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MECHANICAL AND SHRINKAGE BEHAVIOR OF BASALT FIBER REINFORCED ULTRA-HIGH-PERFORMANCE CONCRETE

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ABSTRACT: Ultra-High-Performance Concrete (UHPC) is considered to be a new development of concrete technology with excellent workability, high compressive strength, toughness, and long durability, etc. These characteristics are achieved by the synthetic application of strength enhancements such as the use of mineral additives, optimum particle distribution and especially the use of fiber reinforcement which greatly enhances flexural strength and toughness for the UHPC. In this paper, the influence of basalt fiber content on some properties of UHPC such as workability, compressive strength, flexural strength, elastic modulus and shrinkage were investigated. The results of this paper show that use of basalt fiber with reasonable content will not affect the workability of the concrete mixture while increasing the flexural strength, compressive strength, and elastic modulus of the UHPC. The compressive strength of concrete reaches over 120 MPa, flexural strength is over 10 MPa. UHPC sample using 1.5% fiber content will give the highest compressive and flexural strength values, this value increased about 8.5% compared to the control sample without fibers.

Keywords: Ultra-high-performance concrete; Basalt Fiber; Strength; Modulus elastic, Shrinkage.

1. INTRODUCTION

Ultra-high-performance concrete (UHPC) is a new development of concrete technology, with great fluidity, very high compressive strength, great durability and high toughness, with potential applications such as building super high-rise buildings, large span bridges, thin shell structures, etc. [1–4]. In the world, UHPC is defined as a concrete with compressive strength greater than 120 MPa [5] and even up to 800 MPa if using other special technology measures such as heat treatment, compacting pressure [6]. In terms of composition, it can be understood that UHPC composes of a reasonable proportion of very fine sand, cement, silica fume, water, superplastic additives, and fiber reinforcement. With the very low ratio of W/B (Water to Binder ratio $\leq$ 0.25), the product after curing process has very high strength, with large toughness and high flexural strength, reduced shrinkage as well as limiting the expansion of cracks in UHPC (from 12-35 MPa, when using fiber reinforcement) [7–11].

This is due to the fact that the reinforced fiber has a role of redistributing the load in the cracked area, improving the crack distribution [12]. The force of the adhesion between concrete and fiber surface will play a key role to the strength, bearing, and crack development process and the expansion of fractures in UHPC [13]. There has been a number of studies on the use of fiber-reinforced concrete in improving the strength and durability of concrete [14,15]. Among the existing fibers on the market, basalt fiber (BF) is considered to be good potential use in the UHPC due to some important properties such as high tensile strength, high elastic modulus, alkali resistance, and high temperature resistant [16,17]. Basalt fiber has been used for many years as a reinforcing material in concrete technology. This fiber is a kind of environmental protection material with high performance and is made of natural basalt. Due to its high tensile strength, excellent elastic modulus, and corrosion resistance, basalt fiber is a beneficial admixture for concrete [18,19]. The workability and mechanical properties of basalt fiber reactive powder concrete were investigated by univariate analysis. The addition of basalt improved the flexural strength without any negative impact on the workability performance [16,20,21].

The addition of steel fiber in UHPC not only affects the production costs but also has negative effects on the dead load and may cause corrosion problems [3,22]. Replacing steel fibers with basalt fibers seems to be a feasible solution to these problems [19]. In addition, incorporation of basalt fibers positively effect the workability of concrete. Branston et al found that when the mass content reaches 12 kg/m^3 (equal to 0.46% volume of concrete), the strengthening effect of basalt fiber on the flexural strength and impact strength of concrete is similar to that of steel fiber [21]. It has been validated that the addition of 0.15% basalt fiber and 0.033% polypropylene fiber can increase the flexural and compressive strength of high-performance concrete by 14.1% and 22.8%, respectively [23], Tehmina Ayub et al [20] found that the maximum compressive strength could reach 84.08 MPa with a volume content of 2% basalt fiber in UHPC when 10% cement was replaced by silica fume and kaolin.

This paper presents the experimental results about the role of basalt fiber in improving some properties of UHPC such as compressive strength, flexural strength, elastic modulus and shrinkage. Successful research will be the basis to confirm the advantages of basalt fiber in improving the properties of concrete. The results of the research will contribute more to UHPC research to overcome the current shortcomings and meet the development needs of this special type of concrete.

