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EFFECT OF HIGH TEMPERATURE ON PROPERTIES OF GLASS CONCRETE

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Abstract. In this study, the concrete is mixed with glass fibers which are 0.5%, 1.0% and 1.5% of cement weight and 0.6 cm long. The effect of fiber addition level on the compressive strength, bending strength and residual compressive strength and thermal conductivity after heating of concrete is discussed. The test results show that an appropriate addition of glass fiber to the concrete at room temperature is favorable for the compressive strength. A low addition of relatively short glass fiber has insignificant effect on the bending strength. However, the adverse effect on the bending strength will increase if the addition level is too high. The addition of glass fiber can improve the loss of concrete strength under the effect of high temperature not exceeding 500℃, and a relatively high compressive strength remains under the effect of high temperature not exceeding 800 ℃ . The high temperature can reduce the thermal conductivity of glass concrete, and the higher the addition level of glass fiber is, the lower is the thermal conductivity. Keywords: Glass fiber, concrete, heating, thermal conductivity

1 INTRODUCTION

The high temperature resistant fabric made of glass fiber still keeps 50% of strength when it burns at 370℃, and keeps 25% of strength at 538℃, its thermal expansion coefficient is low [1]. The glass fiber has higher compressive strength and elastic coefficient than cement mortar, so that it becomes an ideal reinforcer. However, the alkali resistance is required for cement concrete, if there is ZrO_2, SnO_2 or La_2O_3, the alkali resistance of glass will increase greatly [2]. The glass fiber with ZrO_2 is water resistant, so it is best suited for concrete [3].

The compressive strength of the concrete with glass fiber increases with the volume ratio of fiber, but the strength decreases slowly when a maximum value is reached. As the glass fiber increases, the initial crack flexural strength and ultimate flexural strength are 3 times and 4.9 times of nonfibrous concrete respectively. The flexural strength increases with the glass fiber content, but the strength growth rate does not decrease. The compressive strength is unrelated to the length of glass fiber. Longer glass fiber is more adverse to the concrete slump [4].

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The concrete is a heat-proof material, but the concrete strength still decreases after burning in the fire. The structure may be damaged if the temperature is too high. This study simulates the effect of an approximate addition of glass fiber to the concrete on the compressive strength, tensile strength and thermal conductivity of concrete in the fire.

2 EXPERIMENTAL PLANNING

The concrete is mixed with glass fibers which are 0.5%, 1.0% and 1.5% of cement weight and 0.60 cm long respectively (mix proportions G5, G10 and G15, control group is C), to discuss the effect of fiber addition level on the compressive strength, bending strength, residual compressive strength and thermal conductivity after heating of concrete. The concrete mix of control group is designed according to ACI method. The slump is 18 cm and the water-cement ratio is 0.5. The additions of water, cement, coarse aggregate and fine aggregate are 218, 436, 720 and 838 kg/m^3 respectively.

In terms of the test for the compressive strength of concrete, the φ15 cm×30 cm concrete cylinder specimen is cured in 23℃±1.7℃ saturated limewater. The compressive strength on Days 7, 14, 21, 28, 49 and 56 is measured respectively. In terms of the test for the bending strength of concrete, a 15cm×15cm×53cm prism concrete is made, cured for 28 days before the thrid-point loading test. In terms of the test for residual compressive strength after heating, the φ15 cm×30 cm concrete cylinder specimen is cured in the 23℃ ±1.7℃ saturated limewater for 28 days, put in the 105±1℃ oven for 3 days, and put in the full electronic high temperature furnace, heated to 440, 500, 580, 800 and 1000 ℃ respectively. According to references, the compressive strength of concrete decreases mainly within one hour under the effect of high temperature [5]. Therefore, there is one hour added after the temperature rises to the set level, it is cooled to the room temperature before compression test. In terms of thermal conduction test, a 15 cm×15 cm×24 cm prism concrete is made, cured for 28 days, the long direction is covered with asbestos, heated in front of the electrothermal high temperature furnace. The temperatures at various points in the long direction of specimen are measured (one point on heating surface, five points inside). The thermal conductivity is calculated by Eq. (1). All data are the mean values of triplicate test results.

$$Q = -KA(\Delta T/\Delta X) \tag{1}$$

Where Q is the heat transfer rate (W), K is the thermal conductivity (W/m℃), A is the heat transfer area (m^2), ΔT is the temperature difference (℃), ΔX is the heat transfer distance (m).

