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EFFECT OF FIBRE MERCERIZATION ON STRENGTH PROPERTIES OF AGAVE CANTULA ROXB. STRENGTHEN FOAMED CONCRETE

Researchers are increasingly becoming fascinated by the possibilities of utilizing natural fibre, which is a byproduct of production processes, as an addition in concrete. This fibre exhibits a low density and is amenable to chemical changes. The primary aim of this research study is to examine the influence of agave cantula roxb. fibre (ACRF) in low-density foamed concrete (FC) after being subjected to different doses of alkali treatment using sodium hydroxide (NaOH). Various weight fractions of treated ACRF were employed in the FC mix, namely 0% (as the control), 1%, 2%, 3%, 4%, and 5%. FC with a density of 1060 kg/m^3 was produced and subsequently tested. The three types of strength properties that have been evaluated and analysed included flexural, tensile, and compressive strengths. The findings from this study have revealed that the inclusion of 3% of treated ACRF in FC yields highly favourable results in relation to strength properties. The use of treated ACRF improves the FC's strength characteristics, particularly its bending and tensile strength, by bridging microscopic cracks and filling up gaps. It is noteworthy to emphasize that accumulation and unequal dispersion of ACRF are possible if the weight fraction of ACRF applied above the optimal value of 3% which led to decrease in FC's strength properties. This exploratory work will lead to a better understanding of the potential applications of treated ACRF in FC. It is critical to encourage the long-term development and implementation of FC products and technology.

Keywords: Foamed concrete; NaOH treatment; agave cantula roxb. Fibre; bending; compression

Nomenclature

FC – Foamed Concrete
ACRF – Agave cantula roxb. fibre
NaOH – Sodium hydroxide
CO_2 – Carbon dioxide
SEM – Scanning electron microscopy
OPC – Ordinary Portland cement

1. Introduction

Nowadays, foamed concrete (FC) is considered to be the most widely used building material worldwide [1]. This material can be used for a variety of purposes, including the construction of buildings, structures, bridges, and other infrastructure-related projects, because of its cost-effectiveness and versatility [2]. FC's limited tensile strength and fracture toughness serve as two of its primary drawbacks. The conventional approach to mitigating the issue of low tensile strength has conventionally involved the major reinforcement method of using steel reinforcing bars [3]. It has been discovered that adding short fibres that are randomly orientated and uniformly distributed significantly increases the material's toughness [4]. This aids in controlling the formation and spread of microcracks [5]. It has been noted that fibres, which are made of a wide range of materials including steel, glass, polypropylene, and other polymeric materials, significantly increase fracture toughness [6]. Most of these fibres do, however, have distinct disadvantages. Steel and carbon fibre, for example, are regarded as rather expensive materials [7]. Furthermore, it is commonly known that asbestos fibres are harmful to human health. It's also important to remember that

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many synthetic fibres have a big environmental impact. For a long time, concrete reinforcing has been used for a variety of useful applications [8]. On the other hand, its exclusive use for FC reinforcement is a relatively new concept [9]. In countries where natural fibres of all kinds are abundant, it makes financial sense to investigate appropriate technology for integrating these fibres. FC reinforced with natural fibres is a revolutionary class of building materials that performs on par with traditional concrete when different kinds of synthetic fibres are used [10].

With an annual output of over 1.35 billion tonnes, the manufacturing of cement represents a major contribution to the release of greenhouse gases, notably CO_2. With the yearly demand for building exceeding one billion metric tons, the output of ordinary Portland cement (OPC) has experienced a notable surge in response. Over the past few years, there has been a noticeable trend in the construction sector to use FC as a favoured building material. FC is a composite material made of foaming agent, fine sand, cement, and potable water. Coarse particles are not used in this specific type of concrete. Fused carbon is made up of trapped bubbles that serve as the aggregate. The use of bubbles improves the concrete's workability, flowability, thermal properties, and ability to reduce weight [11]. FC is noticeably brittle in spite of its improved workability, flowability, thermal properties, and reduced weight. The material's brittleness causes decreased impact strength, weakened breakage severity, insufficient barrier to fracture transmission, and decreased bending strength [12].

