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Eco-friendly self-consolidating concrete production with reinforcing jute fiber

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ABSTRACT

Self-consolidating concrete (SCC) has many advantages compared to traditional concrete. However, it often suffers from high brittleness that limits its various applications. Reinforcing the SCC by fiber inclusion can be a fruitful way to enhance its performance. This study aims to investigate how the rheological and mechanical characteristics of SCC are affected by the addition of jute fibers for a specific length of 20 mm at various volumetric fractions of 0.1%, 0.25%, 0.50%, 0.75%, and 1%. Slump flow, J-ring flow, V-funnel, L-box, and Sieve stability tests were performed to investigate the rheological properties of jute fiber reinforced self-consolidating concrete (JFR-SCC); while, compressive, splitting tensile, and flexural strength tests were conducted to determine mechanical properties at 7 and 28 days. Scanning electron microscopy (SEM) testing was also used to examine the microstructures of JFR-SCC. These rheological and hardened states were then compared with the control SCC. JFR-SCC performed satisfactorily in terms of flowability, viscosity, and segregation resistance. However, adding more than 0.25% jute fiber in SCC mixes significantly affected the passing ability. The maximum improvements in compressive, splitting tensile, and flexural strength were 2%, 21%, and 18%, respectively, over the reference mix at 28 days. The jute fibers can fill the microcracks in concrete and prolong the ultimate failure. Hence, SCC with jute fiber can be adopted as an eco-friendly alternative to SCC with artificial fibers.

1. Introduction

Concrete that exhibits an outstanding flowability property in its rheological state is termed self-consolidating concrete (SCC) [1]. SCC may flow through any obstructions, including reinforcement or small gaps in formwork, and it can compact there without the aid

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of any mechanical consolidation. It also can resist any segregation, which helps preserve the homogeneity of concrete during and after transporting and placing [2,3]. The concept of SCC originated by a Japanese researcher Okamura in the eighties of the last century from the scarcity of proficient workforces at the site. This shortage becomes an obstacle to achieving good quality in construction [4,5]. The use of fibers to strengthen brittle materials dates back to Roman times when people mixed straw or horsehair with clay to make better bricks [6]. Fiber-reinforced concrete (FRC) is a continuation of the same idea. The inclusion of fibers in concrete started in the early 1960s to reduce the fragility of concrete under tensile stress. Fibers of all orientations, randomly embedded in FRC, serve to restrict and delay the coalescence of microcracks, microvoids, and microslips into wide continuous cracks. While the fibers increase the uniaxial tensile and compressive strength only moderately, they are very effective in enhancing the ductility and energy absorption capability. Das, Sobuz, Tam, Akid, Sutan and Rahman [7], Akid, Shah, Sobuz, Tam and Anik [8] reported that the improvement in compressive strength of FRC was led by corresponding tensile and flexural strength respectively. The supplement of fibers in SCC could prevent or delay the initiation and propagation of cracks. In addition, fiber transforms large significant cracks into several smaller cracks, which is expected from a structural safety and durability perspective [9].