Portland Type I cement is used; The maximum particle size of coarse aggregate is 3/4", the saturated surface dry specific gravity is 2.64, the water absorption is 1.21%, the dry rodding unit weight is 1600 kg/m^3; the fineness modulus of fine aggregate is 2.6, the saturated surface dry specific gravity is 2.63, the water absorption is 2.04%. The filament diameter of the alkali-resistant glass fiber for the test is 14±0.8μm, 2400±240 g/km, tensile strength ≥700 MPa.

3 EXPERIMENTAL PLANNING

The values of test results are shown in Table 1 and Table 2.

3.1 Effect of glass fiber on compressive strength of concrete

The test results are shown in Table 1 and Fig. 1. For the control group concrete (C), the concrete strength increases with the curing age, the compressive strength on Day 28 is 32.3 MPa, the strength on Days 7, 14 and 21 is 73%, 90% and 96% of the strength on Day 28 respectively. The compressive strength on Day 56 increases by only 2%, meaning the strength grows fastest during the first 7 days of curing. The strength grows slowly after 28 days. The strength development trend of the concrete with glass fiber is similar to normal concrete, meaning the addition of glass fiber which is 0.5%–1.5% of cement weight has no significant impact on the time-dependent development trend of concrete strength.

Fig. 1 shows that the 0.5% glass fiber in length of 0.60 cm can increase the concrete strength. However, the compressive strength decreases when the addition is 1.0 and 1.5%. For example, at the curing age of 28 days, the strength is increased by 9.6% when the addition is 0.5%. The strength is reduced by 24.1% and 26.6% respectively when the addition is 1.0% and 1.5%.

The results show that in the environment at room temperature, a low addition of short glass fiber to the concrete is favorable for the strength. The addition shall not be too high, otherwise it is adverse to the strength. The range of appropriate addition of long glass fiber which is favorable for the concrete strength is large, and a high addition has slight adverse effect on the strength.

3.2 Effect of glass fiber on bending strength of concrete

The test results are shown in Fig. 2. The bending strength on Day 28 of control group concrete (C) is 5.10 MPa, which is 15.8% of compressive strength on Day 28.

Fig. 2 shows that the 0.5% glass fiber in length of 0.60 cm can increase the bending strength of concrete. However, the bending strength decreases when the addition is 1.0 and 1.5%. The bending strength is increased by 1.0% when the addition is 0.5%. The bending strength is reduced by 2.0% and 8.6% respectively when the addition is 1.0% and 1.5%.

The results show that in the environment at room temperature, a low addition of short glass fiber to the concrete has insignificant effect on the bending strength. The addition shall not be too high, otherwise its adverse effect on bending strength will grow. When the long glass fiber is added in, the range of appropriate addition level favorable for the compressive strength of concrete is enlarged, and the bending strength is increased significantly, especially when the consumption increases to 1.5%.

Table 1. Average compressive strength and bending strength.

No.	Average compressive strength (MPa) (% of 28 days' strength)						28 days' average bending strength (MPa)
	7 D	14 D	21 D	28 D	49 D	56 D	
C	23.7(73)	29.2(90)	31.0(96)	32.3(100)	32.8(102)	33.1(102)	5.10
G5	22.8(65)	31.4(90)	33.3(94)	35.4(100)	36.8(104)	37.8(107)	5.15
G10	19.6(80)	22.2(90)	23.1(94)	24.5(100)	24.6(100)	26.2(107)	5.00
G15	19.2(81)	20.5(86)	22.3(94)	23.7(100)	24.1(102)	24.7(104)	4.66

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Table 2. Average compressive strength and thermal conductivity after heating.