Due to its low density and affordability, agave cantula roxb. fibre (ACRF) shows promise as an effective natural reinforcement for cement composites. The application of ACRF is thought to be an environmentally benign material that has been used in a number of industries, such as the building and automotive sectors [13]. The literature has documented the integration of agave fibres into a range of matrices, including polyester, epoxy, biopolymers, and cement [14-22]. Nevertheless, the strong fibre-matrix adhesion, exceptional toughness, and low damage susceptibility of ACRF make their mechanical qualities remarkable. An appropriate treatment approach has the ability to improve these features [23]. Many of the research in the literature review focus mostly on how unprocessed natural fibres are mercerized [24-26]. As mentioned in the review study by Ramesh et al. [27], the interface affects the final properties of composites.

The addition of fibres to concrete can significantly improve its mechanical qualities, claim Shah and Ouyang [28]. A thorough understanding of the interactions between discrete fibres and concrete is essential to the progress of upcoming projects. Compared to their tensile strength, cementitious materials have a comparatively limited strain capacity and fracture strength. It has been discovered that the addition of fibres significantly affects the development of the tensile force capacity. According to evidence provided by Sathiamurthi et al. [29], the epoxy hybrid composites' flexural strength was found to be highest when they were reinforced with a composite that included 20% ACRF. After several alkali treatments, the morphology of the fibres was investigated using scanning electron microscopy (SEM) [30]. The results of the experiment show that hemicellulose, wax, and other contaminants were successfully removed. Four different treatments namely acetylation, alkali silane, enzymatic were applied to ACRF in a study by Huerta-Cardoso et al. [31]. Enhancing the fibres' morphology and increasing their compatibility with polylactic acid was the aim of these treatments. Jani et al. [32] looked at the characteristics of ACRF that was treated with alkali at concentrations of 7.5% and 10% in their experimental investigation. According to their study's conclusions, the ACRF treated with a 10% concentration of sodium hydroxide (NaOH) had better mechanical and thermal qualities than the ACRF treated with a 7.5 weight percent concentration of NaOH. The effects of different NaOH concentrations (0.5%, 1%, 2%, 4%, and 10%) on the properties of concrete strengthened with sisal were investigated by Jacob et al. [33]. The research findings indicate that the highest tensile strength was achieved by applying a 4% sodium hydroxide (NaOH) treatment at room temperature. Mishra et al. [34] reported that sisal fibre-reinforced polyester composites treated with a 5% NaOH solution concentration had a greater tensile strength than those treated with a 10% NaOH solution concentration.

In addition to practical concerns such as the non-ecological and detrimental ecological implications, concrete exhibits some limitations, including reduced longevity, diminished ability to withstand post-cracking loads, inadequate tensile strength, diminished luminosity, minimal environmental resistance, and restricted fatigue resistance. Hence, there is a pressing demand for alternative materials that possess sufficient strength properties and effectively reduce the overall cost of the end product. Although numerous research works have been performed observe the influence of NaOH treatment of ACRF on cement-based materials, most research had focused on normal strength concrete. No single research had been executed to look into the effects of ACRF treatment on mechanical properties of FC. It should be noted that higher concentrations of alkali lead to increased delignification in natural fibres, which consequently results in the weakening or breaking of the fibres. Hence this research explored the influence of fibre mercerization on the properties of ACRF to strengthen FC. A better understanding of the potential uses of treated ACRF in FC was the outcome of this exploratory study. Fostering the long-term creation and deployment of FC materials and infrastructures is of the utmost importance.

2. Experimental Setup

2.1. Materials

To produce FC samples, it was imperative to have five indispensable components. The aforementioned materials consisted of cement, which functioned as the cohesive substance, fine aggregate, employed as a filler, uncontaminated potable water, and a foaming ingredient derived from proteins, which performed as a surfactant. The incorporation of ACRF as an additive was employed in the formulation of the FC base mixture.

