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ORIGINAL PAPER

Reinforcement of Cement Mortar with Waste Cotton Fluff Fiber

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***Abstract*- Cotton fluffs waste fiber is a useless outcome of cotton milling plant, which is directly thrown away. Laboratory studies show that the use of these fibers in cement mortar got beneficial properties in concrete. In this study, fluff cotton fibers were used as a partial replacement of cement in the 0.5 kg/m^3 to 5 kg/m^3 range. Seven different compositions were made by using these trials and their properties were measured. Samples of 1 kg/m^3 cotton fluff fiber showed 26% increase in compressive strength after 11 days, but these strength differences reached 1% up to 42 days. Microstructure of samples was studied by scanning electron microscopy (SEM) and fiber-concrete bonding. SEM images showed suitable bonding between cement mortar and fibers in low amount of cotton fluff. The observations also showed that in large amounts of fibers, the fibers are not completely dispersed in the composite and form aggregates.**

***Keywords*: composite, cement mortar, cotton fluff fiber, reinforcement, compressive strength**

I. INTRODUCTION

In the light of continuously growing disposal costs, today's waste streams are being studied with increasing care for their recycling potential. A straight forward approach to dispose large quantities of waste is using it as replacement of raw materials in large scales of applications, such as mass concrete or asphalt. A well-known successful story is the use of fly ash, a byproduct of coal combustion, as a replacement of Portland cement. Another finding reveals that waste glass could be identified as a valuable resource for aggregate in concrete. Likewise, concrete with waste carpet fibers shows improvement in the mechanical and durability properties by involving relatively small percentages of fibers [1]. Fibrous residuals generated from pulp and paper mills were characterized and added in concrete, which led to the increase of durability and performance of cement composite [2]. Now, the utilization of cotton fluffs as a natural fiber, which form a fibrous residual of a cotton milling plant, pave its way for consideration. The cotton fluff could then be effective in reinforcement of cement composites, which is mainly regarded this study.

The use of natural fibers was an approach to remove asbestos reinforcement from a wide range of cementitious products applied by James Hardie Co. in Australia, 1960s. Cheap boards were made up of half the asbestos replaced by wood fibers, was the first step to this approach which was followed by CSIRO to find more economical natural fibers [3].

In recent years, with sustainable interest in natural fibers and diversified method of pulping, variety of cement composites were produced and applied. Some instances are coir fiber-reinforced slab specimens which absorbed high level impact energy. The use of coconut fibers shows even better flexural than synthetic fiber (glass and carbon) concrete. Some studies show that the combined use of coconut short fibers and sisal probably delays the restrained plastic shrinkage and therefore controls the crack growth at an early age. Sugarcane bagasse fibers increase concrete fracture toughness. Some natural fibers such as sisal and jute are more suitable for non-structural applications in form of short filament. The compressive

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and flexural properties of hemp fiber-reinforced concretes (FRC) in amount of 0.36% by weight, were examined. The results showed that compressive strength increased by 4%, flexural strength increased by 9%, flexural toughness increased by 144%, and flexural toughness index increased by 214%. Natural fibers are a renewable resource and are available almost all over the world. Therefore, promoting the use of plant fiber reinforced concrete can be a way to improve the durability of concrete as well as sustainable construction [4-10].

The cotton fibers as one of the most important natural fibers often appear as a long, irregular, twisted, and flattened tubes, tapering somewhat at its tip. The cotton content is of about 90% cellulose. With placing cotton fibers in water, hydrogen bonds can be formed between water molecules and the hydroxyl groups of cellulose. Cellulose swells to only a limited extent. All the fibers become more extensible at higher humidity, the modulus becoming smaller and the breaking extension greater. Whereas cotton and other natural cellulose fibers become stronger, and the rest of the fibers become weaker. Cotton density of dry weight is about 1.55 g/cm³ [11].

