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Research paper

Dynamic splitting tensile performance of new and old concrete after high temperature treatment

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Abstract: In order to study the dynamic splitting tensile properties of new and old concrete after high temperature treatment, the effects of different impact velocities and temperatures on failure modes, dynamic splitting strength and energy absorption of new and old concrete were analyzed by impact dynamic splitting tensile test use of variable cross-section Φ 74 mm split Hopkinson pressure bar apparatus. The results show that: Impact velocity and temperature not only affect the dynamic splitting strength of new and old concrete bonding specimens, but also affect the failure modes and degree of breakage. The dynamic splitting strength of new and old concrete increases with the increase of impact velocity, but the increase rate decreased with the increase of temperature. The dynamic splitting strength first increases slowly and then decreases dramatically with the increase of temperature. In the dynamic splitting test of new and old concrete, the energy absorption increases with the increase of impact velocity and decreases with the increase of temperature.

Keywords: new and old concrete, split Hopkinson pressure bar(SHPB), dynamic splitting tensile performance, impact velocity, temperature

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1. Introduction

The mechanical properties of new and old concrete bond play a key role in strengthening and repairing concrete structures, assembling concrete composite slabs and composite beams [1]. Zhao Zhifang, Zhao Guofan et al. [2, 3] studied the effects of bonding surface treatment form, roughness, interfacial agent and other factors on the tensile and flexural mechanical properties of new and old concrete at room temperature. Jin Lina et al. [4] used Z-type specimens to study the influences of two factors on the shear properties of new and old concrete under normal temperature, namely, no reinforcing bars planted in the gouging surface and both gouging and reinforcing bars planted. Scholars at home and abroad have conducted a lot of studies on the interface bonding properties between ordinary concrete and various new concrete materials. There are bond-slip analysis considering shrinkage stress between ordinary concrete-reactive powder concrete (NC-RPC), influence of roughness between ordinary concrete-ultra-high toughness cement-based composite (NC-UHTCC) on tensile strength of interface [5], ordinary concrete – Experimental study on the influencing factors of bonding between cement-based composites (NC-ECC) used in engineering and test of bonding strength between ordinary concrete-self-filling concrete (NC-SCC) under oblique shear conditions [6]. Studies on the bonding properties of new and old UHPC-NC interfaces are gradually being carried out. For example, Hussein et al. measured the bonding strength of UHPC-HSC interface with different roughness through direct tensile test [7] and calculated the friction coefficient of the interface in reverse. Tayeh et al. determined three types of failure of UHPC-NC interface under splitting and pulling tests, and studied the mechanical properties and durability of the composite interface [8]. Carbonell et al. studied the interface bonding performance and freezing-thawing resistance of UHPC-NC specimens under different interface moisture conditions, different interface treatment methods and different ages through experiments [9].At present, the research on the mechanical properties of the bond between new and old concrete mainly focuses on the static or quasi-static mechanical properties under normal temperature [10, 11], while the dynamic mechanical properties of concrete under high temperature mainly focus on the integrated pouring concrete [12–16]. Xu Jinyu et al. [12] analyzed the dynamic impact mechanical properties of concrete after high temperature and high temperature by using separate Hopkinson pressure bar test device. Wang Liwen et al. [13,14] studied and analyzed the influence of strain rate and other factors on the dynamic mechanical properties of reactive powder concrete after high temperature action. Wang Yutao et al. [15] compared and analyzed the difference between static and dynamic mechanical properties of concrete after high temperature action. However, there are few reports on the impact dynamics of the bond between new and old concrete at high temperature. When prefabricated concrete structures or repaired and reinforced concrete buildings suffer from fire, the explosion inside the buildings after high temperature and the sudden collapse of the upper members of the buildings will produce impact loads on the new and old concrete bonding structures or members. Therefore, it is necessary to study the dynamic impact mechanical properties of new and old concrete bonded by high temperature. This paper, by using Φ 74 mm variable cross-section steel split hopkinson pressure bar (SHPB) device for new and old concrete bonding specimens after high temperature impact dynamic splitting tensile test, study different impact velocity and the effect of temperature on the dynamic splitting tensile performance and change rule.