2.1.1. Ordinary Portland Cement (OPC)

Portland cement, namely Ordinary Portland Cement (OPC), was used in the study since it met the requirements set forth in the BS197-1 standard. The initial setting time of normal Portland cement is reported to be 50 minutes, and the soundness has been determined to be 12 mm.

2.1.2. Aggregate

The filler material employed in this study consisted of high-quality river sand. The sand was gotten from a local provider. The choice of fine river sand was made due to its desirable characteristics of homogeneity and gradation, which impact to the enhanced FC workability.

2.1.3. Water

As per the BS-3148 standard, the procedure of blending and maturing the FC necessitates the use of potable water that is free from any contaminants.

2.1.4. Foaming Agents

The application of Noraite PA-1, a surfactant produced from proteins, was conducted. The surfactant and water were combined in a ratio of 1:30. The foam solutions have shown the capacity to achieve a density of 70 ± 5 kg/m^3 during the process of aeration. The pre-foaming method was applied to manufacture foam, using an automatic foam generator known as TM-1. Fig. 1 shows the stable foam produced by the foam generator.

2.1.5. Agave cantula roxb. fibre (ACRF)

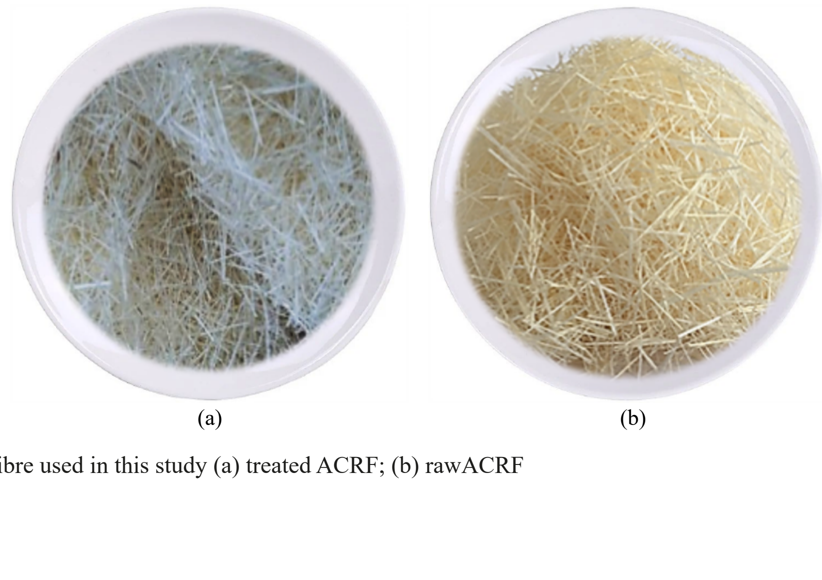
The ARCF utilized in this inspection was brought by DRN Technologies Sdn Bhd. The initial ACRF material underwent

Fig. 1. The stable foam generated from the TM-1 foam generator

a process of being cut to a specific length of 19 mm. The untreated ACRF underwent an alkaline treatment using NaOH tablets dissolved in water at a concentration of 6% (weight/volume) for a duration of 24 hours. Following a 24-hour period of alkali treatment, the ACRF underwent a thorough washing process using a diluted solution of acetic acid, followed by multiple rinses with water until the pH reached a neutral value of 7. The ACRF was evenly distributed on a tray and subjected to natural drying in direct sunlight for a duration of 72 hours. Fig. 2 shows the ACRF used in this examination.

2.2. Mix design

There was a total of six blends were created. A density of 1060 kg/m^3 was accomplished for the FC. The FC blends were supplemented with ACRF at different weight fractions, namely



(a) (b)

Fig. 2. Agave cantularoxb. fibre used in this study (a) treated ACRF; (b) rawACRF

1%, 2%, 3%, 4%, and 5%. A sand-cement ratio of 1:1.5 was utilized in each mixture, while the water-cement fraction was constantly kept at a value of 0.45. The mixture design of ACRF-reinforced FC in the current research is displayed in TABLE 1. Fig. 3 shows the fabrication process of FC.