2. MATERIALS AND METHODS

2.1 Materials

The characteristics of basalt fiber are presented in Table 1 and Fig.1.

Table 1 Specifications of Basalt fiber used in the study

Characteristic	Value
Density (g/cm^3)	2.65
Tensile strength (MPa)	4500
Elastic Modulus (GPa)	100
Elongation at fracture, %	3.1
Highest working temperature (°C)	650
Diameter, (μm)	18
Length, (mm)	12

Fig.1 Basalt fiber used in the study

The particle size distribution curve is shown in Fig. 2. .Materials used in the study include Portland cement (C) PC40 with an average particle diameter of about 21.09μm. The Silica fume (SF) in bulk form of Elkem, has an average particle diameter of 0.15μm with SiO2 content in SF of 92.3%, the active index with cement is 113.5%; aggregates are fine sand (S) with grain size from 100-600μm; polycarboxylate- based super-plasticizer (SP); basalt fiber with the diameter of 18 μm and the length of fiber is 12mm.

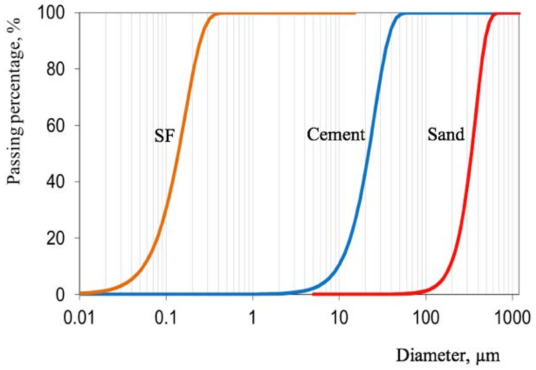

Fig.2 Particle gradation curve of the material used in the study

2.2 Experimental Methods

The flowability of UHPC mixture is determined by the flowability according to BS 4551:2005 standard [24]. Each flowability result is the average of two tests. The flowability of an UHPC mixture was shown in Fig. 3.

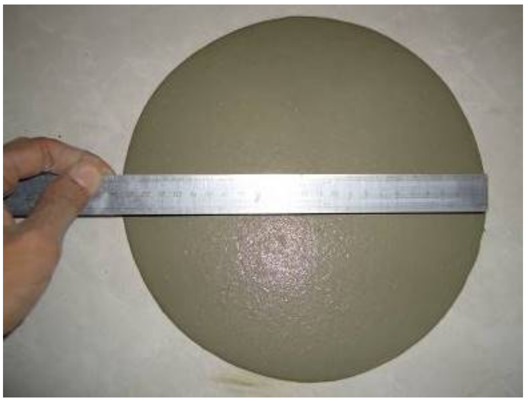

Fig.3 Flowability of the fresh UHPC using basalt fiber

The flexural strength and compressive strength of UHPC is determined on the sample size of 40 × 40 × 160 mm. All 3 prisms were tested for flexural strength, and all 6 resultant half prisms were tested for compressive strength. The test results are the average values of the testing samples.

Elastic modulus of UHPC (Fig. 4) is determined according to ASTM C469M [25] on cylinder samples with the diameter of 100 mm and the height of 200 mm. The final result is the average of three tests.

Fig.4 UHPC elastic modulus test

Endogenous shrinkage of UHPC was performed on samples with dimensions 250 x 250 x 285 mm. The two ends of the sample are fitted with thin corrugated iron sheets, which are placed before casting the sample. Plastic and paraffin sheets are used to minimize friction between the sample and the mold, and to prevent moisture from escaping from the concrete sample to its surroundings. Concrete mixture is poured then proceed to curing on the surface of the concrete to avoid moisture on the surface. Wait until the concrete begins to solidify, then remove the mold, and install a strain gauge with an accuracy of 0.001 mm at the beginning of each concrete sample. Endogenous shrinkage measurements are made as soon as the gauges are finished. The time for starting endogenous shrinkage measurements has not been agreed in litterature, either starting with the maximum sample temperature or after 1 day, or between the initial setting time and final setting times or begin to set [26]. Currently there is only one official standard for endogenous shrinkage of pastes and mortars through a sample cast in ribbed elastic plastic tubes [27], and the moment to start measuring (time-zero) is the final setting time of the pastes or mortars. Therefore, in this experiment, the starting time used for measuring the endogenous shrinkage is the final setting time of each UHPC mixture. The room temperature during the measurement was kept at about 23 ± 1 °C, the influence of the hydration temperature of the test piece was ignored. During the entire first measurement time since the meter is installed, the computer automatically reads the results every 10 minutes. Total shrinkage measument time is about 72 hours. An image of the endogenous shrinkage measurement system can be found in Fig. 5.