One of the considerations in this study could be persistence of cotton fluff fibers under alkaline conditions of a cementitious environment. During cement hydration, substantial amounts of alkalis (sodium and potassium) are released. This is a result of the dissolution of alkali sulfates and the reaction of cement clinker phases. While the ion products of both KOH and NaOH and the corresponding sulfates are significantly higher compared to that of $Ca(OH)_2$, it is assumed that the solution is always saturated with regard to $Ca(OH)_2$. Most sulfates enter products of low solubility and are exchanged with [OH]. Therefore, it was assumed that the amount of [OH] released from cement is equal to the amount of alkali released [12]. According to Ivars Pavasars *et al*., the long term prediction based on modeling of the kinetics shows degradation of cellulose in cementitious environment estimated by about 25% after 3 years. The model indicated that all of the cellulose degraded after only 150-550 years, which represent the persistence of cellulose under alkaline situation [13].

In a cotton milling plant, two sources of cotton wastes are usually fabricated. One of them is reused and fed in the process. The other source is cotton fluff (Fig. 1) defined as dust generated into atmosphere as a result of processing cotton fibers, which is directed to suction devices and gathered on a filter. Having been gathered in a baggage, cotton fluff is directly thrown away. Using optical projection microscope for fluff fiber identification with 25 samples shows average size of 1.1 mm [with 23% error] for length and 10 μm [with 15% error] for diameter.

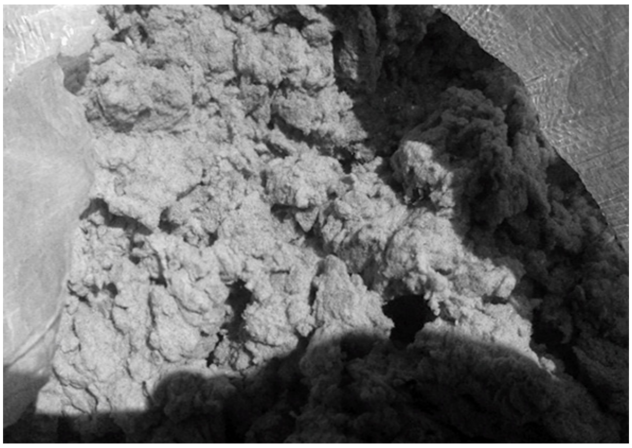


Fig. 1. Cotton fluff fiber.

In this paper, the effect of cotton fluff fibers on mechanical properties of concrete has been investigated. The cotton fluffs bonding and degradation have been studied by SEM.

II. EXPERIMENTAL

A. Materials and Methods

The molds used in the experiments were 15×15×15 cm³ in size. Samples curing was done according to ASTM C192 [14]. The reference mixing applied for this study is used in dry mix shotcrete. It includes cement type 5 as 400 kg/m³, sand as 1500 kg/m³ and water as 200 L/m³.

The sand used in the samples is natural sand. The fineness modulus (FM) coefficient was 3.8 and sand equivalent (SE) coefficient was 0.88%. According to ASTM C192, the sand amount in the mixing, is accounted as dry weight and its moisture percentage is calculated based on the weight of water. Fig. 2 shows the aggregation curve of sand [14].

Cotton fluff fiber in the range of 0.5 kg/m³ to 5 kg/m³, was used in the experiments instead of cement. The water absorption of cotton fibers as well as other natural fibers is high. The use of superlubricant can be effective in increasing the efficiency of mixing.

The amount of additives in the experiments is entitled 0.88% of cement. This additive is a superplasticizer fluid

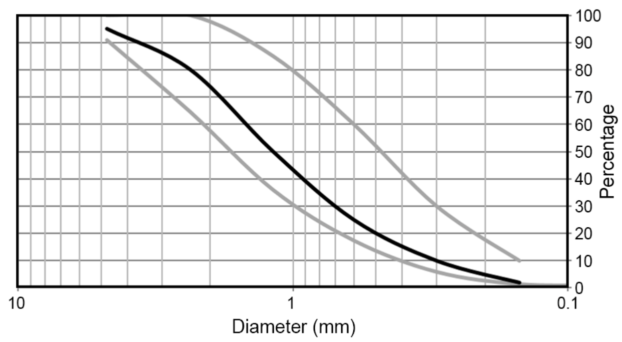


Fig. 2. The aggregation curve of sand.