Since the development of SCC, numerous research studies have been carried out to explore the impact of including fibers in SCC mixtures. A considerable number of researches were conducted by incorporating different types of artificial fibers like steel fiber [10–12], glass fiber [13], carbon fiber [14,15], plastic fiber [13], synthetic fiber [16,17], polypropylene fiber [18,19] and nylon fiber [20] in the SCC mixes for the production of high strength fiber reinforced Self-consolidating concrete (FR-SCC) structures. Several studies also indicate that natural fibers such as sisal fiber, abaca fiber [21], and coir fiber [22] can be utilized in producing high-fluidity concrete composites. Additionally, FR-SCC was studied with the integration of hybrid combinations of two or more artificial, natural, or artificial and natural fibers [21–26]. The rheological and mechanical properties of concrete are significantly influenced by the fiber's length, diameter, aspect ratio, and cross-sectional shape [27,28]. Aslani [27], Pająk and Ponikiewski [28] demonstrate that the addition of fibers makes SCC less workable. This diminution is dependent upon the type, shape, size, and concentration of fibers used. Among all these artificial fibers, steel fibers were used extensively to produce steel fiber-reinforced self-consolidating concrete (SFR-SCC). Abdelrazik and Khayat [26] reported that the addition of steel fibers in SCC affects the flow characteristics, mostly workability in the rheological state. The pace at which workability decreases varies on fiber kinds, concentration, and the cement matrix. da Silva, Christ, Pacheco, de Souza, Gil and Tutikian [5] found that steel fiber doses ranging from 0.25 to 1.00% by the volumetric fraction in SCC, significantly affect the mixture's workability. On the other hand, flexural strength and flexural toughness were found to be affected positively. Mastali and Dalvand [29] investigated hardened properties of recycled SFR-SCC with fiber concentrations of 0.25%, 0.5%, and 0.75% by volume, and 18%, 14%, and 25% strengths improvement were found in the case of compressive, tensile and flexural strength respectively. Nevertheless, nowadays, the applications of steel fibers have been restrained because of their corrosion that causes the vulnerability. Synthetic fibers, along with steel fiber were often adopted to resolve this problem. However, synthetic fibres production costs are huge since they are costly and energy consuming [30]. In these circumstances, the natural fibers might be a potential alternative to produce FR-SCC. Among other natural fibers, jute fiber might be a convenient alternative concerning the environment and energy related issues [31].

In recent years, a continuous effort has been undertaken to incorporate jute fibers into normal vibrated concrete (NVC) in response to the worldwide shift toward eco-friendliness [30,32–34]. Zakaria, Ahmed, Hoque and Hannan [35] studied to improve the properties of NVC incorporating jute fiber by taking fiber lengths of 10, 15, 20, and 25 mm and concentrations of 0.1%, 0.25%, 0.50%, and 0.75% by weight. From their findings, adding 0.25% jute fiber concentration with a length of 15 mm greatly improves the mechanical properties of concrete mixes, with a 35% increase in tensile strength compared to the control mix. Islam and Ahmed [30] investigated the three volumetric dosages of 0.1%, 0.30%, and 0.50% with a fiber length of 20 mm and found that jute fiber reinforced concrete (JFRC) showed better resistance ability against initiation of crack over plain concrete. However, in recent years, there has been hardly any study of SCC with natural fiber, particularly jute fiber. Kim, Lee and Choi [36] investigated the mechanical characteristics of jute fiber-reinforced high-fluidity concrete and found considerable improvement in mechanical properties over normal concrete.

The previous study of the relevant literature makes it abundantly evident that the applications of jute fibers in reinforcing SCC have received a negligibly small amount of attention from previous research studies. After cotton, jute is considered the world's second most widely grown textile fiber. Among other natural fibers, jute fiber is widely available in Bangladesh at an affordable price. Bangladesh is the world's second largest producer of jute, accounting for over 33% of global production [37]. Because cellulose and lignin are the primary compositions of jute, inherently, jute fibers have good tensile strength. In addition, Jute fiber also has good interfacial contact because of its uneven surface. For the sake of already mentioned characteristics, jute has become more advantageous over other natural fibers [38]. Therefore, it is essential to investigate the performance of JFR-SCC and fix acceptance criteria for exploring the potential uses of jute fibers in reinforcing SCC without affecting the fundamental rheological behaviors by following the guideline of EFNARC (2005) [39]. This study aims to conduct an experimental study to investigate the rheological and mechanical properties of JFR-SCC with varying percentages of jute fiber. The influences of jute fiber on SCC mixtures were determined by conducting different fresh and hardened state tests. In addition, analytical correlations and statistical regression analysis were established based on the findings of the hardened properties of JFR-SCC.

1.1. Significance of this study

Jute fibers are easy to obtain with low energy demands and CO_2 emissions. They are considered one of the cheapest natural fibers containing cellulose and lignin [40,41]. Jute fibers have high strength and stiffness and have recently been used as a component for producing sustainable composite materials [42]. Therefore, the use of jute fibers in SCC could become an effective way to reinforce. Nevertheless, the coupled effect of jute fibers and pozzolans on the mechanical properties of SCC has not been investigated. Also, the ingredient proportions of the additives have not been optimized to achieve the optimum performance of SCC. The rheological and