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EFFECT OF CHOPPED BASALT FILAMENT FIBRE ON MODULUS OF RUPTURE OF CONCRETE

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Abstract: Fibre reinforced concrete has been gaining popularity and increasing its uses in various constructions such as building pavements, large industrial floors, and runways. A long-term research work is being undertaken at the University of Windsor to investigate applications of chopped filament and other forms of basalt fibres in concrete. This paper discusses the effect of chopped basalt filaments fibres on the modulus of rupture when added to fresh plain cement concrete. Various lengths and dosages of chopped basalt filament fibres were added and then the concrete specimens were tested at 28 days to study the effect of these fibres on the concrete's modulus of rupture. The study found that the optimum length and optimum amount of basalt fibre are 36 mm and 8 kg/m^3, respectively if a significant improvement in the modulus of rupture is required.

Keywords: basalt fibre, fibre reinforced concrete, modulus of rupture, chopped filament fibre

1. INTRODUCTION

The plain cement concrete is known for its compressive strength, but it is really weak in tension. This is because of the fact that plain concrete contains numerous micro-cracks and they propagate in the concrete matrix when subjected to tensile load. Various studies indicate that the growth of these cracks can possibly be slowed down or arrested if randomly spaced small fibres are mixed in the concrete. It is also reported that the addition of chopped fibres to plain cement concrete also helps in improving the mechanical properties of concrete such as flexural strength, toughness, and resistance to dynamic load. When plain concrete (PC) is mixed with randomly dispersed fibres, it is called fibre reinforced concrete (FRC). Studies using various chopped fibres such as steel fibres, glass fibres, polypropylene fibres, carbon fibres, and basalt fibres are available in the open literature (Ahmad and Lagoudas 1991; Laning 1992; Ramakrishnan et al. 1998; Naaman 2003; Mehta and Monteiro 2006; Bentur and Mindess 2007; Li 2011; Nemati 2013). Among all these fibres, basalt fibre is the most recent construction material available in the market; this fibre is produced from volcanic rock called basalt. Concrete, when mixed with basalt fibre is called basalt fibre reinforced concrete (BFRC). Basalt fibre is environmentally safe and possesses good insulating characteristics and thermal endurance. It is a relatively cheaper and greener material than many other commercially available fibres. The material does not conduct electricity and it possesses a high tensile strength.

From the previous studies, it can be concluded that a low or moderate fibre dose can improve the flexural toughness of FRC, whereas, the improvement in the flexural strength is relatively low. These studies also reported that the flexural toughness and strength increase for a particular fibre type and mix until an optimum fibre length and fibre dose are attained (American Concrete Institute 2002; Mehta and Monteiro 2006). However, a high dose of fibre and fibre with large aspect ratios usually reduce the workability of plastic concrete mixes (Hannant 1978).

Ramakrishnan et al. (1998) is one of the first research groups who undertook research on BFRC and this study used chopped basalt fibres 13 mm long and 12 μm in diameter. The amount of fibres in their study varied from 0.1% to 0.5% by volume. This study concluded that BFRC does not show any improvement in the compressive strength, however, BFRC shows considerable improvement in the impact strength and flexural toughness if large amounts (0.5% by volume) of fibre is added. However, a study by Borhan (2013) showed that the addition of up to 0.3% by volume of basalt fibres increases the compressive strength considerably. However, there was slight reduction in the compressive strength when the amount of basalt fibre was increased to very high amounts (0.5% by volume). KNUCA (2011) concluded that the use of basalt fibres with 16 μm diameter and 24 mm length increases the flexural strength and the compressive strength by 29% and 14% respectively, from plain concrete specimens by adding 5 kg/m^3 of basalt fibres. Hence, the literature review found that few studies on BFRC are available, however, the results reported by Ramakrishnan et al. (1998) do not agree with the results obtained by other researchers (Borhan 2013; KNUCA 2011). The current study was undertaken to study the effect of the dose (amount) and length (aspect ratio) of the basalt filament fibres on the modulus of rupture (MOR) which is an indication of flexural strength. This paper discusses the test method, test matrix, and test data obtained from this study.