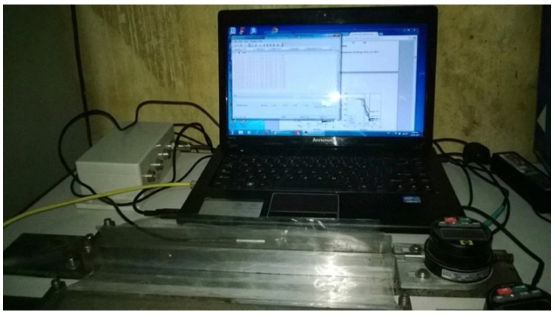

Fig.5 Shrinkage measuring system used in the study

2.3 UHPC Mix Proportions

In this study, six compositions including 5 mixtures with different basalt fiber content and 1 control sample without using fiber. The proportions of UHPC used in the study are given in Table 2. In particular, SF and SP are calculated as percentage by weight of binder. The fiber content is calculated as a percentage of the volume of concrete mixture.

Table 2 Proportion of raw material in UHPC

N°	W/B	S /B	C/B	SF/B	SP/B, %	BF, % by volume of concrete
1	0.16	1	0.8	0.2	1.0	0
2	0.16	1	0.8	0.2	1.0	0.2
3	0.16	1	0.8	0.2	1.0	0.5
4	0.16	1	0.8	0.2	1.0	1.0
5	0.16	1	0.8	0.2	1.0	1.5
6	0.16	1	0.8	0.2	1.0	1.75

The mixing process of the UHPC mixture is as follows: The dry mixture of cement, sand and additions takes place During the first 2 minutes. After that, 70% amount of the water required is added and the mixing process was continued 3 minutes more. Superplasticizer is introduced at minute 5, and it takes 3 minutes to react with cement particles to achieve flowability required. Basalt fibers are added at 12 minutes, once the mixture is flowable.

Due to the high content of binders used in UHPC, it requires a high amount of superplasticizer and a very low ratio of W/B. Therefore, in order to achieve high homogeneity, the BF is evenly dispersed in the mixture, longer mixing time is necessary. After mixing, the concrete mixture was cast in a mold of size 40 x 40 x 160mm^3, then cured in standard conditions (t = 27 ± 2°C, RH≥98%) to the age of testing. The compressive strength of concrete is determined at the ages of 3, 7, and 28 days.

3. RESULTS AND DISCUSSION

3.1 Influence of Basalt Fiber on the Flowability of the UHPC Mixture

The influence of basalt fiber content on the flowability of the UHPC mixture is shown in Fig.6.

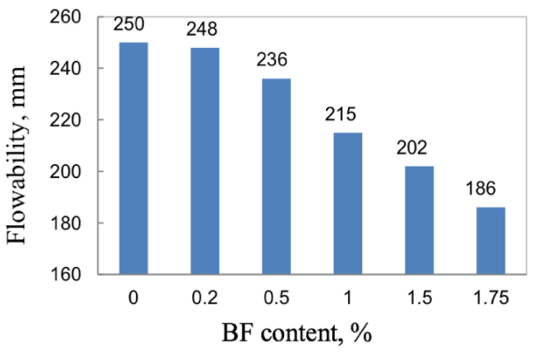

Fig.6 Influence of BF content on flowability of the fresh UHPC mixture

Experimental results show that the flowability of this concrete mixture is in the range of 210-240mm when using basalt fiber with the content of 0-1%, the fresh mixture is quite homogeneous. However, when the fiber content increased to 1.5%, the flowability of the concrete mixture began to decrease quickly. The use of basalt fibers that reduce the flowability of the concrete mixture is related to the fact that dispersed fibers tend to interlock and form tufts or berries of fiber which are difficult to disperse in the cement matrix and reduce the flowability of the concrete mix.