TABLE 1

FC mix design

Mix	AF (%)	AF (kg/m^3)	Sand (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Foam (kg/m^3)
Control	0	—	585	390	195	29
ARCF1	1	11.7	585	390	195	29
ARCF2	2	23.4	585	390	195	29
ARCF3	3	35.1	585	390	195	29
ARCF4	4	46.8	585	390	195	29
ARCF5	5	58.5	585	390	195	29

Fig. 3. Fabrication of FC

2. Experimental setup

2.3.1. Compressive strength test

Samples measuring 100×100×100 mm were used to assess the compressive strength of the cured FC specimens (Fig. 4). The experiment was conducted utilising a universal testing equipment, which could support a maximum load of 3000 kN, inside a concrete laboratory. When testing compressive strength, a load speed of 0.55 MPa/sec was used, in accordance with the specifications outlined in BS12390-3. The compressive strength at each curing interval was determined by testing three samples, and the average of the three measurements was recorded.

Fig. 4. Compression test apparatus

2.3.2. Flexural strength

The investigation involved assessing the flexural strength of FC with a density of 10600 kg/m^3. This was accomplished by using prisms FC specimens of 100×100×500 mm (Fig. 5). In a manner analogous to the evaluation of compressive strength, three specimens were subjected to testing for each respective duration of curing. The average value of the three measured readings was afterward determined as the ultimate flexural strength. The experiment was conducted at a speed of 0.35 kN/sec in compliance with BS12390-5.

Fig. 5. Flexural test setup

2.3.3. Splitting tensile test

The experiment involved conducting a splitting tensile strength test on a prism of 100×200 mm (Fig. 6). The cylindrical samples underwent testing utilizing the identical universal testing machine employed for the evaluation of compressive strength. During the test, a constant speed of 0.75 MPa/sec was used. Additionally, three samples were selected at each specified curing interval and subjected to testing. BS12390-6 was followed while conducting the test.

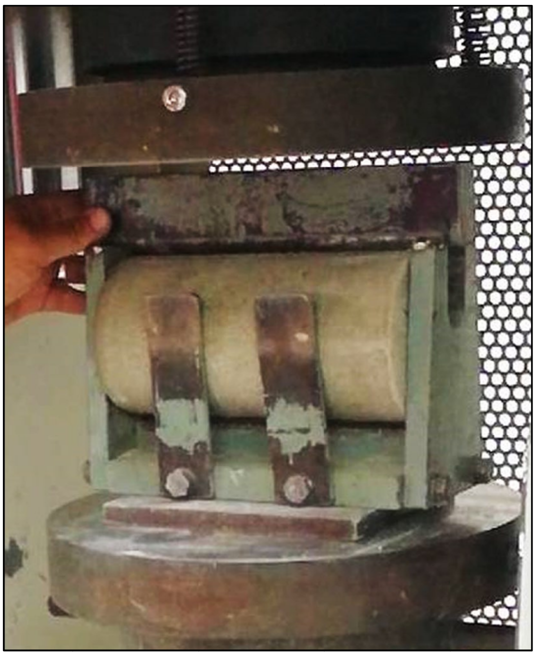


Fig. 6. Split tensile test apparatus

3. Results and discussion

This section will provide an overview of the findings derived from the laboratory evaluation conducted to ascertain tensile, flexural and compressive strengths as well as the modulus of elasticity.

3.1. Compressive strength

The compression strength test results conducted are displayed in Fig. 7. Based on the provided data, it is evident that the inclusion of treated ACRF in FC has consistently resulted in enhanced compressive strength, regardless of the weight fraction. The conducted tests at 7, 28, and 56 days of curing consistently displayed that, overall, the mixtures exhibited superior compressive strength in comparison to the control specimen across all densities. The optimal weight fraction of ACRF was 3%. At a weight fraction of 3%, the ACRF and cement matrix achieved a high level of compaction, leading to excellent mix homogeneity. The compressive strength values achieved at day 56 were 6.14 MPa for mix ACRF3 compared to the control specimen which only achieved a compressive strength of 3.82 MPa. The percentage of enhancement was approximately 61%. At levels exceeding the optimal weight fraction of ACRF addition, agglomeration and uneven dispersion of ACRF can be predicted. This, in turn, leads to a decrease in compressive strength, specifically when the weight fraction of ACRF reaches 4%.The incorporation of treated natural fibre like ACRF into FC has been observed to slow down the hydration process. As a consequence, the strength of FC is reduced initially, although it does improve with time after reaching a certain age. The incorporation of ACRF will contribute to the failure mode under compression stress due to the existence of voids and cracks in the FC as well as at the zone of transition [35].

