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FLY ASH AND BAGASSE FIBER INFLUENCES ON MECHANICAL PROPERTIES OF GREEN HYBRID FIBER-REINFORCED CEMENTITIOUS COMPOSITES

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In this paper, a new green fiber-reinforced cementitious composite containing high volume fly ash and hybrid steel and bagasse fibers is developed. Eco-friendly bagasse fibers from industrial waste and steel fibers are used to improve the mechanical behavior of the new composite, and high-volume fly ash is used to decrease the usage of cement in order to be more environmentally friendly. The influence of the fiber content and fly ash/cement ratio on the mechanical properties of the composite is investigated through the study of the mechanical properties of the new composite, such as compressive strength, modulus of elasticity, and modulus of rupture. It is found that compressive strength, Young's modulus of the composite, decreases with the increase of the fly ash/cement ratio and bagasse fiber content. However, the modulus of rupture of the composite increases firstly with bagasse fiber content, and decreases when bagasse fiber content reaches 3% by volume.

Keywords: Compressive strength, Steel fiber, Fly ash-cement ratio, Sustainability, Concrete manufacturing, Carbon emissions.

1 INTRODUCTION

Research and development of fiber-reinforced cementitious composites have attracted great research interest over the years. Fiber-reinforced cementitious composites could often exhibit superior mechanical behavior than the conventional concrete materials (Li 2007, Qian 2000, Soe *et al.* 2013, Bell *et al*. 2012). However, these materials usually demand large amounts of cement, which have caused severe environmental impact due to the large amounts of CO_2 emission (Yang *et al*. 2007) during its manufacturing. Therefore, development of sustainable and eco-friendly fiber-reinforced cementitious composites is of great significance.

Fly ash, a by-product of coal-fired power stations, has been used with a high volume fraction to partly replace cement in a high performance fiber-reinforced cementitious composite. This has exhibited outstanding mechanical behaviors (Yang *et al*. 2007). In addition to the benefits to environment, the use of high volume fly ash could also improve the long-term mechanical behavior of the composites and reduce the business cost (Mehta 2004).

Natural fibers such as banana fiber, bagasse fiber, coir fiber, jute fiber, and sisal fiber have also been used in these composites to improve the mechanical behavior

(Coutts 1990, Gassan et al. 1999, Andrade et al. 2010). Bagasse fiber, which is the by-product of the cane sugar industry, is a totally eco-friendly material, and has been found to change the setting behavior and improve the basic mechanical properties of the matrix (Aggarwal 1995, Bilba et al. 2003).

In previous research, fly ash and natural fibers were used in cementitious composites individually, but the benefits from combined application of natural fiber and fly ash on improving the mechanical behavior of the composites was not known yet. With the high-volume fraction of fly ash, the matrix gets a lower alkali degree, and this may reduce the corresponding degradation of the natural fiber and improve the mechanical properties of the composite, especially after long-term curing (Marikunte 1994). Thus it is important to investigate the combined influence of high volume of fly ash and natural fiber on the fiber-reinforced cementitious composites. In this paper, a new green hybrid bagasse-fiber and steel-fiber reinforced cementitious composite is developed. The influence of fly ash/cement ratio and bagasse fiber content on the mechanical properties of the composites is studied by evaluating the essential mechanical properties, such as compressive strength, modulus of elasticity, and modulus of rupture.

2 A NEW GREEN FIBER-REINFORCED CEMENTITIOUS COMPOSITE

A new green fiber-reinforced cementitious composite with cement, fly ash, sand, water, and reducing agent is developed. Ordinary Portland Cement (OPC) and a low-calcium Class F fly ash are used. The high-range water-reducing agent used was Grace ADVA 142. The average size of sand used was 250 µm, with a maximum size of 300 µm. The steel fiber used was provided by Ganzhou Daye Metallic Fibers Co. Ltd., with a length of 13 mm and a diameter of 0.2 mm. Original bagasse fibers were provided by Australian Prime Fiber Company, and modified to improve its mechanical and chemical properties before mixing. After the modification, the bagasse fiber had a mean length of 10.1 mm, and mean diameter of 0.39 mm.

In order to study the influence of fly ash content and bagasse fiber content on the mechanical properties of the new composite, a varying fly ash-to-cement ratios of 1.2, 1.6 and 2.0, and different fiber content of 3%, 8%, and 12% by volume, were applied in the test. The mixture proportions of the composite with different fly ash-to-cement ratio and fiber content are listed in Table 1.

3 SPECIMEN PREPARATION AND TESTING

Test specimens were prepared according to relative ASTM standards. The solid ingredients, including cement, sand, and fly ash, were first mixed for approximately 2 minutes. Then bagasse fibers were blended with water first, then added to the matrix to make sure these natural fibers dispersed evenly. Once a consistent mixture was obtained steel fibers were added gradually, and then followed by blending for 10 minutes. The finished fresh mixture was then casted into molds, followed by 3 minutes' vibration. Specimens were demolded after 24 hours, and then placed in a curing chamber with a constant temperature of 23℃ and 100% relative humidity until the day of testing.

