ISSN 1027-5495. Functional Materials, 26, No.3 (2019), p. 573-578.
doi:https://doi.org/10.15407/fm26.03.573

Mechanical properties of lightweight aggregate concrete at high temperature

R.Guan

Puyang Vocational and Technical College, 457000 Henan, China

Received April 11, 2019

The purpose of this study was to study the mechanical properties of lightweight aggregate concrete at high temperature. In view of the defects of lightweight aggregate concrete, shale ceramsite with high cylinder compressive strength and low porosity was used ‘as coarse aggregate to ensure the strength of lightweight agregate concrete. In addition, basalt fiber with high elastic modulus, high tensile strength and high temperature resistance and polypropylene fiber with light weight and good elasticity were added into lightweight aggregate concrete to study the influence of fiber on various mechanical properties of lightweight agregate concrete at high temperature. The results showed that HRL2 had the best fire resistance. Therefore, the fiber light aggregate concrete LC30 prepared in this study had the lowest strength and excellent high temperature resistance, and can be applied to the main structure with high fire protection requirements.

Keywords: lightweight aggregate concrete, high temperature, porosity, compressive strength, fiber.

Изучены механические свойства заполнителя бетона при высокой температуре. Сланцевый керамзит с высокой прочностью на сжатие и низкой пористостью использован в качестве заполнителя для обеспечения прочности легкого бетона. Базальтовое волокно с высоким модулем упругости, высокой прочностью на растяжение и высокой температурной стойкостью и полипропиленовое волокно с легким весом и хорошей эластичностью добавлены в заполнитель бетона для изучения их влияния на механические свойства бетона при высокой температуре. Показано, что бетон с легким волокнистым заполнителем имел низкую прочность и отличную стойкость к высоким температурам, что позволяет его применять для конструкций с высокими требованиями к противопожарной защите.

Механічні властивості легкого заповнювача бетону при високій температурі. *R.Guan*.

Вивчено механічні властивості легкого заповнювача бетону при високій температурі. Сланцевий керамзит з високою міцністю на стиск і низькою пористістю використано як важкий заповнювач для забезпечення міцності легкого бетону. Крім того, базальтове волокно з високим модулем пружності, високою міцністю на розтягнення і високою температурною стійкістю і поліпропіленове волокно з легкою вагою і хорошою еластичністю додано у легкий заповнювач бетону для вивчення їх впливу на механічні властивості легкого заповнювача бетону при високій температурі. Показано, що бетон з легкого волокнистого заповнювача, приготований в цьому дослідженні, мав найнижчу міцність і відмінну стійкість до високих температур, яку можна застосовувати для основної конструкції з високими вимогами до протипожежного захисту.

1. Introduction

The research on the high temperature resistance of concrete is important in the field of concrete research [1, 2].

The high-temperature working state of concrete is usually divided into two categories. Firstly, the temperature of working environment of reinforced concrete, which is about 500 – 600°, such as high temperature obtained in metallurgical plants, boiler chimney structure, etc. Secondly, the sudden rise of temperature caused by accidental fire events, in this case, the temperature rise rate is fast, and the temperature is high, sometimes the local temperature can reach thousands of degrees, causing great damage to the building. The causes of concrete damage in fire can be mainly attributed to two types: firstly, the uneven effect of high temperature on concrete leads to uneven temperature field inside the concrete and large additional stress inside the structure, resulting in the failure of the concrete structure. Secondly, under the action of high temperature, serious property changes have taken place in the concrete, such as material deterioration, strength reduction, or serious expansion or deformation.

Recently, the high-temperature failure mechanism of concrete playing a great role in promoting the improvement of the fire-resistance performance of concrete was discussed in the number of papers.

Tazky mixed basalt fiber into inorganic polymer cement concrete and Portland cement concrete to compare and study the influence of fiber content on fracture toughness of two types of concrete matrix [3]. The results showed that adding basalt fiber can improve the fracture performance of inorganic polymer cement concrete. Through the experimental study of concrete mixed with basalt fiber, Guo found that the influence of basalt fiber on static compressive strength and splitting tensile strength was not obvious [4]. However, under impact load, it showed obvious enhancement effect, and the effect was more significant when the content was 0.1 %, indicating that BFRC had good impact resistance. Shen studied the influence of air entraining agent, mineral admixture and steel fiber on the mechanical properties of concrete after high temperature by adding them into concrete respectively. The experimental results showed that compared with air entrainment and mineral admixtures, steel fiber had better inhibitory effect on mechanical property degradation of High-Performance Concrete (HPC) [5]. Real studied the influence of hybrid fiber (polypropylene fiber and steel fiber) on the mechanical properties of concrete after high temperature, and found that the hybrid fiber concrete did not burst in high temperature and the specimen maintained a certain integrity, thus the residual strength of hybrid fiber light aggregate concrete after high temperature was higher [6].