3.2 Influence of Basalt Fiber on the Compressive Strength of UHPC

Experimental results in Fig.7 present the influence of basalt fiber content with different ratios by volume of concrete. With content from 0 to 1.5%, the BF has an influence on the compressive strength of UHPC, the value of compressive strength of concrete is from 97.7 MPa to 108.3 MPa at 7 days and from 135.8MPa to 145.6MPa at 28 days. The compressive strength of BF reinforced UHPC is a little higher than that of the control sample without fiber. When the fiber content increased by more than 1.5%, the compressive strength at 28 days tended to decrease from 145.6 MPa when using 1.5% fiber to 124.5 MPa when increasing fiber content to 1.75%. The use of basalt fiber in UHPC with content greater than 1.5% by volume will reduce the compressive strength of concrete, this may be the formation of clumps of the fiber in concrete occurs due to the increase in fiber content, reducing the homogeneity in concrete, bring down the strength of concrete.

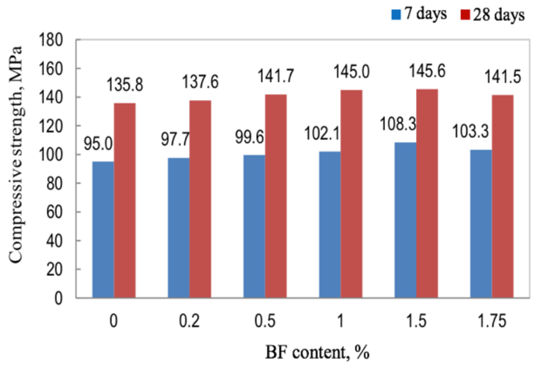

Fig.7 Influence of BF content on compressive strength of UHPC

3.3 Influence of Basalt Fiber on the Flexural Strength of UHPC

The test results of the flexural strength of UHPC samples with fiber content from 0 - 1.75% are shown in Fig.8.

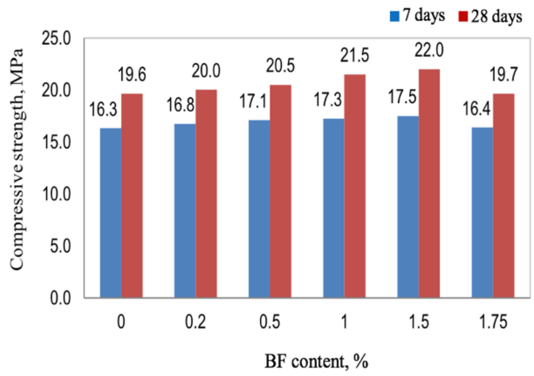

Fig.8 Influence of BF content on the flexural strength of UHPC

Experimental results show that: when increasing fiber content, the flexural strength of concrete tends to increase, but not very much. The flexural strength at 28 days reached the maximum value of 22MPa at the fiber ratio of 1.5%, an increase of 12.2% compared to the control sample (without fiber). With the fiber volume increasing from 1.5 to 1.75%, the flexural strength of concrete tends to decrease at both 7 days and 28 days, respectively. The flexural strength of concrete at 7 days decreases from 17.5 MPa decreased to 16.4 MPa and decreased from 22 MPa to 19.7 MPa at 28 days. From that, it shows that the fiber ratio is too high, causing the fiber to coagulate and create tufts, affecting the ability of fiber dispersion, leading to reduced flexural strength of concrete.

The use of fiber in reinforced concrete will significantly improve flexural strength and compressive strength for concrete. The proportion of BF put into the mix at a reasonable content of 1.0-1.5% bring goods efficiency and meet the expectation of replacing other fibers and cheaper. The interaction between scattered fiber reinforcement and binder matrix will increase the mechanical properties of reinforced concrete. If the fiber is randomly distributed in concrete, the role of the fiber will be evaluated according to the process of transmitting the load from the base material to the fiber and the "bridging" effect of the fiber through the cracking process. The load transmission increases rapidly when increasing the load acting on the substrate to the crack limit of the substrate. When the load continues to increase to a certain value, it will reach the elastic state of the fiber and at the same time begin to lose the link between the fiber and the concrete substrate. If the load continues to increase, the elastic shear stress reaches its maximum value, losing the ability to link between the fiber and the substrate and the fiber slips. Thus, fiber has shown its role as a binding material and "bridging" through cracks, greatly improving mechanical properties.