2. Experimental procedure

2.1. Raw materials and test pieces

Cement: P•O42.5R ordinary Portland cement; Sand: fineness modulus 2.6 ordinary river sand; Gravel: 5–10 mm continuous graded gravel; Water: Tap water. The new concrete datum designed strength is C35, while the old concrete datum designed strength is C30. See Table 1 for the mix ratio. The average compressive strength of new and old concrete standard cube test blocks is 44.7 N/mm^2 and 38.5 N/mm^2, respectively.

Table 1. Mix proportions of old concrete and new concrete (kg/m^3)

	Strength grade	Water	Sand	Cement	Limestone rubble
Old concrete	C30	231	623	442	1089
New concrete	C35	218	598	482	1168

In advance, the old concrete with a thickness of 18.5 mm is made in the steel mold, and its bonding surface is brushed. The sand irrigation method [17] was adopted to measure the roughness H of the old concrete bonding surface, so that the roughness H was controlled within the range of 4.56–5.78 mm, in accordance with the provisions of the technical Code for Assembled Concrete Structures (JGJ1-2014) on the concave and convex depth of the rough surface of prefabricated slabs. The new concrete with a thickness of 18.5 mm is then poured and cured for 28 days in accordance with the standard requirements. According to existing studies [18, 19], in the SHPB test, when the aspect ratio of the specimen is 0.5, the inertia effect and friction effect are the minimum. So the specimen is made into a Φ 74 × 37 mm cylinder by drilling machine, grinding machine and other equipment. Under the same conditions, the static splitting tensile test specimens of the new and old concrete cubes of 150 × 150 × 150 mm (both the dimensions of the new and old concrete parts are 150 × 150 × 75 mm, and the bonding surface is 150 × 150 mm) are made, and the static splitting tensile strength of the new and old concrete bond specimens is measured as 2.78 N/mm^2.

2.2. Test method

Put the prepared specimen into the box-type resistance furnace and set the heating rate of 10°/min. The predetermined temperatures in the furnace were set at 200°, 300°, 400° and 500° respectively. When the predetermined target temperature was reached, the temperature was maintained for 2 h, so that the temperature inside and outside the specimen was the same. Open the furnace door to cool it naturally, take out the specimen and wait for it to cool down before conducting dynamic impact splitting test.

The experiment was carried out in the dynamics laboratory of Anhui University of Science and Technology by using Φ 74 mm SHPB dynamic test system. The impact bar, the incident bar and the transmission bar are all of the same high-strength alloy steel material. The length of impact bar is 600 mm, the length of incident bar is 2400 mm, and the length of transmission bar is 2000 mm. Because the reflected wave signal is strong, the transmitted wave signal is weak, so the incident bar chooses to paste the ordinary strain gauge, while the transmission bar chooses to paste the semiconductor strain gauge. Before the test, in order to ensure the uniform distribution of specimen stress, vaseline was evenly applied to the impact contact surfaces of incident bar, transmission bar and specimen, and the axes of the test piece, incident bar and transmission bar to be tested were kept in the same horizontal line. The test loading mode is shown in Figure 1.