2. Methodology

2.1 Design of mix proportion

In this test, fiber light aggregate concrete was mainly used as high-temperature resistant structural concrete. The design strength grade of fiber lightweight aggregate concrete was LC30. According to the loose volume method in JGJ51-2002 "Technical specification for lightweight aggregate concrete", two types of lightweight aggregate concrete with different water-cement ratios were prepared, with no addition of water reducing agent lightweight aggregate concrete (LC) and with addition of water reducing agent lightweight aggregate concrete (LC1). According to "Chopped basalt fiber for cement concrete and mortar" GB/23265-2009 and "Synthetic fiber for cement concrete and mortar" GB/T21120-2007, under the condition of consistent water-cement ratio, basalt fiber and polypropylene fiber were mixed into lightweight aggregate concrete to prepare basalt fiber light aggregate concrete with six mix proportions (the volume content was 0.05 %, 0.1 %, 0.15 %, 0.2 %, 0.25 % and 0.3 %, respectively, and the serial numbers were BRLC1, BRLC2, BRLC3, BRLC4, BRLC5 and BRLC6) and polypropylene fiber light aggregate concrete with three mix proportions (the volume content was 0.1 %, 0.2 % and 0.3 %, respectively, and the serial numbers were PRLC1, PRLC2 and PRLC3). The mechanical properties of two kinds of fiber lightweight aggregate concrete were tested. The optimal volume content of two kinds of fiber was chosen to be 0.2 %. In addition, keeping the water-cement ratio unchanged, the total fiber volume content was 0.2 %, and mixed fiber lightweight aggregate concrete with three mix proportions was prepared (the proportions of fiber volume content were 0.05 % of basalt fiber and 0.15 % of polypropylene fiber, 0.1 % of basalt fiber and 0.1 % of polypropylene fiber, 0.15 % of basalt fiber and 0.05 % of polypropylene fiber respectively, and the numbers were HRLC1, HRLC2 and HRLC3, respectively).

2.2 Type and size of specimen

At room temperature, $100\times100\times100$ mm^3 specimens were used to determine the compressive strength of various types of lightweight aggregate concrete, and $100\times100\times400$ mm^3 specimens were used to

Table. Color of materials in BRLC4 specimens after high temperature treatment

Category	Room temperature	100°	200°	300°	500°	700°	900°
Mortar	Steel gray	Steel gray	Steel gray	Gray	Light gray	Greyish white	Yellow grey
Lightweight aggregate	Dark grey	Dark grey	Dark grey	Dark grey	Gray	Light gray	A few orangered
Manufactured sand	Grayish blue	Grayish blue	Grayish blue	Grayish blue	Gray	Greyish white	White

determine the flexural strength of various types of lightweight aggregate concrete.

2.3 Equipment for testing compressive strength

According to the "Standard for test methods of ordinary concrete (GB/T50081-2002)", the compressive strength of the cube specimens after curing for 28d and high-temperature experiment was tested with the YES-2000 digital display pressure testing machine of Jinan new assay testing machine Co., Ltd.

2.4 Flexural strength test

According to "GB/T50081-2002 standard for test methods of ordinary concrete", the specimen (size: 100×100×400 mm^3) maintained for 28d was tested with the hydraulic universal testing machine WE-300.

2.5 Heating scheme

In case of fire, due to the difference of surrounding environment and building structure type, the moisture content of fire-affected materials is also different. In addition, the water absorption rate of aggregate itself is higher, which leads to a greater difference in the moisture content of lightweight aggregate concrete under different conditions. In this study, in order to ensure the consistent moisture content of the specimens, all the specimens were taken out after the standard curing, and the room temperature strength test and high temperature fire resistance test were conducted under the condition of moisture saturation.

3. Results and discussion

In this study, six temperatures (100°, 200°, 300°, 500°, 700°, 900°) used. Target temperature treatment was carried out on the water-saturated specimen, light aggregate and fiber of LC, LC1, BRLC2, BRLC3, BRLC4, PRLC2 and HRLC2. The apparent characteristics of basalt fiber, polypropylene fiber, lightweight aggregate and the specimen after high temperature were observed, the cylinder compression strength of light aggregate after high temperature was measured, and the mass of the specimen after high temperature was weighed and the residual compressive strength after high temperature was measured.