TABLE I
RESULTS OF AVERAGE COMPRESSIVE STRENGTH FOR 11 AND 42 DAYS SPECIMENS

Mix	Age (d)	Fiber dosage (kg/m³)	Density (g/cm³)	Strength (MPa)
M-1	11	---	2.22	12.4±0.8
M-2	42	---	2.22	23.6±0.3
M-3	11	0.5	2.22	13.7±0.6
M-4	42	0.5	2.22	23.2±0.8
M-5	11	2	2.16	13.1±0.5
M-6	42	2	2.16	21.2±0.8
M-7	11	3.5	2.14	10.6±0.5
M-8	42	3.5	2.14	18.1±0.1
M-9	11	5	2.16	10.8±0.5
M-10	42	5	2.16	18.0±0.9
M-11	11	1	2.23	16.1±1.6
M-12	42	1	2.23	22.6±0.4
M-13	11	1.5	2.17	15.7±0.4
M-14	42	1.5	2.17	23.9±1.5

based on corrected polycarboxylic.

Due to its high moisture absorption, cotton wool is used in saturated form in experiments. To obtain the necessary moisture in saturation point, a definite amount of fibers was weighted and leached in water. Water absorption of the fibers continued up to reach stability of moisture weight and saturation moisture. Consequently, the difference between dry and moisture weight of the fibers was calculated after filtration. As a result, each gram of fiber absorbs 5 mL of water for saturation.

The dispersion of fibers will be considered as the next step in preparation of the fibers. The fibers including some short strips were dispersed before sampling. This process could be done by placing the fibers in water and using a surfactant. The surfactant used in this experiment was sodium lauryl sulfate (SLS). SLS breaks the moisture obstacle of the matters membrane and facilitate penetration of other elements. This characteristic facilitates dispersion of cotton fluff in water. The amount of surfactant used is 0.3% of the mass percentage of the fibers [15].

In each step of the experiments, the fibers were previously saturated with the obtained ration, and then dispersed by putting the fibers in water and adding surfactant for at least 24 h.

Experiments were done in two stages. First series of the experiments were done by replacement of 0.5, 2, 3.5, and 5 kg/m^3 of cements with cotton fluff fibers. In this step, approximate place of optimum amount of the fibers was distinguished. According to the results of first series of the experiments, the second stage was done at a range of 0.5 kg/m^3 to 2 kg/m^3 of the fibers used for replacement of cement. In the experiments, 6 cubic samples were obtained. 4 samples, after 11 days, and 2 samples, after 42 days, were tested for compressive strength.

After breaking cubic specimens, in a compression-testing machine, visual inspection also took place by a scanning electron microscope. For preparation of cement samples, the fracture surfaces of cubic samples were coated by a thin gold layer. To avoid damage to the structure and crack conditions, polishing of the samples was neglected [16,17].

III. RESULTS AND DISCUSSION

According to Table I, in the first stage of experiments, samples M-2 and M-5 showed compressive strength of 13.7 and 13.1 MPa, respectively. Compressive strength in both samples was higher than that in reference sample. The results of samples M-7 and M-9 were undesirably obtained. Compressive strength for samples M-4 and M-6 was orderly 23.2 and 21.2 MPa. These samples showed lower

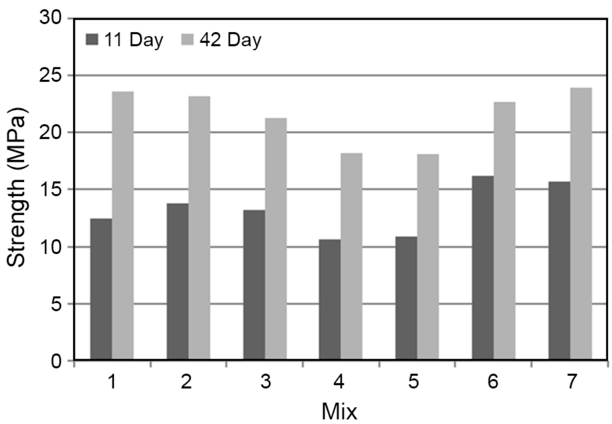


Fig. 3. Comparison of compressive strength in 11 and 42 days specimens.

