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Mechanism of Influence of Sawtooth Interface Parameters on Shear Behavior of New and Old Concrete

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Abstract

The repair and reinforcement of concrete structures have become an important engineering field. In order to investigate the shear strength curve and crack evolution law of new and old concrete bonded and locked under the notch, and to extract the mechanical parameters of new and old concrete, a method for establishing a refined concrete model is provided. Combined with the numerical simulation method, the shear peak stress and failure mode of new and old concrete superimposed bodies under different vertical pressures with different numbers of serrated locks are further studied. The results show that the shear stress-shear deformation curve of the new and old concrete superimposed body under a triangular serrated notch is composed of five parts: initial compaction stage, pre-peak linear stage, pre-peak nonlinear stage, brittle fracture stage, and residual strength stage. With the increase of the number of locking, the shear strength of the new and old concrete increases, and the increase rate gradually decreases. When the locking area is greater than 60% of the bond area, it almost does not increase. The increase in vertical pressure will weaken the influence of the number of locking serrated teeth. With the increase in the number of locks, the binding surface cracks will gradually change from shear cracks to tensile cracks, the cohesion of the specimen increases, the internal friction angle decreases, and the shear stiffness remains unchanged.

Keywords

New and old concrete, interface, direct shear, shear failure, numerical simulation

1. Introduction

Whether in the repair of old concrete structures or the construction of prefabricated concrete structures, there may be concrete joints cast in different periods. The common reinforcement and connection methods include enlarging the cross-section method, adding the prestressing method, reinforcement method with planting bars, carbon fiber reinforcement and repair technology, etc., which all require the casting of new concrete surface on the old concrete. The commonly used adhesive surface treatment techniques include high-pressure water jet, manual chiseling, sandblasting, slotting, and other methods. Compared with other methods, the slotting method has the advantages of high mechanization, simple construction, and convenient unified control and evaluation of the construction quality of the new and old concrete adhesive surface. The discussion on the new and old concrete covers many areas of issues. At present, there are many relevant research results on the adhesive characteristics of new and old concrete and their use skills in practical projects worldwide [1-5]. According to the research, the bonding performance of the new and old concrete interface is related to the strength of the new and old concrete, the treatment method of the bonding interface, the type of interface agent, the roughness of the interface, the orientation and environment of the adhesive surface and other factors [6-10]. Lin, et al. [11] investigated the shear force of concrete interfaces poured at different times under the condition of planting reinforcement. The study found that with the increase in the use of reinforcement, the shear resistance would also be improved accordingly. Wu, et al. [12] pointed out that when the content of silicon ash was 4%~5%, silicon ash played an important role in improving the bonding strength of concrete-based grouting material (CGM) and concrete interface. Huang, et al. [13] established geometric models of old and new concrete with different fractal dimensions by using the Monte Carlo method and aggregate grading theory. The results showed that with the increase of fractal dimension, the shear strength of the interface increased first and then decreased. Yang [14] conducted an in-depth study on the influence of interface inclination and positive pressure on the shear characteristics of new and old concrete. The results showed that the maximum shear stress of new and old concrete increased with the increase of interface inclination and showed a linear growth trend with the increase of positive pressure. However, the research on the mechanical properties of triangle serrated groove locking adhesive surfaces needs to be further studied. In this paper, the indoor direct shear test and numerical simulation were combined for different serrated groove locking of new and old concrete, and the shear resistance of new and old concrete under different vertical pressures and different numbers of locking serrated teeth was studied and discussed, providing a reference for the subsequent research on the mechanical properties of new and old concrete joint surface under shear.

2. Test System

2.1 Test Equipment

The shear test of the joint surface of old and new concrete adopts the RMT-150C test system. This equipment can be loaded by the experimental machine in the vertical direction and is mainly used to test the mechanical properties of rock concrete, and other materials. In addition, the computer processing system of stress and strain of rock mass can track and analyze the axial stress, confining pressure, and strain value of rock-like materials in real-time, so as to study the mechanical properties of rock in different environments.

2.2 Specimen Making

The concrete test block is a composite cube of old and new concrete, and the old concrete is a batch of standard concrete test blocks labeled C25 made in 2021. The old concrete is cut on the cutting machine and processed into 150mm*150mm*75mm test blocks, and 20mm equiangular sawtooth grooves are cut on them. The processed old concrete is put into the mold to pour the new concrete into 150mm*150mm*150mm composite cubes of old and new concrete. The standard concrete test blocks of 150mm*150mm*150mm of the same batch are made for the uniaxial compression test.