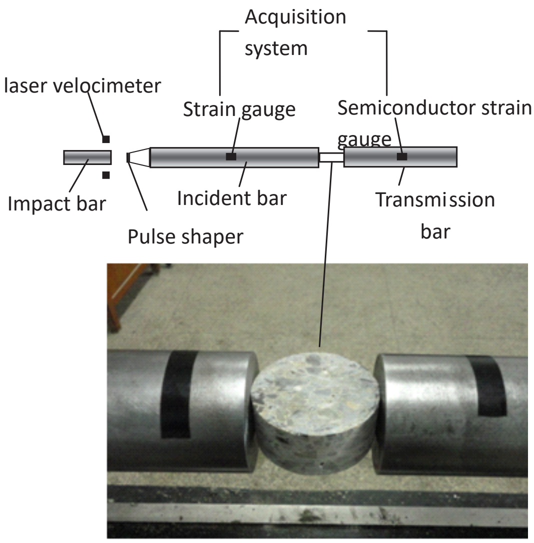


Fig. 1. Loading mode in dynamic splitting test

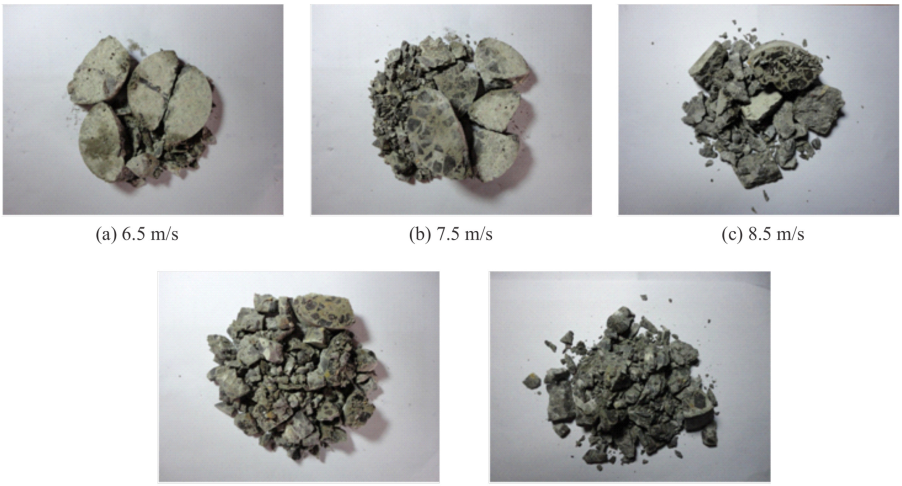
The impact velocity of the impact bar is respectively set at 6.5 m/s, 7.5 m/s, and 6.5 m/s, 8.5 m/s, 9.5 m/s and 10.5 m/s. The reaction temperatures of the samples were 20°, 200°, 300°, 400° and 500°, respectively. The test results of the 3 specimens under each working condition were averaged.

3. Results and discussion

3.1. Failure pattern analysis

According to SHPB impact splitting test results, the impact velocity and temperature not only affect the dynamic splitting strength of new and old concrete bonding specimens, but also affect the failure form and degree of breakage.

The change of failure morphology of the new and old concrete bond specimens with impact velocity at room temperature (20°) is shown in Fig. 2. It can be seen from Fig. 2 that, in terms of failure form, when the impact velocity is low, the new and old concrete bonding specimen is radial split along the bonding surface, and its section is the tensile failure of the new and old concrete bonding surface. And with the increase of the impact velocity, most of the specimens show the splitting and crushing form. From the perspective of crushing degree, with the increase of impact velocity, the size of the fragments of the new and old concrete bonding specimens in the splitting failure gradually decreases, while the number of fragments increases significantly, showing an obvious correlation of impact velocity.

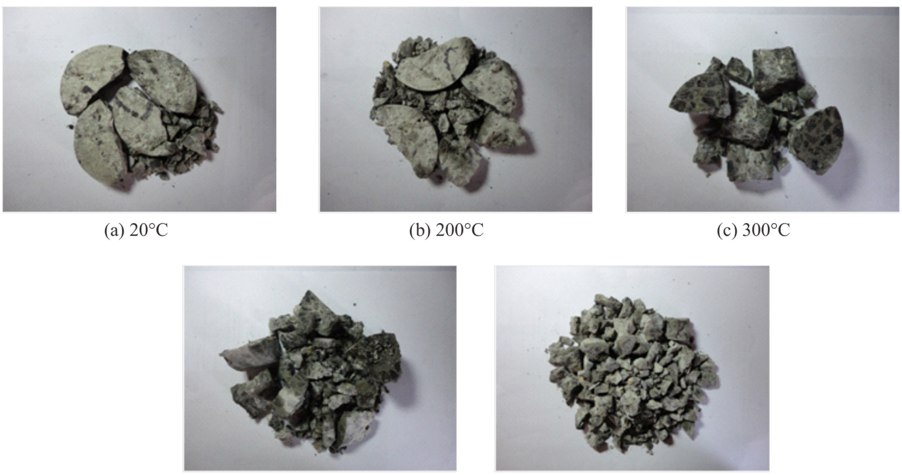


(a) 6.5 m/s (b) 7.5 m/s (c) 8.5 m/s

(d) 9.5 m/s (e) 10.5 m/s

Fig. 2. Failure modes of new and old concrete bond specimens under different impact velocities at room temperature

Under the same impact velocity (7.5 m/s), the failure modes of the new and old concrete bond specimens subjected to different temperatures are shown in Fig. 3. It can be seen from Fig. 3 that, from the failure form, when the temperature is below 200°, the new and old concrete



(a) 20°C (b) 200°C (c) 300°C

(d) 400°C (e) 500°C

Fig. 3. Failure modes of new and old concrete bond specimens under the action of the same impact velocity and different temperature

bonding specimen splits along the bonding surface radial. With the increase of temperature, most of the new and old concrete bond specimens show a comminuted failure pattern. From the perspective of crushing degree, with the increase of temperature, the size of the split pieces of the test piece decreases gradually. When the temperature reaches 500°, almost all the pieces after the split failure of the test piece are in the shape of fine gravel.