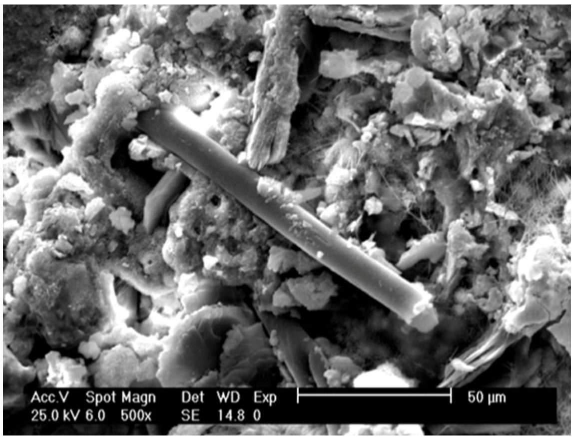


Fig. 4. Rod-shaped cotton fluff fiber as a reinforcement in cement composite.

strength than the reference sample after 42 days.

The first stage of the tests showed that the replacement of 0.5 and 2 kg increased the 11 days compressive strength of the samples. As shown in Fig. 3, this trend in the 42 days samples does not follow the 11 days compressive strength results, as expected.

In the second stage of the tests, 1 and 1.5 kg of cement were replaced by cotton fluff fibers. Considering the first stage results, the second stage was accomplished to find optimum amount of the fiber in the range of 0.5 kg to 2 kg of the applied fibers.

According to Fig. 3, replacement of 1 kg of cement with fiber (sample M-11) revealed the highest 11 days compressive strength (16.1 MPa). The compressive

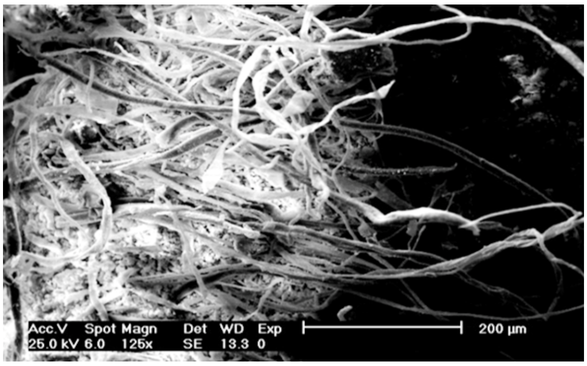


Fig. 6. Unsuitable dispersion of fiber in M-5.

strength of this mixing (M-12) was slightly lower than that of reference mixing at 42 days.

In sample M-13, the replacement of 1.5 kg of cement with cotton fluffs fibers provided significant compressive strength after 11 days (15.7 MPa). 42 days strength of M-14 was more than 42 days strength of other samples (23.9 MPa). Compared to a 0.36 % hemp fiber reinforcement that results in a 4 % increase in compressive strength, replacement of 0.37% cement (weight) by cotton fluff fibers indicates a 26% increase in 11 days strength and 1% increase in 42 days compressive strength.

Referring to Fig. 4, the structure of the fiber rod in low values whose dispersion is optimally applied, acts as an appropriate reinforcement. This reinforcement featured high bonding with mortar. As shown in Fig. 5, an increase in compressive strength of samples containing 0.5 kg to 1.5 kg fiber can be considered as the result of this adhesion. As