The residual strength of BRLC2, BRLC3 and BRLC4 was compared and analyzed, and the influence of basalt fiber and its volume content on the high-temperature mechanical properties of lightweight aggregate concrete was studied in detail in combination with the apparent phenomenon of the specimen after high temperature and the characteristics of basalt fiber. The residual strength of PRLC2 was analyzed, and the action mechanism of polypropylene fiber on lightweight aggregate concrete at high temperature was analyzed in combination with the characteristics of polypropylene fiber and relevant research results.

According to the data results and apparent characteristics of the light aggregate concrete specimens with 7 mixture ratios after high temperature, the mechanical properties of the specimens with each mixture ratio under 6 temperature ranges were compared and analyzed, and the optimal mixture ratio with comprehensive fire- resistance performance was selected.

3.1 Appearance and internal characteristics of fiber lightweight aggregate concrete

In LC1, BRLC2, BRLC3, BRLC4, PRLC2 and HRLC2, the types of materials in all phases were the same except the types of fiber doped. After high temperature treatment, the appearance and internal characteristics of various lightweight aggregate concrete specimens were roughly the same. Taking BRLC4 as the demonstration specimen, the appearance and internal characteristics of the specimen after high temperature treatment were studied. The colors of the materials in each phase after high temperature are shown in Table.

From 100°C to 300°C, the apparent color change of the test piece was small, and it gradually changed its color from blue-gray

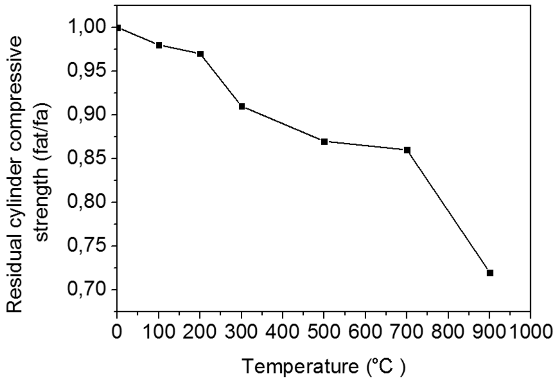

Fig. 1. Relative residual cylinder strength of lightweight aggregate after high temperature

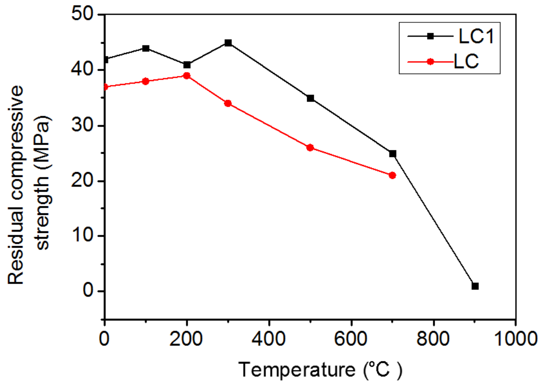

Fig. 2. Residual compressive strength of LC and LC1 after high temperature treatment.

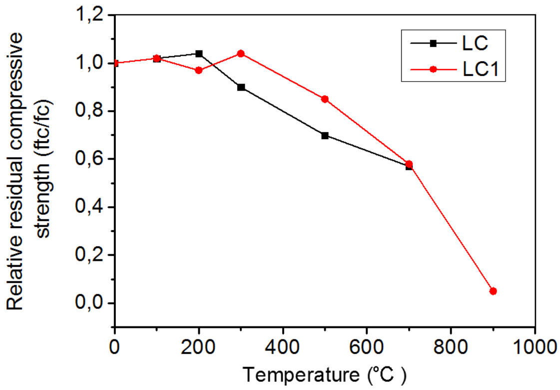

Fig. 3. Relative residual compressive strength of LC and LC1 after high temperature treatment.