No.	Average compressive strength after heating (MPa) (residual strength % compared with strength without heating)				
	440℃	500℃	580℃	800℃	1000℃
C	25.8(80)	25.2(78)	15.7(49)	5.7(18)	5.0(16)
G5	32.2(91)	31.4(89)	20.4(58)	8.5(24)	3.7(11)
G10	22.8(93)	22.1(90)	14.7(60)	7.1(29)	2.7(11)
G15	22.3(94)	21.7(91)	15.5(65)	7.6(32)	3.0(12)
No.	Average thermal conductivity after heating (W/m·K) (compared with 440℃ test result, %)				
	440℃	500℃	580℃	800℃	1000℃
C	2.37	1.70(72)	1.19(50)	0.67(28)	0.45(19)
G5	2.25	1.62(72)	1.13(50)	0.57(25)	0.43(19)
G10	2.09	1.49(71)	0.83(40)	0.52(25)	0.40(19)
G15	1.98	1.33(67)	0.78(39)	0.51(25)	0.38(19)

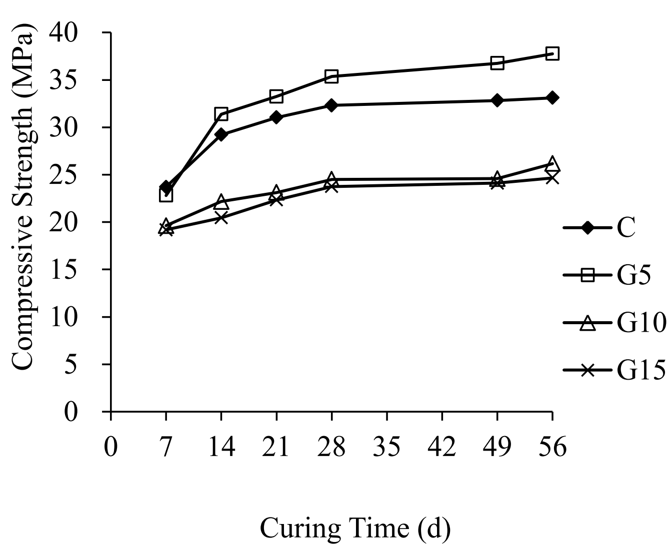

Fig. 1. Compressive strength of glass concrete at different ages.

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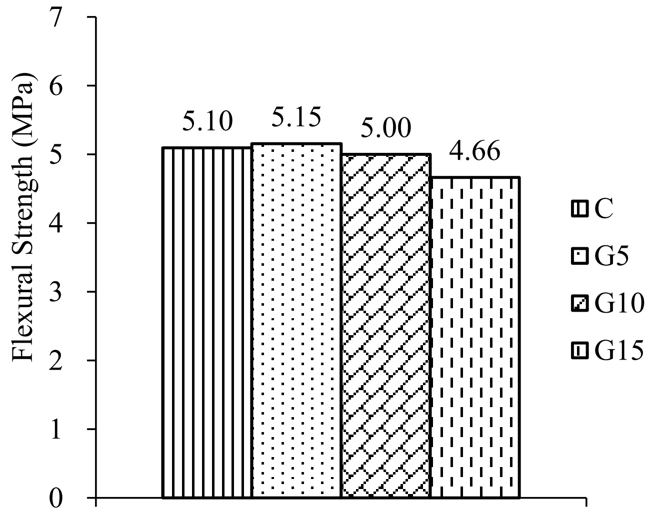

Fig. 2. Glass concrete bending strength comparison.

