48%, respectively. It was revealed that the 7, 14 and 28-day compressive strength, splitting tensile strength and flexural strength results from SCC mixtures produced with basalt fibres become highest for the fibre utilisations of 0.3%, 0.4% and 1.4%, respectively.

Ponikiewski and Katzer [33] conducted a study in which the effect of fibre type and content on the rheological properties of SCC was analysed. It was stated that SCC can be successfully formed despite the deterioration of the workability due to fibre addition.

Rohilla et al. [34] examined fresh and hardened properties of SCC reinforced with various fibre contents. It was stated that the addition of fibre to SCC induces to loss of the fresh concrete characteristics. Also, it was revealed that 28-day compressive strength, split tensile strength and flexural strength results of SCC incorporated with the content of 0.25% basalt fibre causes the increase by about 50%, 34% and 61% compared to the control concrete, respectively. In this study it was indicated that basalt fibre is the best option to improve the overall quality of SCC pertaining to optimum dosage and cost.

Accordingly, the recent increase in the use of basalt fibre as a micro-reinforcement in the concrete production industry has brought about the need to investigate how the basalt fibre utilisation affects the engineering properties of SCC. Although several studies [4,6–30] have been carried out to establish the influence of basalt fibre addition on the properties of conventional concrete, most of the previous studies [31–37] pertaining to self-compacting concrete have been conducted to investigate the influence of only the amount of basalt fibre and the invariant fibre length. In order to overcome this shortcoming in the current literature, the presented paper focuses on the behaviour of self-compacting concrete using two factors influencing the results that are the varying amounts (0.1–0.5%) and lengths (3–24 mm) of basalt fibre. These engaging varying independent variables provide an opportunity to identify the optimum basalt fibre length and amount that should be utilised in an effective SCC mixture design incorporated with basalt fibre. Accordingly, the objective of this study is to investigate the potential use of basalt fibre and identify these optimum levels for the amount and length of basalt fibre affecting the mechanical and permeability related properties of SCC. In this respect, this paper tackles this important issue and provides the scientific data required by the concrete industry for the production of SCC reinforced with basalt fibre.

2. Experimental details and methodology

2.1. Materials

The materials used in this research are CEM I 42.5R Portland cement, natural fine and coarse aggregates, superplasticizer and basalt fibre having the length of 3, 6, 12 and 24 mm. The typical chemical compositions and some physical