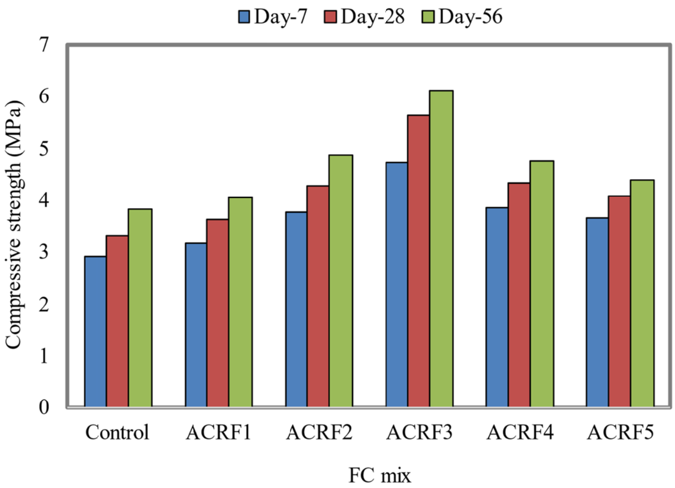


Fig. 7. Compressive strength of 1060 kg/m^3 density FC with different weight fractions of ACRF

3.2. Flexural strength

Overall, the addition of ACRF to FC resulted in a significant improvement in flexural strength, regardless of the weight fraction of ACRF added to the FC mixture. The findings of flexural strength achieved for a density of 1060 kg/m^3 with different weight fractions of ACRF are illustrated in Fig. 8. The control mixture had the lowest flexural strength, with only a marginal increase observed over the course of the testing period. Nevertheless, the inclusion of ACRF in FC specimens results in a notable expansion in flexural strength over time. The flexural strength of the control FC on day 28 was measured to be 0.76 MPa. The optimal weight fraction of ACRF that yielded the most favourable outcomes in terms of flexural strength was determined to be 3%. The highest flexural strength achieved on the 56th day was 1.41 MPa when a weight fraction of 3% of ACRF was present. The incorporation of ACRF in FC acts a substantial role in enhancing the strength of the cementitious matrix in FC. This addition also leads to a transformation in the material's properties, transitioning it from a brittle state to a ductile elastic-plastic state. The use of ACRF serves to improve the flexural strength of FC [36]. Nevertheless, the excessive inclusion of ACRF weight fraction in FC, above 3%, can result in a decrease in the bond strength.

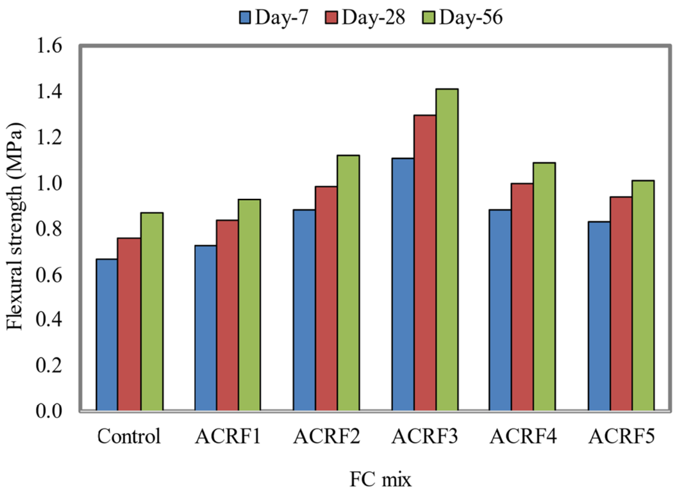


Fig. 8. Flexural strength of 1060 kg/m^3 density FC with different weight fractions of ACRF