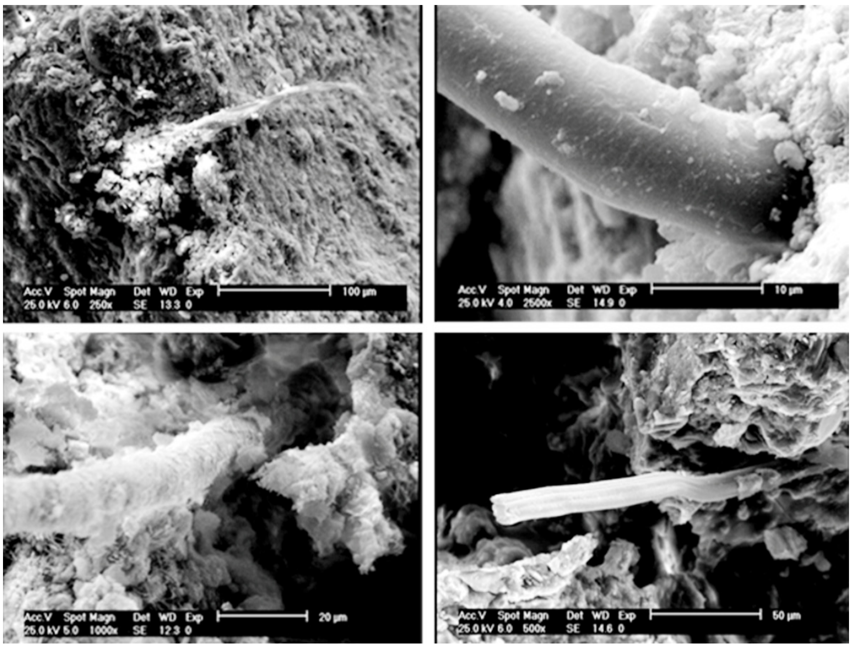
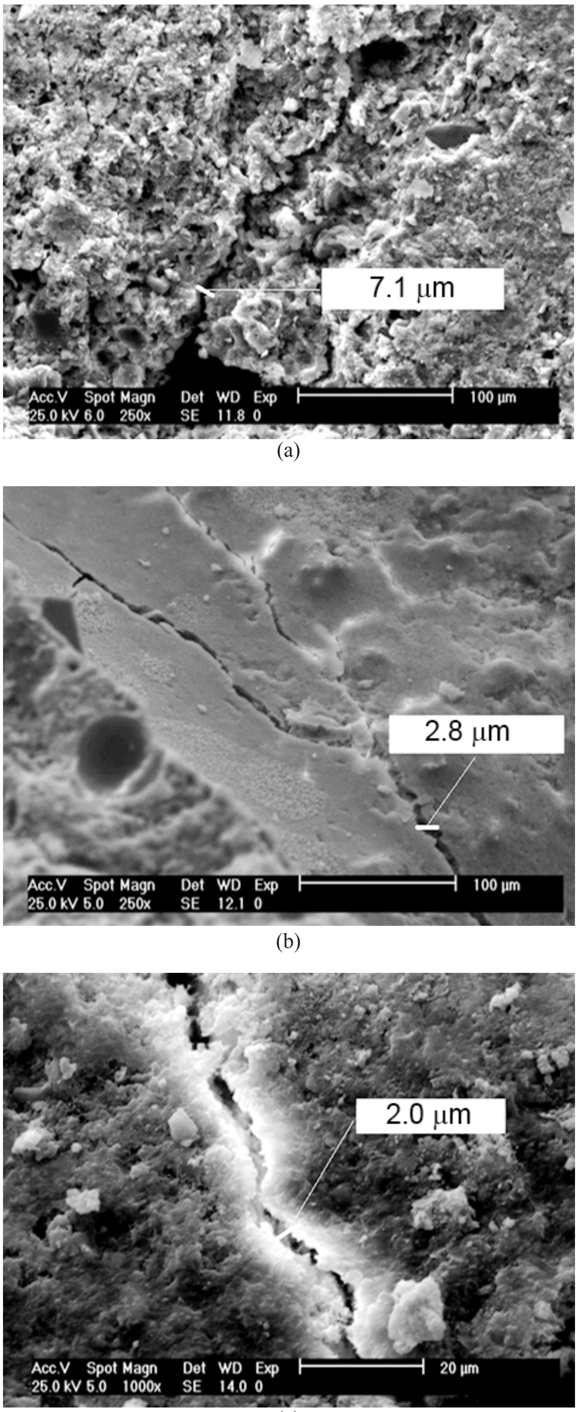


Fig. 5. Occasional high fiber-to-mix bonding.