2.3 Calibration of concrete meso-parameters

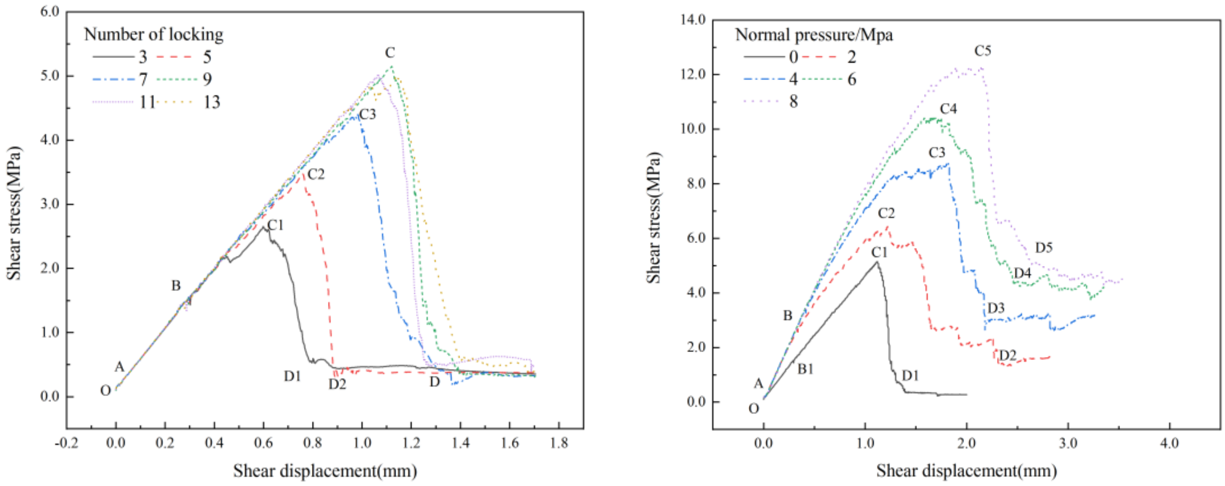
After the contact model of various materials is determined, the meso-parameters of the model contact need to be calibrated in detail before calculation. By comparing the uniaxial compression test results of new and old concrete with the simulation results, peak stress, and strain are all less than 5%.

3. Shear mechanical properties of old and new concrete with different locking numbers

the numerical calculation was conducted on the bond interface of old and new concrete with a number of locking segments I (3,5,7,9,11,13) under vertical pressure p (0.1,2,4,6,8 Mpa). Fig. 1 is the shear stress-shear deformation curve (partial numerical calculation results, Fig. a: i=9, Fig. b: p=0.1 Mpa).

3.1 Shear Stress-Shear Deformation Characteristics

The shear stress-shear deformation curve of old and new concrete with a serrated locking section interface can be divided into 5 stages as shown in Figure 1. In the initial compaction stage (OA), the initial microcracks existing in the bonding surface of new and old concrete will be compacted under the shear action, and the curve is represented by the tiny nonlinear deformation of the initial segment, which can be ignored. In the pre-peak linear elastic stage (AB), the graph of this stage is a straight line, and the shear stress shows a linear rising trend, and there is no crack in the specimen in this stage. When the vertical stress is the same, the shear stiffness is constant. With the increase of vertical stress, the initial defects of the bonding surface are compacted, and the shear stiffness increases (the slope of the pre-peak curve increases). The shear stiffness in this stage is independent of the number of locking surfaces. In the pre-peak nonlinear stage (BC), the bonding interface of new and old concrete begins to show microcracks, and the bonding surface climbs. The shear force of new and old concrete is jointly borne by the interface bonding force and the interface serrated. With the increase of shear displacement, the microcracks develop and merge rapidly, and the interface bond is destroyed. The force is mainly borne by the serrated. In this stage, the shear stiffness decreases with the development of cracks, the sample curve shows a slightly “convex” shape, and the serrated begins to produce microcracks. In the brittle fracture stage (CD), after reaching peak point C, the interface sawtooth of the new and old concrete is affected by the compressive shear force, forming a large number of microcracks and damage. When the near-force surface sawtooth is damaged, the shear stress borne by the sawtooth is transferred to the distal sawtooth. Due to the short transmission distance and the existence of a large number of microcracks, the cracks develop rapidly and connect the whole shear surface, resulting in brittle fracture and loss of shear resistance, and the shear stress decreases rapidly. There can be a small jitter during the stress decrease, but the overall trend is downward. Under the same vertical stress, the decrease rate of shear stress at this stage decreases with the increase in the number of interface locks. In the residual deformation stage (after point D), the bond surface sawtooth is damaged, and after the shear stress falls, the specimen still has a certain degree of shear resistance. The stress at this stage is relatively stable and basically remains at the same value. In this process, the strength source is the friction force generated by the normal stress and the weight of the specimen.



(a) p=0.1Mpa (b) i=9

Figure 1. Shear stress-shear deformation curve.

3.2 Characteristics of bond surface cracks under compressive-shear action

The new and old concrete binding surfaces are mainly sheared, while the sawtooth is mainly pulled. With the increase in the number of locking segments, the interface cracks under direct shear gradually change from shear cracks to tensile cracks.