3.3 Effect of high temperature on compressive strength of glass concrete

The test results are shown in Table 1 and Fig. 3. When the control group concrete (C) is exposed to 440℃, 500℃, 580℃, 800℃ and 1000℃ for one hour, the residual strength is 80%, 78%, 49%, 18% and 16% respectively compared with the specimen free of high temperature. The compressive strength decreases gradually under the effect of high temperature. The compressive strength decreasing amplitude is small before 500℃, it decreases by 0.046% (22%/(500-23)) when the temperature increases by 1℃. The strength is lost because when the temperature is 400－500℃, most of bound water of C-S-H colloid has been lost. The compressive strength decreasing amplitude is the largest, about 0.363%/1℃ at 500℃－580℃. Because the Ca(OH)2 is decomposed at 500－580℃ [6]. The decreasing amplitude is the second largest at 580℃－800℃, about 0.141%/1℃. The decreasing amplitude is about 0.010%/1℃ at 800℃－1000℃, meaning the concrete strength of control group has been lost severely at 800℃.

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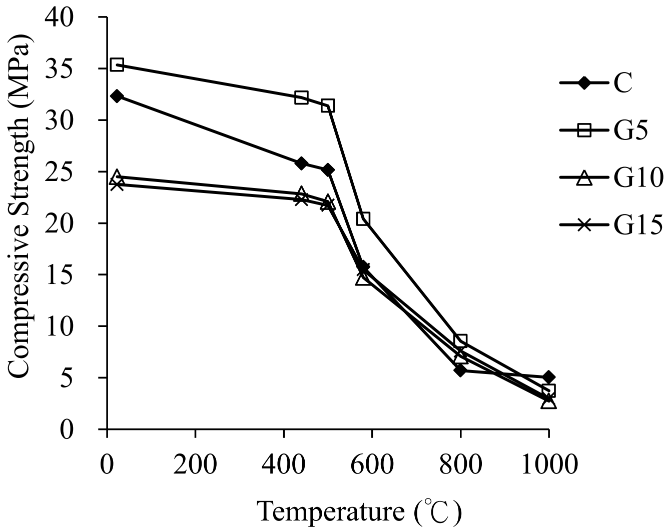

Fig. 3. Effect of high temperature on compressive strength of glass concrete.

Fig. 3 shows when the concrete is mixed with 0.5% short glass fiber (0.60 cm), the compressive strength decreasing amplitude is relatively small before 500℃. It decreases by 0.023% when the temperature increases by 1℃, lower than that of control group. The compressive strength decreasing amplitude is the largest at 500℃ – 580℃, about 0.388%/1℃, slightly different from control group. The decreasing amplitude is the second largest at 580℃ – 800℃, about 0.155%/1℃, slightly different from control group. The decreasing amplitude is about 0.065%/1℃ at 800℃ – 1000℃, higher than control group. The concrete with 1.0% and 1.5% glass fibers has the same trend. In addition, the addition of glass fiber can improve the loss of concrete strength under the effect of high temperature not exceeding 500℃, and the compressive strength is higher than control group under the effect of high temperature not exceeding 800℃. However, when the temperature is 1000℃, the residual strength of the concrete with glass fiber is lower than control group, it may because the glass fiber has lower melting point than aggregate. The loss of strength resulted from high temperature can be reduced by increasing the addition of glass fiber.

3.4 Effect of high temperature on compressive strength of glass concrete

The thermal conductivity of normal concrete is 1.5-3.5 W/m•K. Table 2 shows that after the control group concrete (C) is exposed to 440℃, 500℃, 580℃, 800℃ and 1000℃ for one hour, the thermal conductivity is 2.37, 1.70, 1.19, 0.67 and 0.45 W/m•K respectively. The thermal conductivity decreases gradually as the temperature rises. The test results of 500℃, 580℃, 800℃ and 1000℃ are 72%, 50%, 28% and 19% of 440℃ test result respectively. Fig. 4 shows the decreasing amplitude of thermal conductivity of concrete is the largest at 440℃ – 500℃, followed by 500℃ – 580℃, 580℃ – 800℃, and 800℃ – 1000℃.

