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Design of Composition of Basalt Fibre Concrete

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ABSTRACT

Fibre-reinforced concrete is an emerging trend that delivers new materials with high quality for construction. Basalt fibre, an mineral fibre, has high potential to be used for reinforcing concrete, but there has been little research conducted into using this fibre for concrete reinforcement worldwide and no research work on this fibre reinforced concrete has been published in Vietnam. Therefore, researching into Baslat fibre reinforced concrete to establish fundamental understandings and material mixture recommendations is considered to be scientifically significant and practically worthwhile, especially for the climate and construction conditions in Vietnam. With the use of theoretical and experimental research methods, a procedure for designing the composition of Basalt fibre reinforced concrete was achieved and presented in this paper.

Keywords: Basalt fibre, Fibre reinforced concrete, Concrete, Concrete component design

INTRODUCTION

In recent years, there have been many studies on fibre reinforced concrete in the world with reinforced fibre types such as steel fibre, glass fibre, mineral fibre, lignin fibre, polyester fibre, etc. The published research works have been mainly concentrated on the effect of fibre to concrete, the selection of suitable fibre and the determination of optimal fibre volume fraction. Sim and Park (2005) who studied on basalt fibre reinforced concrete indicated that the tensile strength of basalt fibre reinforced concrete increased 1.5 to 2 times, and elongation capacity of the reinforced concrete raised 4÷6 times as opposed to the respective properties of a traditional concrete. Dias and Thaumaturgo (2005) showed that concrete reinforced by basalt fibre with 2.65kg/m3 could increase compressive and fracture tensile strength by 26.4% and 12%, respectively compared to those of a traditional concrete. Some of the research works in China (Jie, 2011; Chang, 2012; Zhaoxian, 2009) have showed that: when basalt fibre volume fractions of 0%, 0.1%, 0.2% and 0.3% were used in concrete with B30 grade, the tests showed that the compressive strength for 28 days increased with the increase of the volume fraction of the fibre and the maximum increase of the strength was 31.5%; however, the strength only increased slightly in B50 grade when the volume fractions of the fibre increased; when fibre volume fraction increased, the properties of concrete increased accordingly with the compressive strength and fracture tensile strength being the most sensitive to the increase. In Vietnam, there have also been some studies on this field: Doan (2010) carried out investigation on improving the performances of Jute/Polyproplyene composite; Nguyen (2014) researched on enhancing shear strength for concrete beam by glass fibre; Hoang (2017) experimental study on some features of Polypropylene fibre concrete.

Through the review of the previous research work above, it has shown that experimental methods were helpful for the studies of fibre reinforced concrete. However, the number of experiments and the systematic methodologies were still limited. There has been little research on Basalt fibre and none has published on the design method of concrete composition for this fibre reinforcement. Therefore, the research work presented in this paper has been focused onto Basalt fibre as reinforcement for concrete. With the use of the experimental testing method through slump criteria and compressive strength properties, composition of Basalt fibre-reinforced concrete was investigated and presented in this paper.

MATERIAL AND METHODS

Materials

Portland cement PCB-40 manufactured in Vietnam was used. The technical properties of this cement are in accordance with Vietnam standard TCVN 2682:2009 (2009). Its typical properties are shown in Table 1. Fine aggregate and coarse aggregate used for this study was produced from local sources in Hanoi city of Vietnam. Technical properties of fine and coarse aggregates were in accordance with Vietnam Standard (2006). Water used for mixing the concrete was as per the recommendation in Vietnam Standard (2012). The fibre used was basalt fibre. The picture of basalt fibre is shown in Figure 1, and its properties are shown in Table 2.

Table 1. Typical properties of cement PCB-40

N^o	Typical properties	Request
1	**Compressive strength** - 3 days (± 45 minutes) - 28 days (± 8 hours)	 ≥ 21 N/mm^2 ≥ 40 N/mm^2
2	**Setting time** - Initial - Final	 ≥ 45 mins ≤ 375 mins
3	**Fineness** - The amount of 0,09 mm sieve - Blain rate	 ≤ 10 % ≥ 2800 cm^2/g

Figure 1. Basalt fibre

Table 2. Properties of Basalt fibre

Properties	Value
Density	2,65 g/cm^3
Ultimate elongation	3.1%
Diameter	7 ÷ 13µm
Fiber length	6 ÷ 12mm
Melting point	1050^0
Tensile strength	4100 ÷ 4840 MPa
Resistance to acid and base	Good
Young's modulus	93.1 ÷ 110 GPa
Water absorption	N/a
Health risk	Safe, non-toxic

Methods

The theoretical and experimental methods were used to design the concrete components. By theoretical calculations in combination with laboratory tests, the concrete components were determined through two indicators, namely, the strength and slump of the concrete mixture. In particular, the following procedure was carried out:

1) Determine the amount of mixing water (W);

2) Determine the ratio of cement to water (C/W);

3) Determine the amount of cement (C) and basalt fibre (F);

4) Determine the amount of coarse and fine aggregate (C_a), (F_a);

5) Finalise the theoretical calculations;

6) Verify the calculations by experimental tests.