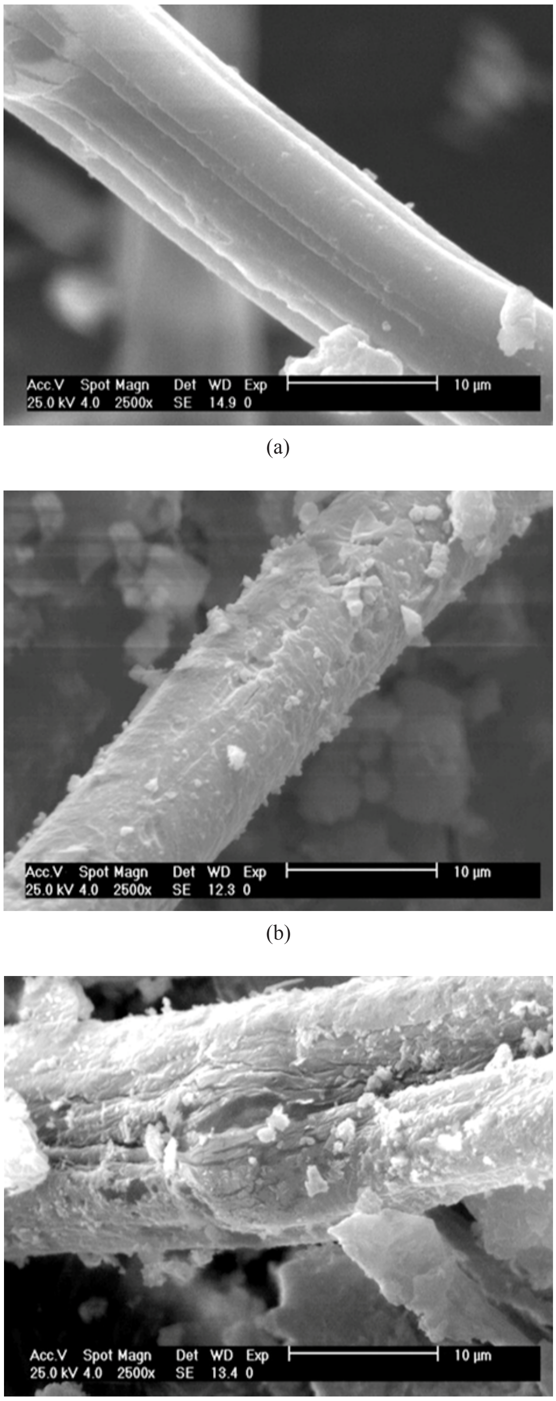


(a)

(b)

(c)

Fig. 7. SEM images of shrinkage cracking in: (a) plain specimen, (b) 1 kg/m^3 fiber specimen, and (c) 1.5 kg/m^3 fiber specimen.



(a)

(b)

(c)

Fig. 8. Fiber degradation over time: (a) virgin cotton fluff fiber, (b) cotton fluff fiber in alkaline environment of cement composite after 11 days, and (c) cotton fluff fiber in alkaline environment of cement composite after 42 days.

shown in Fig. 6, when the fibers amount increases, an undesirable dispersion will be resulted in an unsuitable bond of fibers and cement mortar. The fibers are settled in a massed shape in the composite structure. This may explain the cause of decline in the compressive strength of samples with 2-5 kg fibers.

One of the benefits of using cotton fluff is the control of fractures that occurred due to the shrinkage on the sample. Based on Fig. 7, cotton fluff fibers are effective in reducing the fractures width through limiting and minimizing the water evaporation in the samples.

SEM images in Fig. 8 indicate the fibers destruction in cement mixtures. This destruction occurred along the fibers at the time of the separation of cellulose fibers. This may be associated with partial cellulose degradation in the alkaline medium of mixtures. The result of the 42 days strength decrease is proportional to their 11 days strength.

IV. CONCLUSION

- The results of the 7 tested commixtures indicate an increase in the compressive strength for replacing cement with 0.5 kg/m^3 to 1.5 kg/m^3 cotton fluff fibers. Replacing 1.5 kg/m^3 cement by fibers (0.37% of cement by weight) indicates a 26% increase in 11 days strength and 1% increase in the 42 days compressive strength of cube samples in proportion to the reference sample.
- The data obtained from 42 days compressive strength tests do not agree with the trend of 11 days strength. Although the result of sample M-14 shows the average of 42 days strength as to being more than reference sample's strength.
- Electron microscope images of low amount of cotton fluff shows suitable bondings between cement mortar and fibers. On the contrary, the observations show that in a larger amount of fibers, the dispersion did not occur completely and appeared partially in the form of aggregates in the composite. In addition, one major problem in dealing with cotton fluff fibers is the long time taken in the process of dispersion.
- SEM inspection of 42 days samples illustrated the fibers destruction over time. Viewing these images showed the destruction of the fiber in the direction of its length and its fibrillated shape. No destruction throughout the fibers section was recognized.
- Efficient water reducing additives were used to solve the problem of high water absorption in fluffy cotton fibers. To check the amount of fibers consumed, a certain percentage of this additive was used continuously in 7 commixtures. The use of water-reducing additives in cement composite reinforced with water-absorbing fibers is a suitable method to maintain the efficiency of the mixture.
- The statistical analysis of the data indicated a significant error in the data. Length diversity of cotton fluff fibers in cement composites causes more scattering in test data.