Fig. 3 shows the concrete mixed with short glass fiber (0.60 cm), compared with the test results of control group, the thermal conductivity of concrete is reduced under the effect of high temperature, and the thermal conductivity decreases as the addition level of glass fiber increases. However, the trend of effect of high temperature on the thermal conductivity of glass concrete is identical with control group.

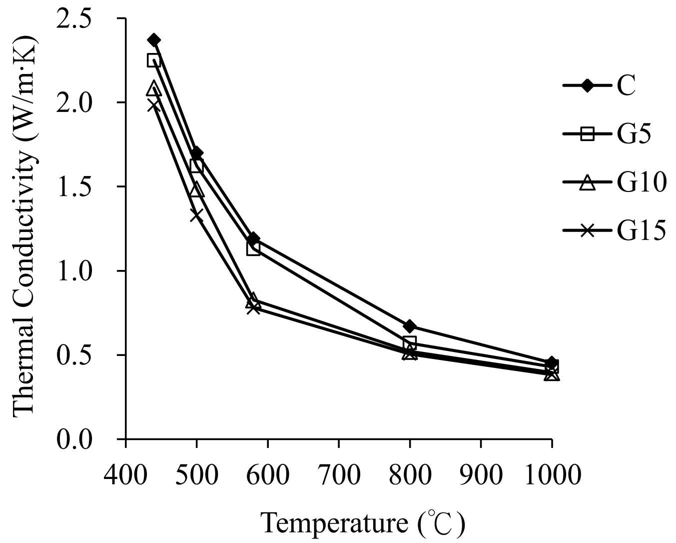

Fig. 4. Effect of high temperature on thermal conductivity of glass concrete.

4 CONCLUSION

The concrete is mixed with glass fibers which are 0.5%, 1.0% and 1.5% of cement weight and 0.60 cm long, to discuss the effect of fiber addition level on the compressive strength, bending strength, residual compressive strength and thermal conductivity after heating of concrete. The conclusions are described below:

(1). In the environment at room temperature, a low addition of short glass fiber to the concrete is favorable for the strength. The addition shall not be too high, otherwise it is adverse to the strength.

(2). In the environment at room temperature, a low addition of short glass fiber to the concrete has insignificant effect on the bending strength. The addition shall not be too high, otherwise its adverse effect on bending strength will grow.

(3). The addition of glass fiber can improve the loss of concrete strength under the effect of high temperature not exceeding 500℃, and the compressive strength is higher than control group under the effect of high temperature not exceeding 800℃. When the temperature is 1000℃, the residual strength of the concrete with glass fiber is lower than control group.

(4). The thermal conductivity of concrete decreases under the effect of high temperature, and the thermal conductivity decreases as the addition level of glass fiber increases. The trend of effect of high temperature on the thermal conductivity of glass concrete is identical with control group.

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References

1. C.C. Chang, (trans) "Corpora of Glass Fiber and Super POM", Taipei City, Xushi Culture & Education Foundation. (1976)

2. C.C. Chang, "Application of FRP", Taipei City, Xushi Culture & Education Foundation. (1980)
3. C.C. Chang, "Glass Fiber Reinforced Cement Construction Manual", Taipei City, Xushi Culture & Education Foundation. (1987)
4. N. Henry, Jr. Marsh, L. Lawrence, and Jr. Clack, “Glass fiber reinforced concrete base materials”, Fiber Reinforced Concrete, ACI Publication SP-44: 147–264. (1974)
5. C.Z. Wolfgang, “Cement chemistry and physics for civil engineers,” English Edition. (1980)
6. C.R. Cruze, “Elastic properties of concrete at high temperatures”, PAC Research Bulletin. (1971)
7. Y.F. Lin, "Discussion about Fire Performance of Lightweight Concrete Bricks in Mixed Sizes", Master’s thesis, National Chung Hsing University. (2004)