Material properties of the specimens such as compressive strength, Young's modulus, and modulus of rupture were tested at 7 days, 14 days and 28 days. Three specimens were tested for each test to get a mean value of the material property.

Table 1. Mixture proportions of the new composite with different fly ash/cement (F/C) ratio and fiber content (by volume).

Bagasse-fiber content (v%)	F/C	Cement [kg/m^3]	Fly ash [kg/m^3]	Sand [kg/m^3]	Water [kg/m^3]	Reducing agent [kg/m^3]
3	1.6	487.78	780.45	439	329	6.34
8		462.5	740	416.25	312.65	6.01
12		442.3	707.7	398	299	5.74
3	1.2	560.89	673.07	504.8	320.83	7.29
	1.6	487.78	780.45	439	329	6.34
	2.0	431.54	863.08	388.38	336.6	5.61

4 EXPERIMENTAL RESULTS

4.1 Influence of Fly Ash Content/Cement Ratio on the Mechanical Behavior of the Composite

To study the effect of fly ash content on the mechanical behavior of the composite, the mechanical properties of the composite with varying fly ash/cement ratios of 1.2, 1.6 and 2.0, with a fixed bagasse fiber content of 3% by volume, were tested at 7 days, 14 days, and 28 days. The compressive strength of the composite from compression tests are shown in Table 2. It can be seen that the compressive strength of the composite is comparable with normal concrete, with the highest value reaching 42.37 MPa for the fly ash/cement ratio of 1.2 at 28 days. As curing time increases from 7 days to 28 days, an increase of 35.4%, 51.2%, and 55.7% in compressive strength could be found for the composites with fly ash/cement ratios of 1.2, 1.6 and 2.0, respectively. Also, it can be found that the compressive strength decreases gradually with the increase of the fly ash content at 28 days.

Table 2. Compressive strength (MPa) of the composite with different fly ash/cement ratio.

Fly Ash/Cement Ratio	Days at Testing		
	7	14	28
F/C = 1.2	31.3	35.66	42.37
F/C = 1.6	24.24	28.24	36.67
F/C = 2.0	21.72	24.82	33.82

Young's modulus of the composite with varying fly ash/cement ratio was also tested at 7 days, 14 days, and 28 days, and the results are shown in Table 3. It can be found that Young's modulus of the mix shows an up-going trend, with an increase of 92.05% for the fly ash/cement ratios of 1.2, 60.52% for the fly ash/cement ratio of 1.6, and 68.52% for the fly ash/cement ratio of 2.0 from 7 days to 28 days. Also, the Young's modulus tested at the same curing age could be found to decrease with the increase of the fly ash/cement ratio.

Table 3. Young's modulus (GPa) of the composite with different fly ash/cement ratio.

Fly Ash/Cement Ratio	Days at Testing		
	7	14	28
F/C=1.2	9.68	12.99	18.59
F/C=1.6	9.5	11.88	15.25
F/C=2.0	8.45	9.61	14.24

Table 4 shows the modulus of rupture of the composite with varying fly ash/cement ratios of 1.2, 1.6, and 2.0 tested at the age of 7, 14 and 28 days. The highest modulus of rupture of the composite is 5.74 MPa for the fly ash/cement ratio of 1.2 at 28 days, followed by 5.22 MPa (a decrease of 9.06%) and 4.67 MPa (a decrease of 18.64%) for fly ash/cement ratios of 1.6 and 2.0 respectively. All of the modulus of rupture for different mixes is over 3 MPa at the age of 7 days, and these values increase gradually through the whole curing stage, with an increase of 24.51% for the the fly ash/cement ratio of 1.2 at the age of 28 days, 61.61% for the fly ash/cement ratio of 1.6, and 55.15% for the fly ash/cement ratio of 2.0, respectively.

Table 4. Modulus of rupture (MPa) for the composite with different fly ash/cement ratio.

Fly Ash/Cement Ratio	Days at Testing		
	7	14	28
F/C = 1.2	4.61	4.84	5.74
F/C = 1.6	3.23	4.2	5.22
F/C = 2.0	3.01	3.79	4.67

4.2 Influence of Bagasse Fiber Content on Mechanical Behavior of the Composite

To study the effect of bagasse fiber content on the mechanical behavior of the composite, the mechanical properties of the composite with varying bagasse fiber content of 3%, 8% and 12% by volume, with a fixed fly ash/cement ratio of 1.6, were tested at 7 days, 14 days and 28 days.

Table 5. Compressive strength (MPa) of the composite with different bagasse fiber content.

Bagasse fiber content (%)	Days of testing		
	7	14	28
3	24.24	28.24	36.67
8	12.54	23.54	32.96
12	10.55	18.76	25.78

The compressive strength of the composites is shown in Table 5. It can be observed that with the increase of the bagasse fiber content, the early-age compressive strength of the composite decreases significantly. At 7 days, the compressive strength of the composite with 3% bagasse fiber content is 24.24 MPa. This figure drops to a much lower value of 12.54 MPa and 10.55 MPa respectively for the composite with bagasse fiber content of 8% and 12% (only 51.7% and 43.52% of that for 3% bagasse fiber). However, when specimens are 28 days old, the compressive strength of the composite with different bagasse fiber content shows a more stable trend. The compressive strength of 36.67 MPa for bagasse fiber content of 3% is reduced to 32.96 MPa (a decrease of 10.2%) for the bagasse fiber content of 8%, and to 25.78 MPa (a decrease of 29.7%) for the bagasse fiber content of 12%.