3.2. Dynamic splitting tensile strength

The two-wave method [20] was adopted to process the relevant test data, and the stress of the specimen was calculated according to Formula (3.1).

$$\sigma(t) = \frac{2A}{\pi d b} E \varepsilon_T(t) \tag{3.1}$$

where σ(t) is the stress of the specimen. d and b are respectively the diameter and thickness of the specimen. E and A are the elastic modulus and section area of the compression bar respectively, and $\varepsilon_T(t)$ is the transmitted waves measured in the test.

Fig. 4 shows the relationship between dynamic splitting tensile strength of new and old concrete bond specimen and impact velocity. Where, the impact velocity is the velocity of the impact bar hitting the incident bar measured by the SHPB loading system. Dynamic splitting tensile strength is the peak split tensile strength reached by the specimen, which is the strength index reflecting the concrete specimen material.

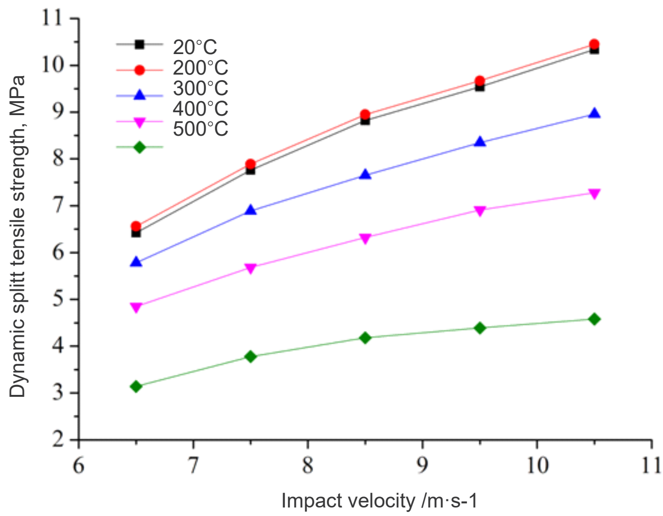


Fig. 4. Relationship between dynamic splitting tensile strength and impact velocity

It can be seen from Figure 4 that the dynamic splitting tensile strength of the bond between new and old concrete at different temperatures increases with the increase of impact velocity. The greater the impact velocity, the greater the dynamic splitting tensile strength, which shows an obvious impact velocity effect. With the increase of action temperature, the increasing trend of dynamic splitting tensile strength of specimens decreases somewhat with the increase of impact velocity. At room temperature, the dynamic splitting tensile strength of the specimen at an impact velocity of 10.5 m/s was 1.61 times that at an impact velocity of 6.5 m/s, and 3.72 times the static splitting tensile strength. After 300° action, the dynamic splitting tensile strength of the specimen at an impact velocity of 10.5 m/s was 1.55 times that at an impact velocity of 6.5 m/s. Under the action of 500°, the dynamic splitting tensile strength of the specimen at the impact velocity of 10.5 m/s was 1.46 times that at the impact velocity of 6.5 m/s.

New and old concrete bond specimens are damaged due to the generation and expansion of internal cracks, and the energy required for the generation of cracks is much higher than that required for the expansion of cracks. The higher the rate of impact velocity, the more cracks are created, and thus the more energy is required. Because the loading time of high-speed impact is short and the deformation of material is small, there is not enough time for energy accumulation, so the external impulse or energy can only be offset by increasing the stress. As a result, the failure stress of the material increases with the increase of the impact velocity.