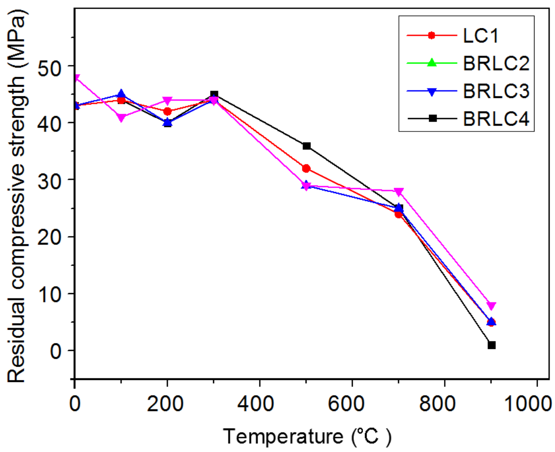

Fig. 4. Residual compressive strength of LC1, BRLC2, BRLC3, and BRLC4 after high temperature treatment.

to gray. At 100°C and 200°C the center of the cross-section surface of the specimen was darker than other areas. At 300°C the surface color of the section was the same. It can be concluded that the free water in the test piece gradually leaked out. The free water in the surface area of the test piece was released preferentially, and the free water discharge path in the center area was long, which led to the color difference between the central area and the surrounding area of the test piece. At room temperature, the lightweight aggregate on the fracturing section of fracture, the other part of mortar and lightweight aggregate debonding without damage, 100°C, 200°C, 300°C specimen fracturing section, the vast majority of lightweight aggregate fracture damage. At room temperature, part of the lightweight aggregate on the cracked section of the test piece was broken. The other part of the mortar was debonded from the lightweight aggregate without damage. At 100°C, 200°C, and 300°C, most of the lightweight aggregate fractures were broken on the cracked section of the specimen. At 500° – 900°, the apparent color of the specimen changed obviously from light gray to yellow gray, and the process was mainly hydrate decomposition. At 500°C and 700°C, there was a small amount of mortar and light aggregate peeling on the surface of the test piece. At 700°C, visible microcracks appeared on the surface of the test piece. At 900°C except for the HRLC2 test piece, the surface of other types of lightweight aggregate concrete specimens fell seriously, LC1 was the most serious, followed by PRLC2 and BRIC4.

3.2 Residual compressive strength of lightweight aggregate after high temperature

The residual cylinder compressive strength of lightweight aggregate at each target temperature was shown in Fig. 1. In two temperature zones from room tempera-

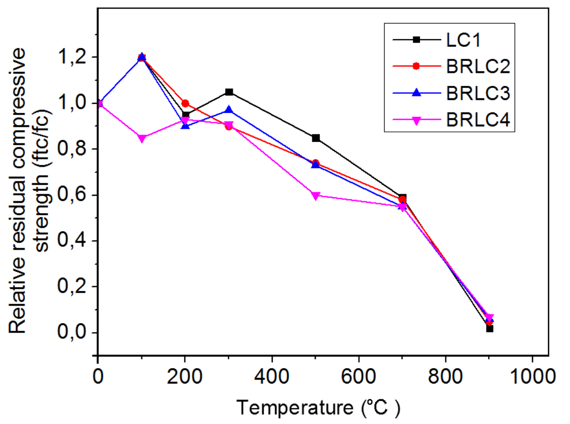

Fig. 5. Relative residual compressive strength of LC1, BRLC2, BRLC3, and BRLC4 after high temperature treatment.

ture to 200°C and from 300°C to 700°C, the cylinder compression strength of light aggregate declined slowly. In two temperature ranges of 300°C – 500°C and 700°C – 900°C, the decrease of cylinder compressive strength of light aggregate was steep. At 100°C – 300°C, the residual strength of light aggregate was 91 %. At 500°C – 700°C, the residual strength of light aggregate was 85 %. At 900°C, the residual strength of the lightweight aggregate was 72 %. After 900°C, the lightweight aggregate still maintained a strength of more than 70 %, indicating that it had high fire resistance.

3.3 Residual compressive strength of LC/LC1

As can be concluded from Fig. 2–4, the LC1 intensity at each temperature range was greater than LC, and the residual strength of LC1 was also higher than LC as a whole.

3.4 Residual compressive strength of LC1, BRLC2, BRLC3, BARLC4

At 100°–300°, the intensity of BRLC2 and BRLC3 did not change significantly. The intensity of BRLC4 decreased with the increase of temperature. Compared with LC1, BRLC2, BRLC3 and BRLC4 had higher compressive strength, good homogeneity and high compactness, as shown in Fig. 5–7. At 500°C, the strengths of BRLC2, BRLC3 and BRLC4 were less than for LC1. At this temperature, free water and combined water in the specimen had been fully spilled, the cementitious material of the specimen began to decompose, the aggregate — mortar interface deteriorated, and the fiber — mortar interface also deteriorated. At 700°C – 900°C, the complete decomposition of

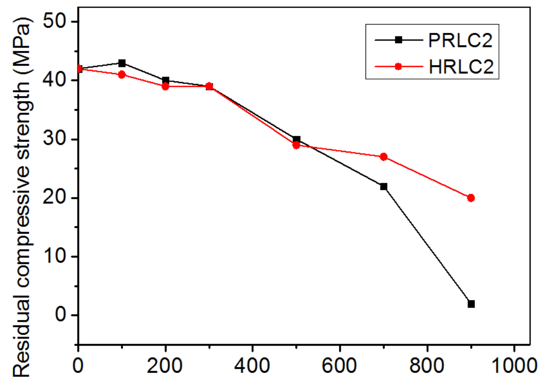

Fig. 6. Residual compressive strength of PRLC2 and HRLC2 after high temperature treatment.