2. TEST PROGRAM

This study was undertaken to determine the effect of fibres on the 28-day modulus of rupture (MOR) of BFRC made with chopped filament basalt fibres of various doses (amounts) and lengths (aspect ratios). The concrete mix used general use Portland cement, sand, and graded coarse aggregates with a maximum size of 19 mm and the weight ratio of 1:1.4:2.8 (cement: fine aggregate: coarse aggregate). The mix used a water-cement ratio of 0.5. Basalt filament fibres of 16 μm in diameter and three different lengths were used in this study. The lengths chosen for this study were: 12 mm, 36 mm, and 50 mm. The control specimen used in this study was made of plain cement concrete (PC). As a second control specimen, steel fibre reinforced concrete (SF) was also used in this study and these steel fibres were hooked end, cold drawn steel fibres, 0.9 mm in diameter and 38 mm long.

The test matrix used in this study is shown in Table 1. This paper reports average values obtained from three identical specimens tested for each specimen. Specimen names are chosen to identify the key parameter of that specimen. For example, for specimen BF 50-12, the first two letters (BF) represent that it is a BFRC specimen made of basalt filament fibre, the next numerical value (50) represents that the length of fibre is 50 mm; and the last number (12) indicates that this specimen used fibre dose of 12 kg per one cubic meter of plain concrete. Specimens labelled PC indicates that it is a plain cement concrete specimen and it has no fibre and is a reference specimen. Only one type of steel fibre reinforced concrete (SF) specimen was prepared and tested in this study and it is labelled SF 38-40 in Table 1. This specimen used steel fibres at 40 kg per one cubic meter of plain concrete and the length of steel fibre is 38 mm. In this study, the dosage of basalt fibres varied from 4 kg/m^3, 8 kg/m^3, and 12 kg/m^3 and the length of fibre varied from 12 mm, 36 mm, and 50 mm.

Table 1: Test matrix

Specimen type	Fibre type	Fibre length (mm)	Fibre amount (kg/m^3)	Fibre amount (% volume)
PC	No fibre	N/A	0	0
BF 12-4	Basalt fibre	12	4	0.15
BF 12-8	Basalt fibre	12	8	0.31
BF 12-12	Basalt fibre	12	12	0.46
BF 36-4	Basalt fibre	36	4	0.15
BF 36-8	Basalt fibre	36	8	0.31
BF 36-12	Basalt fibre	36	12	0.46
BF 50-4	Basalt fibre	50	4	0.15
BF 50-8	Basalt fibre	50	8	0.31
BF 50-12	Basalt fibre	50	12	0.46
SF 38-40	Steel fibre	38	40	0.51

3. TEST RESULTS

A slump test is generally used to measure the workability of a concrete mix. Figure 1 shows the slump data obtained from all the mixes. This figure shows that the slump (workability) in general decreases with an increasing dose of basalt fibre for all three fibre lengths. However, the rate of decrease in slump for 50 mm long fibre was alarming. The lowest slump value recorded from these specimens was 100 mm when the large amount of fibre (12 kg/m^3) for 50 mm long fibre was added. It is difficult to work when slump is that low. Further, balling of fibres was observed during mixing of concrete when 50 mm long fibres at the fibre amount of 12 kg/m^3 (for specimen BF 50-12) was used. However, the issues of low slump and balling can probably be resolved by adding superplasticizer or adding fine particles like fly-ash or using round shaped gravel rather than crushed stones. This was not, however, investigated in this study.