Figure 5 shows the relationship between the dynamic splitting tensile strength of new and old concrete bond specimen and temperature. Under the condition of the same impact velocity, with the increasing temperature, the dynamic splitting tensile strength of the specimen showed a trend of slowly increasing at first and then significantly decreasing. When the temperature increases from normal to 200°, the dynamic splitting tensile strength of the specimen increases slowly with the temperature. After increasing from 200°, the dynamic splitting tensile strength of the specimen decreased significantly with the increase of temperature. When the temperature rose to 300°, the dynamic splitting tensile strength of the specimen was lower than that of the normal temperature. When the temperature rose to 400°, the dynamic splitting tensile strength of the specimen was about 70–75% of that at room temperature. When the temperature rose to 500°, the dynamic splitting tensile strength of the specimen decreased significantly, which was about 45–50% of the dynamic splitting tensile strength at room temperature.

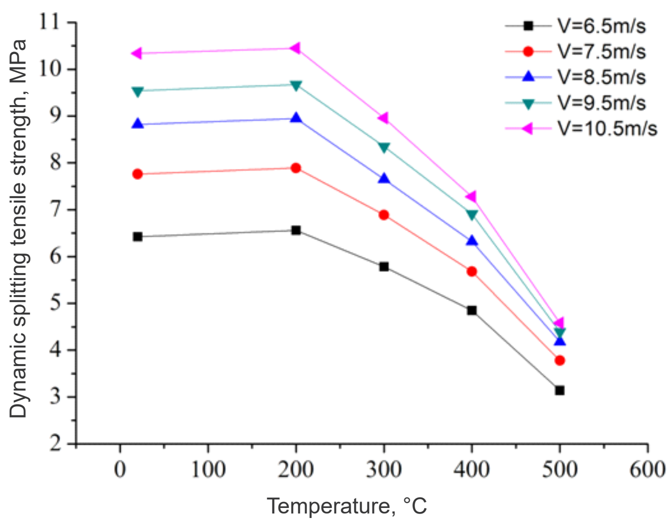


Fig. 5. Relationship between dynamic splitting tensile strength and temperature

When the temperature rises from normal temperature to 200°, the free water inside the concrete is evaporated, and the new and old concrete bond specimens form microcracks inside. When subjected to impact load, the concrete is compacted and the dynamic splitting tensile strength is enhanced. When the temperature rises to 300°, due to differences in the thermal performance of cement and aggregate, the bonding surface of new and old concrete produces cracks and rapidly expands, and the dynamic split tensile strength gradually decreases. When the temperature rises to 500°, the aggregate in concrete will undergo phase change and thermal decomposition, resulting in further expansion of concrete volume, rapid development of cracks in the bonding surface of new and old concrete, and almost complete loss of cohesive force. Therefore, the dynamic splitting tensile strength of specimens decreases sharply.

3.3. Energy absorption analysis

The strain waveform data signals measured on the pressure bar of the SHPB test device can be used to calculate the incident energy W_I, reflected energy W_R and transmitted energy W_T on the pressure bar during the whole process from loading to unloading of the specimen. Thus, the energy absorption value W_L of the specimen during the whole loading process can be deduced, which can be used to represent the toughness of the material. The calculation formula is shown in Equation (3.2):

$$W_L = W_I - W_R - W_T = \frac{cEA}{A_s l_s} \int \left(\varepsilon_I^2 - \varepsilon_R^2 - \varepsilon_T^2\right) \mathrm{d}t \tag{3.2}$$

where: c, E and A are respectively the elastic wave velocity, elastic modulus and cross-sectional area of the compression bar; A_s and l_s are the cross-section area and length of the specimen, respectively; The ε_I, ε_R and ε_T are the incident, reflected and transmitted wave strain signals measured on the pressure bar, respectively.

The relationship between energy absorption and impact velocity of new and old concrete bonding specimens is shown in Fig. 6. As can be seen from Fig. 6, the energy absorbed by the specimen increases with the increase of impact velocity, showing a strong correlation of impact velocity. When the impact velocity is low, the specimen absorbs little energy. It is the crack with less energy consumption that determines the failure of new and old concrete bond specimens. Because the number of such cracks is small, the size of the block is large during the impact failure of the specimen, and the critical stress value required to reach the impact fracture is also low, that is, the dynamic fracture strength value is low. As the impact velocity increases, the energy absorbed by the specimen also increases, resulting in more crack propagation and a sharp increase in the number of cracks. As a result, the number of pieces of the specimen is increasing, the size of the block is decreasing, and the dynamic splitting tensile strength is also increasing.