The experimental method for determining the slump and compressive strengths

The slump of mixture and compressive strength of the concrete were determined according to Vietnamese standard TCVN3106 (1993) and TCVN 3118 (1993).

RESULTS AND DISCUSSION

Determining the amount of mixing water

The amount of water (W) was determined based on the conditions of the materials and designing requirements. Chosen concrete grade was B15 with average compressive strength R_b = 20Mpa; the coarse aggregate used had the largest diameter D_{max}= 20mm.

The slump of concrete mixture and the amount of mixing water was selected by the method used in common constructions (Pham et al., 2011): for coarse aggregate, crushed stones with D_{max} = 20mm were used, and the slump of mixture was about 6 ÷ 8cm. The amount of water determined for 1m^3 of the concrete was 205 litres.

Determining the ratio of cement to water

The ratio of cement to water (C/W) was based on the Bolomey – Skramtaev formula (Pham et al., 2011):

Regular concrete (C/W = 1.4 ÷ 2.5):

$$\frac{C}{W} = \frac{R_b}{AR_C} + 0.5$$

High strength concrete (C/W > 2.5):

$$\frac{C}{W} = \frac{R_b}{A_1 R_C} - 0.5$$

In which: R_C – the strength of cement (R_C = 40MPa); R_b – the strength of concrete at 28 days; A and A_1 – the factors of raw materials, were indicated in reference (Pham et al., 2011). The raw materials used were with good quality and the strength of concrete was 20MPa. Therefore, the formula was selected for a regular concrete with A = 0.55.

The cement –water ratio was finally calculated to be: C/W = 1.41.

Determining the amount of cement and fibre

Determining the amount of cement (C) was based on C/W ratio which was determined in the above step.

$$C = \frac{C}{W} W \text{ , kg}$$

From the amount of water W = 205 litres and the C/W ratio = 1.42 determined above, the amount of cement for $1m^3$ of concrete was calculated to be 290 kg. The amount of cement should be compared to the amount of minimum and maximum cement (C_{min} and C_{max}) which are based on the design standard. The determined cement amount was within the range for the minimum and maximum cement in Vietnam standard.

The reinforcing fibre content was determined from the published research results in the research communities (Sim and Park, 2005; Thaumaturgo, 2005; Jie, 2011; Chang, 2012; Zhaoxian, 2009). Based on the review of the published results, the amount of basalt fibre for $1m^3$ of concrete was selected to be 2.5 kg.

Determining the amount of coarse and fine aggregate

Determining the amount of coarse aggregate (crushed stone - C_a): The formula for 1m3 of concrete was determined as follows:

$$C_a = \frac{1000}{\frac{k_d r_{Ca}}{\gamma_{oCa}} + \frac{1}{\gamma_{aCa}}}, kg$$

Where: r_{Ca} - porosity of crushed stone; k_d - loss coefficient, determined in Table 3; γ_{0Ca} - volumetric weight of crushed stone, g/cm^3; γ_{aCa} - density of solid particles of crushed stone, g/cm^3.

Table 3. Loss coefficient in concrete

Cement in $1m^3$ of concrete	Crushed stone	Graval
250	1.30	1.34
300	1.36	1.42
350	1.42	1.48
400	1.47	1.52

The cement amount calculated above was C = 292kg, from Table 3, k_d = 1.36; crushed stone having: volumetric weight of crushed stone: γ_{0Ca} = 1.48g/cm^3; density of solid particles of crushed stone: γ_{aCa} = 2.8g/cm^3 and porosity of crushed stone: r_{Ca} = 0.47.

Substituting all the parameters into the formula, the amount of crushed stone in $1m^3$ of concrete was calculated to be C_a = 1267kg.

Determining the amount of fine aggregate (Sand - F_a): After the amount of the mixing water, cement and crushed stoneware determined, the sand for $1m^3$ of concrete was calculated using the following formula:

$$F_a = \left[1000 - \left(\frac{C}{\gamma_{aC}} + \frac{C_a}{\gamma_{aCa}} + W\right)\right].\gamma_{aFa};kg$$

Where: γ_{aC} – weight of solid particles of cement (γ_{aC} = 3.05g/cm^3); γ_{aCa} – weight of solid particles of cursed stone (γ_{aCa} = 2.8 g/cm^3); γ_{aFa} – weight of solid particles of sand (γ_{aFa} = 2.75g/cm^3).

Substituting all these parameters into the above formula gives the amount of sand: F_a = 681kg.

Summarizing the theoretical calculation results

The calculated results for $1m^3$ of concrete is shown in Table 4.

Table 4. The results of the theoretically calculated ingredients

C_a (kg)	F_a (kg)	C (littre)	W (kg)	F_a (kg)
1267	681	290	205	2.5

Verifying the calculated results by experiment and adjustment

Checking the slump of mixture: Kneading the mixture with the identified ingredients in the theoretical calculations (Table 4) and testing the slump of mixture.

If the experiment slump is smaller than the required slump ($S < S_{yc}$) the amount of water and cement must be adjusted with the W/C ratio being maintained constant.