3.4 Influence of Basalt Fiber on the Elastic Modulus of UHPC

In this study, the effects of basalt fiber content of 0%, 1% and 1.5% on the elastic modulus of UHPC will be considered. Experimental results showing the relationship between compressive stress and deformation of the UHPC samples are shown in Figs. 9, 10, 11. The elastic modulus of concrete is shown in Table 3.

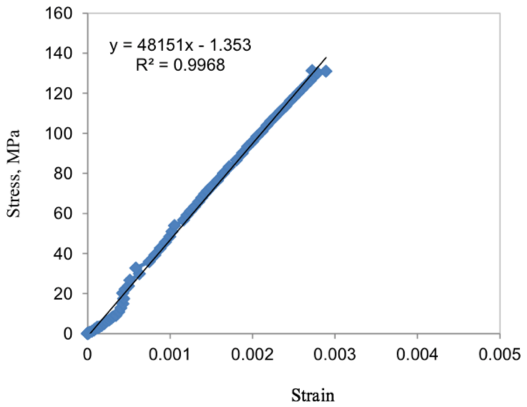

Fig. 9: Relationship between the compressive stress and strain of UHPC using 0 % BF

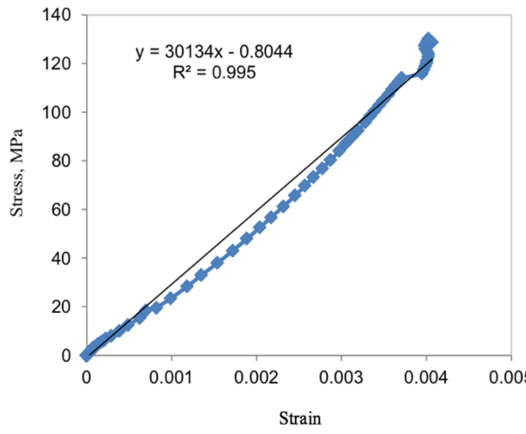

Fig. 10: Relationship between the compressive stress and strain of UHPC using 1.0 % BF.

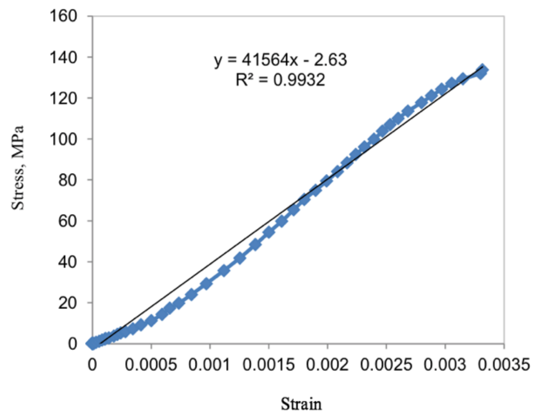

Fig. 11: Relationship between the compressive stress and strain of UHPC using 1.5 % BF.

Table 3 Influence of basalt fiber content on elastic modulus of UHPC

BF content	Maximum stress, MPa	40% Maximum stress, MPa	Strain	Elastic Modulus, GPa
0 %	131.3	52.5	0.001045	50.275
1.0 %	130.2	52.1	0.001005	51.804
1.5 %	133.7	53.5	0.001012	52.854

Experimental results show that the elastic modulus of the concrete increases with the amount of fiber, but the level of increase is not much. When 1.0% and 1.5% fiber were used, the increase in elastic modulus of the concrete sample increased by 3% and 5.1%, respectively, when compared with the control. Thus, the results show that the basalt fiber does not improve much of the elastic modulus with the UHPC sample.

3.5 Influence of Basalt Fiber On the Elastic Modulus of UHPC

Experimental results on the effect of basalt fiber content on shrinkage deformation of UHPC are shown in Table 4 and Fig.12.