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REFERENCES

[1] G. Vilkner, C. Meyer, and S. Shimanovich, "Properties of glass concrete contacting recycled carpet fibers", *PhD dissertation*, Columbia University, 2003.

[2] Y.-M. Chun and T.R. Naik, "Concrete with paper industry fibrous residuals", *ACI Mater. J.*, vol. 102, no. 4, pp. 237-243, 2005.

[3] S.P. Coutts Robert, "A review of Australian research into natural fiber cement composites", *Cem. Concr. Compos.*, vol. 27, pp. 518-526, 2005.

[4] S.S. Munawar, K. Umemura, and S. Kawai, "Characterization of the morphological, physical and mechanical properties of seven nonwood plant fiber bundles", *J. Wood Sci.*, vol. 53, no. 2, pp. 108-113, 2006.

[5] Z. Li, L. Wang, and X. Wang, "Compressive and flexural properties of hemp fiber reinforced concrete", *Fiber. Polym.*, vol. 5, no. 3, pp. 187-197, 2004.

[6] F. de Andrade Silva, B. Mobasher, and R.D. de Toledo Filho, "Advances in natural fiber cement composites: a material for the sustainable construction industry", 4th Colloquium on Textile Reinforced Structures (CTRS4), pp. 377-388, 2009.

[7] F.P. Torgal and S. Jalali, "Vegetable fiber reinforced concrete composites: A review", https://repositorium.sdum.uminho.pt/bitstream/1822/10453/1/Materials_2009.pdf

[8] G. Ramakrishna and T. Sundararajan, "Impact strength of a few natural fiber reinforced cement mortar slabs: a comparative study", *Cem. Concr. Compos.*, vol. 27, no. 5, pp. 547-553, 2005.

[9] S.C. Paul, G.P.A.G. van Zijl, and B. Šavija, "Effect of fibers on durability of concrete: a practical review", *Materials*, vol. 13, no. 20, pp. 1-26, 2020.

[10] S.O. Amiandamhen and S.O. Osadolor, "Recycled waste paper–cement composite panels reinforced with kenaf fibers: durability and mechanical properties", *J. Mater. Cycles Waste Manag.*, vol. 22, pp. 1492-1500, 2020.

[11] W.E. Morton and J.W.S. Hearle, *Physical Properties of Textile Fibers*, 4th ed., Cambridge, England: Woodhead, 2008.

[12] R.J. van Eijk and H.J.H. Brouwers, "Prediction of hydroxyl concentrations in cement pore water using a numerical cement hydration model", *Cem. Concr. Res.*, vol. 30, pp. 1801-1806, 2000.

[13] I. Pavasars, J. Hagberg, H. Borén, and B. Allard, "Alkaline degradation of cellulose: mechanisms and kinetics", *J. Polym. Environ.*, vol. 11, no. 2, pp. 39-47, 2003.

[14] ASTM C192/C192M- 07, "Standard practice for making and curing concrete test specimens in the laboratory", Updated: Oct 24, 2012.

[15] P. Soroushian and H. Jer-wen, American Patent: Patent

08/885644, 1999.
[16] V.S. Ramachandran and J.J. Beaudoin, *Handbook of Analytical Techniques in Concrete Science and Technology*, Institute for Research in Construction, National Research Council of Canada, 2001.
[17] S.L. Marusin, “Sample preparation–the key to SEM studies of failed concrete”, *Cem. Concr. Compos.*, vol. 17, no. 4, pp. 311-318, 1995.