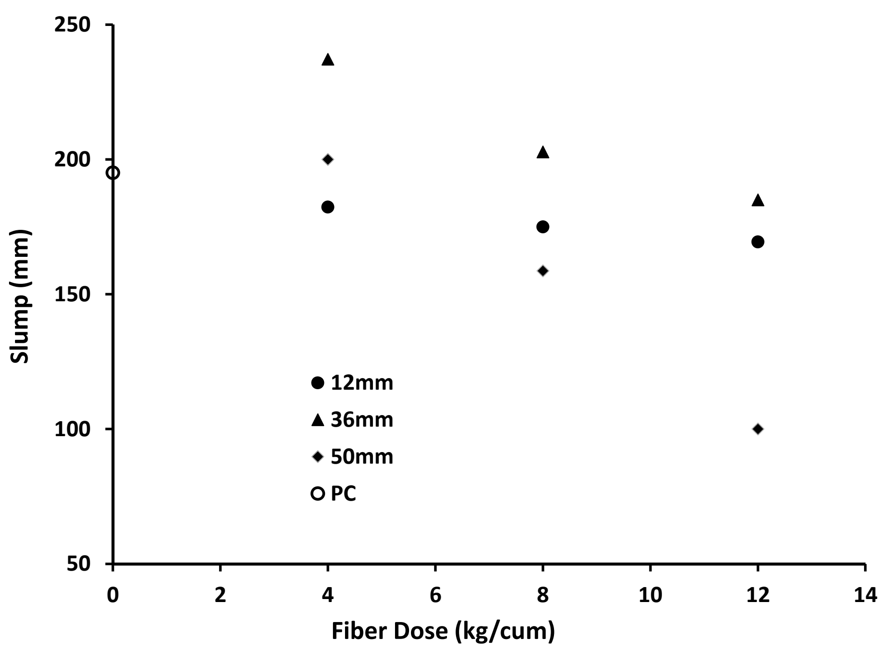

Figure 1: Effect of fibre length and dose on slump

Figure 2 shows the effect of basalt fibre length on the modulus of rupture (MOR). It can be seen from this figure that there is no strong correlation between the fibre length and the MOR when fibre amount is only 4 kg/m^3. However, a general trend of increasing MOR with the increasing fibre length can be found when fibre dose is increased to 8 kg/m^3. The MOR values for PC and BFRC specimen made with 12 mm long fibres (BF 12-8) were found to be 4.1 MPa and 4.4 MPa, respectively. Hence, the MOR of BF 12-8 is 7.3% higher than that of PC though this increase may not be that significant. The maximum value of MOR obtained was 5 MPa when 36 mm long fibre (BF 36-8) was used; this MOR is 22% higher than that of PC. This is a significant gain in the MOR. Figure 2 and Table 1 show that the maximum dose of fibre used in this study is 12 kg/m^3. It can be observed that the trend of increasing MOR with increasing length is much clearer when the dose of fibre was increased to 12 kg/m^3. The MOR of PC and BFRC specimens made with 12 mm long fibres (BF 12-12) were found to be 4.1 MPa and 4.7 MPa, respectively. Hence, a sharp increase of 15% in the MOR can be observed when 12 mm long fibre was added and this gain in the MOR is significant. The increase in the MOR for the change in fibre length from 12 mm (BF 12-12) to 36 mm (BF 36-12) and from 36 mm (BF 36-12) to 50 mm (BF 50-12) are only 2.1% and 2.0%, respectively. The reasoning for these minimal changes could be due to the clumping problem at 12 kg/m^3. Hence, this study found that long fibres (50 mm long) at the high fibre amount (12 kg/m^3) are not suitable. Figure 2 shows that the 36 mm long fibre is the optimum one if the MOR is the only parameter to be targeted for improvement.