Table 4 Shrinkage reduction efficiency of UHPC using basalt fiber

Amount of Fiber, %	Shrinkage, mm/m		% shrinkage reduction (compared with control sample)	
	7 days	28 days	7 days	28 days
0	-0.928	-0.956	0	0
0.2	-0.736	-0.928	20.7	2.9
0.5	-0.552	-0.716	40.5	25.1
1.0	-0.152	-0.672	83.6	29.7
1.5	-0.036	-0.412	96.1	56.9
1.75	-0.016	-0.08	98.3	91.6

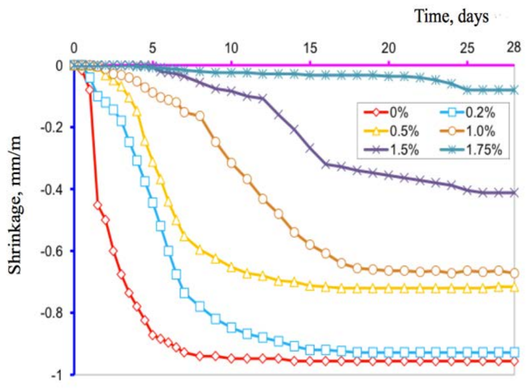

Fig.12 Shrinkage of UHPC using basalt fibers

From the experimental results it can be seen that the use of basalt fibers significantly improved the shrinkage of the UHPC and the efficiency depending on the fiber content. The shrinkage reduction effect at 7 days of UHPC using basalt fiber is shown in Table 4. The results showed that, when the fiber content increased, the shrinkage of the UHPC decreased significantly. With concrete using 0.5% fiber, the shrinkage reduction efficiency compared to the control reached 40% in the first 7 days. When using fibers up to 1.0%, the shrinkage reduction effect of concrete is very great, reaching 84% compared to the control. Continuing to increase the fiber content to 1.75%, the shrinkage reduction efficiency of UHPC reached 98% compared to the control.

For the non-fiber control concrete sample, the shrinkage strain of the UHPC sample at 28 days was 0.956 mm / m. This value does not differ much from results at the age of 7 days. The shrinkage of the concrete will decrease when using fiber. Specifically, when the fiber content used is 0.5%, the shrinkage of the concrete reaches 0.716 mm / m, a decrease of 25% compared to the control sample. With the fiber content increased to 1.5% and 1.75%, the shrinkage will be decreased by 56.9% and 91.6%, respectively, compared with the control sample.

The UHPC shrinkage improvement can be explained when using fibers in concrete mixes. Along with the hydration of the cement, there will be a decrease in moisture in the UHPC and shrinkage of the concrete. However, in concrete that uses micro-sized basalt fibers, the fiber will then play a role as a bridge to distribute stress evenly in the concrete, thus significantly reducing shrinkage in concrete. However, when increasing the fiber content from 1.5 to 1.75%, the shrinkage reduction effect for concrete does not increase much. This can be explained by increasing the fiber content used to a certain value when the fibers tend to clump together to form yarn balls. Thus, the distribution of fibers in concrete will be less uniform and make the role of reducing the shrinkage of fibers in concrete not much increased. In general, the effects of basalt fibers on the mechanical properties and shrinkage of UHPC in this study are consistent with the results of previous studies.

4. CONCLUSIONS

Through the research results, some conclusions can be drawn as follows:

Dispersed basalt fiber can be used in the fabrication of UHPC with the achieved properties: very good flowability, the compressive strength of concrete above 120 MPa, flexural strength above 10 MPa. The concrete samples using 1.5% fiber content will give the highest 28-day compressive and flexural strength values: $R_{compressive}$ = 145.6 MPa; $R_{flexural}$ = 22 MPa, this value increased about 8.5% compared to the control sample without fibers.

The elastic modulus of UHPC reached over 50GPa, however, the use of basalt fiber did not improve much on the elastic modulus of concrete. When using the fiber content of 1.0% and 1.5%, the increase in elastic modulus of concrete samples is only about 3% and 5.1% compared to the control samples.

When using basalt fiber in the UHPC, the results showed that the shrinkage of the concrete decreased with the increase of fiber content, especially at an early age. The shrinkage reduction effect is achieved when the fiber content using 0.5%, shrinkage deformation of concrete reaches

0.716 mm/m, a decrease of 25% compared to the control sample. While the fiber content continues to increase to 1.5% and 1.75%, the shrinkage strain decreased by 56.9% and 91.6% respectively when compared to the control sample.

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