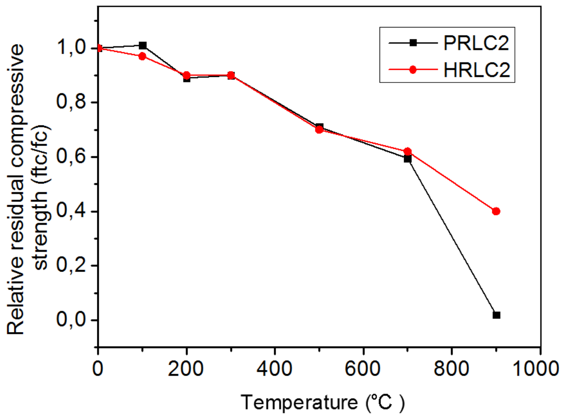

Fig. 7. Relative residual compressive strength of PRLC2 and HRLC2 after high temperature treatment.

the cementitious material slowed down the increase of porosity, and the retarding effect became more significant with the increase of fiber volume content, as shown in Fig. 4.

The residual strength at 100°C – 500°C was the lowest for BRLC4, followed by BRLC3, BRLC2 and LC1, indicating that the higher the strength grade in high temperature, the greater the strength loss of lightweight aggregate concrete. At 700°C the residual strength of BRLC4, BRLC3, BRLC2, and LC1 was equivalent. At 900°C BRLC4 had the highest residual strength, followed by BRLC3, BRLC2, and LC1.

3.5 Residual compressive strength of PRLC2 and HRLC2

In general, the intensity of PRLC2 and HRLC2 decreased with increasing temperature, and the intensity of PRLC2 increased at 100°C by 2 % as compared with room temperature. When the temperature was between 100°C and 500°C, the compressive strength of PRLC2 and HRLC2 was equivalent to the residual compressive strength. At 700°C – 900°C HRLC2 had the highest compressive strength and residual strength, followed by BRLC4, LC1 and PRLC2.

4. Conclusions

In this study, the residual mechanical properties of BRLC2, BRLC3, BRLC4, PRLC2 and HRLC2 after high temperature treatment were compared with mechanical properties of LC and LC1 used as the reference. The compressive strength decrease of BRLC2, BRLC3 and BRLC4 was higher than that of LC1 from 100°C to 500°C, and the compressive strength decreased faster with the increase of basalt fiber volume. When the temperature was between 700°C and 900°C, the tensile strength of the basalt fiber was impaired and deteriorated. As the volume of the basalt fiber increased, the tensile strength decreased. When the temperature was between 100°C and 500°C, the polypropylene fiber melted to form a channel to promote the rapid release of water vapor, which reduced the damage caused by the water vapor pressure and thermal stress on the internal structure of the test piece, resulting in the decrease of the compressive strength of PRLC2 and HRLC2 being slower than that of BRLC4. At 700°C ~ 900°C, the tensile effect of basalt fiber delayed the material damage and degradation, and the melting of polypropylene fiber released steam pressure in advance, so the residual compressive strength of HRLC2 decreased slowly. At 900°C, the HRLC2 specimens maintained a certain degree of integrity, with the highest residual compressive strength of 42 % and 27 %.

References

1. P.Ogrodnik, J.Szulej, *Construct. Build Mater*, **157**, 909 (2017).
2. M.S.Nadesan, P.Dinakar, *Construction & Building Materials*, **176**, 665 (2018).
3. M.Tazky, L.Bodnarova, R.Hela, *Mater. Sci. Forum*, **908**, 106 (2017).
4. R.Guo, H.E.Kecheng, M.A.Qianmin et al., *J. Build. Mater.*, **20**, 333 (2017).
5. D.Shen, J.Jiang, J.Yang et al., *Construct. Build. Mater.*, **135**, 420 (2017).
6. S.Real, J.A.Bogas, B.Ferrer, *Mater. Struct.*, **50**, 101 (2017).