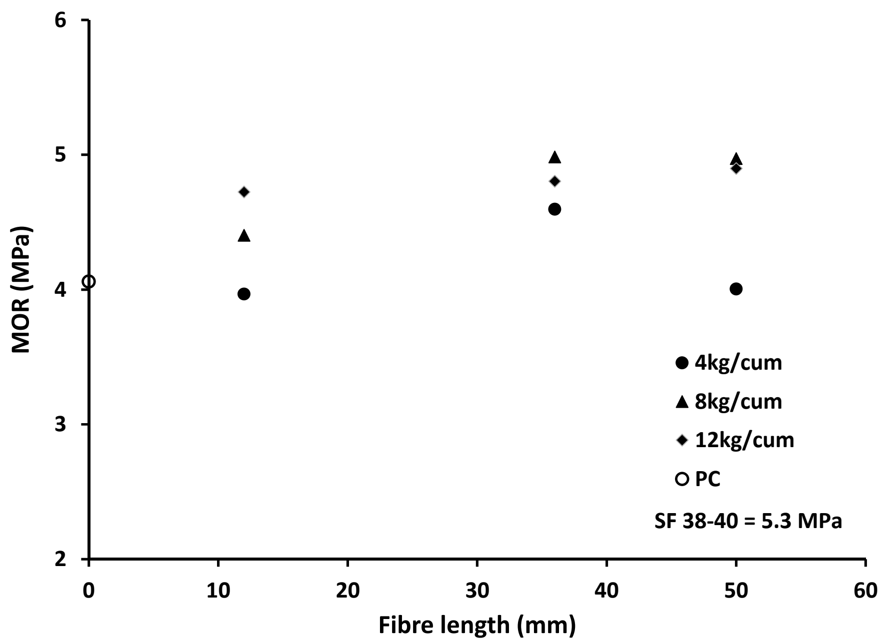

Figure 2: Effect of fibre length on the MOR

Figure 3 shows the effect of fibre dose (amount) on the MOR of BFRC. The amount of fibre was varied from 4 kg/m^3, 8 kg/m^3, to 12 kg/m^3. This figure shows a general trend of increasing MOR with an increasing fibre length for all fibre doses. The maximum MOR of 4.7 MPa was obtained when the fibre amount was 12 kg/m^3 and this value is 14.6% higher than the MOR of PC and hence, this increase is considerable. Nonetheless, this MOR is slightly less than the value of SFRC specimen, SF 38-40, which was found to be 5.3 MPa (Figure 3). Hence, this study found that for BFRC made of short or 12 mm long fibres, a very high amount of fibre (8 to 12 kg/m^3) is needed if a significant increase in the MOR is required. It can be observed that for BFRC made with 36 mm long fibres (specimens BF 36-4, BF 36-8, and BF 36-12), the MOR increases with an increase in the amount of fibre and the trend is clear until the fibre amount exceeds 8 kg/m^3. With a further increase in the fibre amount to 12 kg/m^3, the MOR does not change much. Hence, this study shows that for 36 mm long basalt fibre, the optimum dose is 8 kg/m^3.

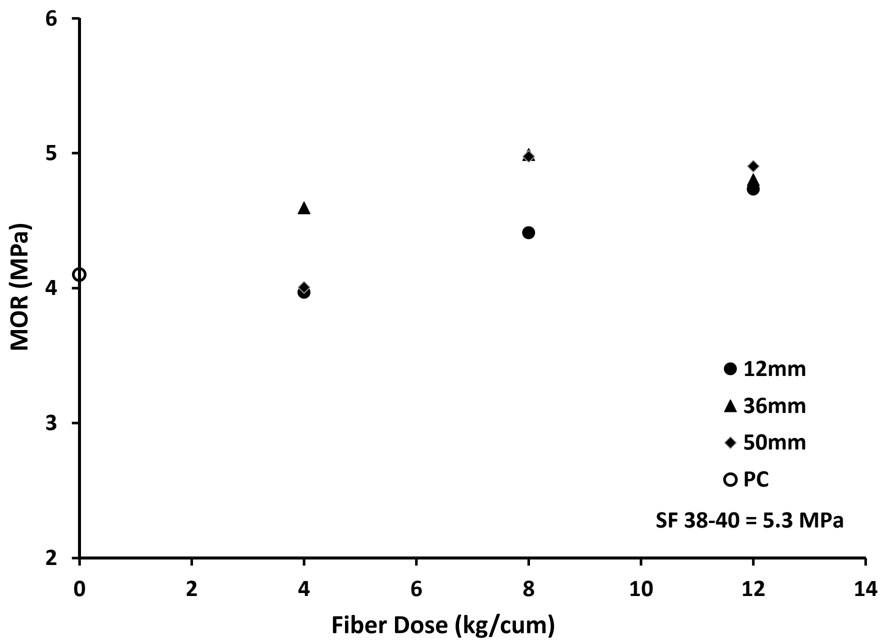

Figure 3: Effect of fibre dose on the MOR

This figure shows no clear relationship between the fibre amount and the MOR when 50 mm long fibres are used. This could be a result of clumping being more prominent for longer fibres, especially at the highest fibre amount. The maximum value for the MOR was found to be 5 MPa, which is the same as that obtained from the BFRC specimens made with 36 mm long fibres and comparable to the MOR of SF 38-40. There was no improvement in the MOR of the BFRC made with 50 mm long fibres (BF 50-4) at 4 kg/m^3 compared to PC. Hence, this study found that the optimum fibre amount for BFRC specimens made with 50 mm long fibres is 8 kg/m^3.

4. CONCLUSIONS

The conclusions presented in this paper are based on the scope of work of this study and results obtained. The workability of concrete reduces as the fibre length and fibre amount increase. Low slumps were recorded when a very large amount (12 kg/m^3) of fibre was added.

1. The low fibre amount of 4 kg/m^3 did show some improvement in the MOR.
2. BFRC made with short fibres (12 mm long) required a large amount (12 kg/m^3) of fibres to show a considerable increase in the MOR.
3. This study found that the optimum length and optimum amount of basalt fibre are 36 mm and 8 kg/m^3 if a substantial increase in the MOR is required.
4. Performance in terms of the MOR similar to SFRC can be achieved in BFRC if the amount and length of basalt fibre are chosen to be 36 mm and 8 kg/m3, respectively.

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