3.3. Split tensile strength

Fig. 9 displays the outcomes pertaining to the tensile strength of FC when various weight fractions of ACRF were incorporated. The investigation revealed a consistent pattern, wherein the incorporation of ACRF at a weight fraction of 3% yielded the most favourable outcomes in terms of tensile strength. As depicted in Fig. 9, the inclusion of a 3% weight fraction of ACRF resulted in the highest splitting tensile strength of 0.96 MPa at day 56, whereas the control specimen, which did not have any fibre addition, only gained a tensile strength of 0.59 MPa. Upon surpassing the optimal amount of ACRF addition, the occurrence of accumulation and the non-even dispersal of ACRF was noticed. Consequently, this led to a reduction in splitting tensile strength, specifically at a weight fraction of 4% of ACRF. The rise in splitting tensile strength can be ascribed to the improved toughness of FC resulting from the inclusion of ACRF [37]. The addition of 3% ACRF content further boosts the raise of strength in FC by facilitating an optimum pozzolanic response with ordinary Portland cement (OPC) content [38]. As a result, the FC becomes denser and exhibits more strength [39]. The findings of this study demonstrate that the incorporation of ACRF positively impacts the tensile strength of FC, irrespective of the weight percent of ACRF.

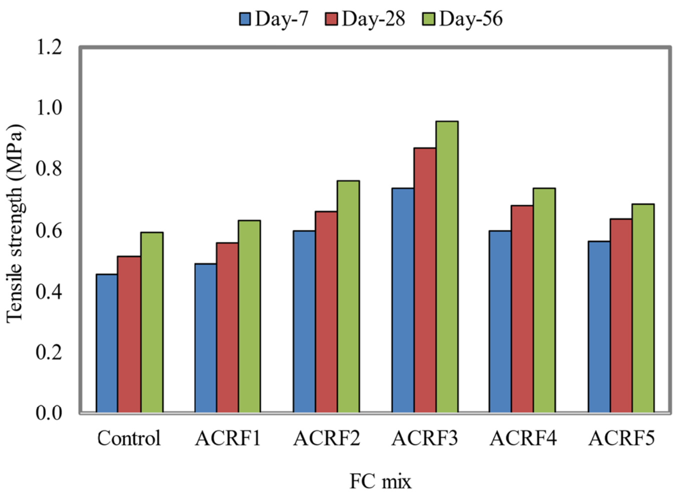


Fig. 9. Splitting tensile strength of 1060 kg/m^3 density FC with different weight fractions of ACRF

4. Conclusions

This laboratory investigation designed to examine the stimulus of using treated ACRF in FC to increase its strength characteristics. The weight fractions of ACRF incorporated in FC mixtures were 0%, 1%, 2%, 3%, 4%, and 5%. The evaluated strength properties encompassed flexural, compressive and tensile strengths. The current study presents a concise overview of its research findings in the following manner:

1. The incorporation of a 3% dosage of treated ACRF has been determined to result in the most favourable results in relation to compressive, flexural, and tensile strengths.
2. Employment of treated ACRF serves to fill voids and connect micro-cracks within the FC, leading to enhanced strength properties, particularly in terms of bending and tensile strength. The use of ACRF effectively mitigated the dissemination of cracks in FC under applied loads.
3. However, it should be noted that when the weight fraction of ACRF added exceeds the ideal value of 3%, there is a tendency for agglomeration and non-uniform dispersion of ACRF to occur.
4. Chemical treatments of natural fibre serve many functions, such as removing non-cellulosic materials and waxes to expose more reaction sites for fibre reactions. Some compounds bridge matrix-fibre interactions while the others produce free radicals and improving composite constituent interaction. Chemical treatment also improves fibre mechanical characteristics. Different treatments improve characteristics differently. Since economic issues are involved, choice condition must be chosen to maximize treatment benefit.

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