3.3 Characteristics of Failure Strength of Peak Bonding Surface

The shear stress-shear deformation curves of old and new concrete composites with different locking amounts almost did not change in the elastic stage, but the peak strain increased with the increase of the locking amount. As shown in Figure 2, the shear stress peak of the bonding surface with different locking amounts under 5 vertical stresses was summarized. When the vertical pressure was 0~6Mpa, under the same vertical stress, the shear strength increased with the increase of the number of bonding surface locking segments. It is worth noting that when the number of bonding surface locking segments increased to 60% of the bonding surface (i=9), the number of bonding surface locking segments continued to increase, and the shear strength remained almost unchanged. With the increase of vertical pressure, the increase rate decreased. When the vertical pressure was greater than 6Mpa, the number of bonding surface locking segments had no effect on the shear peak.

The shear peak of different vertical stresses with different locking amounts under 6 locking amounts was summarized and fitted respectively. As shown in Figure 3, it conforms to the Mohr-Coulomb strength criterion. The obtained cohesion c, internal friction angle φ, and fitting coefficient R^2 are listed in Table 1. The cohesion c of the bonding surface increased with the increase of the number of locking segments; the internal friction angle φ decreased with the increase of the number of locking segments. The change in cohesion is the main reason for the difference in shear strength. As can be seen from Figure 3, the peak strength increases linearly with the increase of vertical pressure, and the fitting coefficient is above 97%. The peak strength increases with the increase in the number of locking segments. The smaller the tooth spacing, the smaller the shear force difference between the teeth, and the more conducive it is to the simultaneous play of all the serrated shear strengths, which is represented by the increase of cohesion. That is the more the number of locking segments, the more "evenly" the teeth are distributed on the joint surface, the more "evenly" they are forced, the more fully they play the shear performance, and the greater the shear strength.

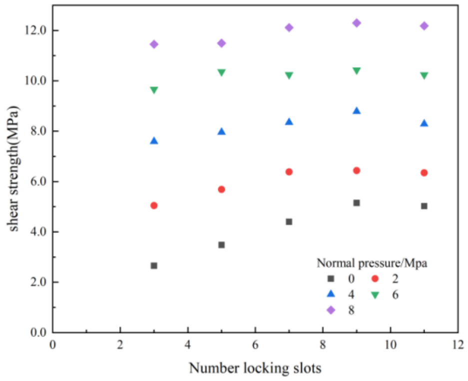


Figure 2. Number of locked segments and shear strength.

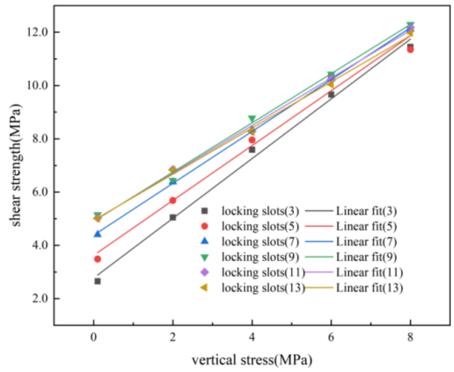


Figure 3. Vertical stress and shear strength.

Table 1. Fitting values of shear parameters for different numbers of locked segments.

Number of locking slots	Cohesion c/MPa	internal friction angle φ/(°)	R^2
3	2.7729	48.27	0.99
5	3.6262	45.85	0.97
7	4.3807	44.24	0.99
9	4.9034	42.74	0.99
11	4.9204	41.80	0.99
13	4.9384	40.99	0.99

4. Conclusion

In order to study the shear strength curve and crack evolution law of new and old concrete bonded by serrated locking, indoor shear tests were conducted on new and old concrete composite specimens, and mechanical parameters were extracted from concrete of different periods. The extracted mechanical parameters were applied to PFC2D to establish a discrete element numerical model, and the numerical calculations were close to the results of indoor tests. By combining the test with numerical calculation, the shear strength changes and failure behavior of new and old concrete with different numbers of serrated locking under different vertical stresses were analyzed, and the following conclusions were obtained:

(1) Different numbers of serrated locking specimens showed different forms of crack propagation under different vertical pressures, and the number of serrated locking had an impact on the failure mode of the shear failure zone.

(2) The number of different serrated locking segments affected the shear strength, cohesion, and internal friction angle of new and old concrete composites. Under the same vertical pressure, with the increase in the number of locking segments on the bonding surface, the shear strength increased, and the increase rate decreased. The shear stiffness was almost unchanged. The cohesion of the bonding surface c increased with the number of locking segments; the internal friction angle φ decreased with the number of locking segments, and the change in cohesion was the main reason for the difference in shear strength.

(3) With the same number of grooves locking segments, the shear strength of the new and old concrete superposition increases linearly with the increase of vertical pressure, and the fitting degree is over 97%. The increase in vertical pressure will weaken the influence of the number of sawtooth locking on the shear performance of the specimen.

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