If $S > S_{yc}$: the amount of sand and crushed stone must be changed; however, the F_a/C_a ratio must be kept constant.

If $S = S_{yc}$: The result was used and the raw materials were adjusted for $1m^3$ of concrete.

The adjustments of the raw materials were calculated by the following formulas:

$C_a' = 1000. C_a/V$; $F_a' = 1000. F_a/V$;

$C' = 1000. C/V$; $W' = 1000. W/V$

Here: C_a, F_a, C, W: the amount of the crushed stone, sand, cement and water for the volume (litre) of the concrete mixture (kg), respectively;

C_a', F_a', C', W': the amount of the crushed stone, sand, cement and water for $1m^3$ of the concrete mixture after the adjustment for the slump, respectively.

The experiment conducted for this study is illustrated in Figure 2.

Figure 2. Checking the slump of mixture

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The result of the first slump testing is presented in Table 5. These results indicate that the average slump is smaller than the required slump. Therefore, the raw materials for the mixed concrete need to be adjusted. In particular, the amount of cement and water was increased while C/W ratio was kept constant. The water and cement was added and the slump was monitored by subsequent slump tests until the required slump was reached.

It took several rounds of the adjustment of the amount of water and cement and slump tests until the required slump was achieved. The final results for the desirable portions of the raw materials are shown in Table 6. With the proportion of the ingredients in the Table 6, the slump of the samples are shown in the Table 7.

Table 5. The result of the first slump testing, cm

Sample 1	Sample 2	Sample 3	Average
5.5	4.0	3.0	4.2

Table 6. The final result of the adjusted ingredients

C_a (kg)	F_a (kg)	C (littre)	W (kg)	F_a (kg)
1267	681	300	210	2.5

Table 7. The results of the satisfactory slump tests, cm

Sample 1	Sample 2	Sample 3	Average
7.5	7.0	6.5	7.0

Verifying compressive strength of the concrete: The concrete mixture that gave the satisfactory slump was used to make samples for the compressive strength tests. The concrete mixture was maintained for 28 days. During this period, the concrete mixture was covered with wet cloth for the first day and soaked in water for the remaining 27 days. The average compressive strength (R_{b28}) was then determined and compared with the required compressive strength (R_b):

If $R_{b28} > R_b$ and the average compressive strength was 15% larger than the required compressive strength, then the amount of the cement was reduced. If $R_{b28} > Rb$ but the average compressive strength is not 15% larger than the required compressive strength, the results were considered acceptable.

If $R_{b28} < R_b$, the cement grade needed to be re-selected and other materials needed to be re-calculated.

If $R_{b28} = R_b$ we accept the result of the design and adjusting raw materials for 1m3 of concrete. The method is conducted same as conducting for slump.

The experiment for the compressive strength is shown in Figure 3. The results of the experiment for the concrete compressive strength made from a mixture of the ingredients that had been corrected for the slump are presented in Table 8. The results in Table 8 show that the average compressive strength of the concrete sample are greater than the required compressive strength, but the difference is not too greater than 15%. Therefore, the results of the concrete mixture design were considered acceptable. A summary of the experimental results is presented in Table 9.

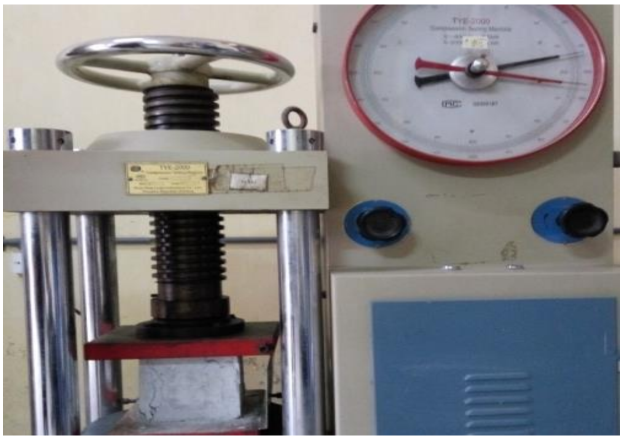

Figure 3. Testing conducted for the compressive strength

Table 8. The results of compressive strength test, MPa

Sample 1	Sample 2	Sample 3	Average
23.33	22.13	24.22	23.23

Table 9. Summary of the experimental results

C_a (kg)	F_a (kg)	C (kg)	W (littre)	F (kg)	S (cm)	R_b (MPa)
1267	681	300	210	2.5	7.0	23.23

CONCLUSION

In reality, different methods could be used for the design of the concrete mixture components. However, combining the theoretical calculations with suitable experimental tests has been considered the best method for high accuracy. With the goal of designing the concrete components using basalt as fibre reinforcement to make a mixture that has a 20MPa compressive strength, the theoretical calculations in combination with experimental testing through slump and compressive strength indicators of the samples have been successfully used for the study in this paper to achieve the desirable results of the concrete mixture. The basic ingredients for 1m3 of concrete have been identified and a specific procedure has been established for the design of the basic components for the polypropylene basalt fibre-reinforced concrete.

Competing interests

The author declare that it has no competing interests.

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