The relationship between energy absorption and temperature of new and old concrete bonding specimens is shown in Figure 7. As can be seen from Fig. 7, with the increase of temperature, the energy absorbed by the new and old concrete bonding specimens decreases, showing a strong temperature correlation. With the continuous rise of temperature, the damage degree of new and old concrete bonding surface and internal structure of materials is more serious, and the number of cracks also increases sharply, leading to loose structure. Moreover,

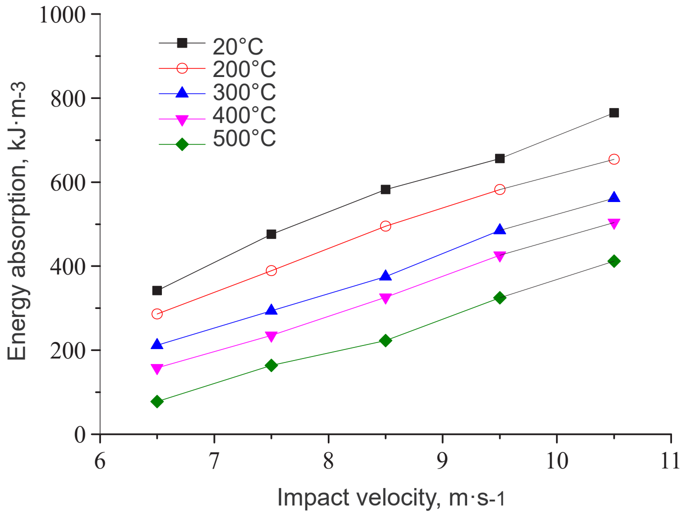


Fig. 6. Relationship between energy absorption and impact velocity

the bonding strength between quartz sand aggregate and cement stone and old and new concrete is greatly reduced. Therefore, the absorption energy needed for crack propagation is also greatly reduced. Therefore, under the same impact velocity, the higher the temperature is, the smaller the absorption energy required by the impact splitting and pulling failure of the new and old concrete bond specimens will be. Therefore, the dynamic splitting tensile strength is also lower.

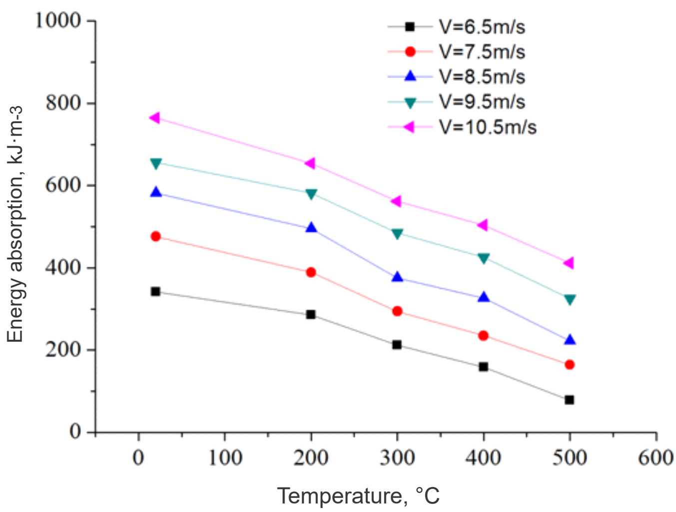


Fig. 7. Relationship between energy absorption and temperature

4. Conclusions

The impact splitting and tensile properties of the new and old concrete bonding specimens were tested, and the test results were analyzed. The main conclusions were as follows:

1. Impact velocity and temperature not only affect the dynamic splitting tensile strength of new and old concrete bond specimens, but also affect the failure form and crushing degree of the specimens.
2. The dynamic splitting tensile strength of new and old concrete bond specimens increases with the increase of impact velocity. And with the increase of action temperature, the amplitude of dynamic splitting tensile strength increases with the increase of impact velocity decreases.
3. The dynamic splitting tensile strength of new and old concrete bond specimens showed a trend of slow increase and then significant decrease with the continuous increase of temperature. When the temperature rose to 500°, the dynamic splitting tensile strength of the specimens decreased significantly, which was about 45–50% of the dynamic splitting tensile strength at room temperature.
4. In dynamic tensile splitting test of new and old concrete bond specimens, the energy absorption increases with the increase of impact velocity and decreases with the increase of temperature.

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