Table 6. Young's modulus (GPa) of the composite with different bagasse fiber content.

Bagasse fiber content (%)	Days of testing		
	7	14	28
3	9.5	11.88	15.25
8	7.91	9.21	13.51
12	6.93	7.89	11.76

The tested Young's modulus of the material is shown in Table 6. It can be found that the Young's modulus of the composite also decreases with the increase of bagasse fiber content. At 28 days, the Young's modulus of the composite is 15.25 GPa with the bagasse fiber content of 3%, which decreased to 13.51 GPa (a decrease of 11.41%), and to 11.76 GPa (a decrease of 22.89%) with the bagasse fiber content of 8% and 12%, respectively.

Table 7 shows the modulus of rupture of the composite with varying bagasse fiber content of 3%, 8% and 12% tested at 7, 14 and 28 days. It is exhibited that the composites containing 3% bagasse fiber shows the highest modulus of rupture of 5.22 MPa at the age of 28 days. As the fiber content increases, the modulus of rupture declined gradually to 5.05 MPa for the composites with 8% bagasse fiber content and 3.89 MPa for the composite with 12% bagasse fiber content.

Table 7. Modulus of rupture (MPa) of the composite with different bagasse fiber content.

Bagasse fiber content (%)	Days at Testing		
	7	14	28
3	3.23	4.2	5.22
8	2.94	4.17	5.05
12	2.57	2.68	3.89

5 CONCLUSIONS

A new hybrid bagasse fiber and steel fiber reinforced cementitious composite was developed in this paper, and the influence of fiber content and fly ash content on the mechanical behavior of this new material was studied.

It is found from this study that the increase of the fly ash content in the composite generally reduces the compressive strength, Young's modulus, and the modulus of rupture of the composite. The compressive strength of the composites comes to a value between 33 MPa and 43 MPa after 28 days, when bagasse fiber content is fixed at 3%, and the Young's modulus changes from 14 GPa to 19 GPa. The modulus of rupture of the composites drops from 5.74 MPa to 4.67 MPa when fly ash/cement ratio increases from 1.2 to 2.0.

It is also found that compressive strength and Young's modulus of the composite decreases with the increase of the bagasse fiber content, while the modulus of rupture increases first until the bagasse fiber content reaches 3% , and decreases gradually with the further increase of bagasse fiber.

References

Aggarwal, L.K., Bagasse-reinforced cement composites, *Cement & Concrete Composites*, 17, 107-112, 1995.

Andrade, S. F. D. F., Toledo, R. D., Melo, F. J. D. A., and Rego, F. E. D. M., Physical and mechanical properties of durable sisal fiber–cement composites, *Constr. Build. Mater*., 777-785, 24, 2010.

Bell, J., Zhang, Y. X., Soe, K., and Hermes, P., High velocity impact behaviour of hybrid-fiber engineered cementitious composite panels, *Adv. Mater. Res.-Switz*., 450-451, 563-567, 2012.

Bilba, K., Arsene, M. A., and Ouensanga, A., Sugar cane bagasse fiber reinforced cement composites. Part I. Influence of the botanical components of bagasse on the setting of bagasse/cement composite, *Cement & Concrete Composites*, 25, 91-96, 2003.

Coutts, R. S. P., Banana fibers as reinforcement for building products, *Materials Science Letters*, 9, 1235-1236, 1990.

Gassan, J., and Bledzki, A. K., Correlation between structure and properties of cellulose-based fibers and their effects on composite properties, in *Fifth International Conference on Woodfiber-Plastic Composites*, 147-152, 1999.

Li, V. C., Engineered Cementitious Composites (ECC) – *Material Structural and Druability Performance*, CRC Press, Boca Raton, 2007.

Marikunte, S., and Soroushian P., Statistical evaluation of long-term durability characteristics of cellulose fiber-reinforced cement composites, *ACI Materials Journal*, 91, 607-616, 1994.

Mehta, P. K., High-performance, high-volume fly ash concrete for sustainable development, in *Proceedings of The International Workshop on Sustainable Development and Concrete Technology*, University of California, Berkeley, USA, 2004.

Qian, C. X., and Stroeven P., Development of hybrid polypropylene-steel fiber-reinforced concrete, *Cement Concrete Res*., 30, 63-69, 2000.

Soe, K., Zhang, Y. X., and Zhang, L. C., Material properties of a new hybrid fiber-reinforced engineered cementitious composite, *Constr. Build. Mater*., 43, 399-407, 2013.

Yang, E. H., Yang,Y. Z., and Li, V. C., Use of high volumes of fly ash to improve ecc mechanical properties and material greenness, *ACI Materials Journal*, 104, 303-311, Nov.-Dec., 2007.