

Experimental Study on Shear Mechanical Properties of Water-Soluble Polyurethane Concrete

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Abstract. The water-soluble polyurethane is widely used in repairing, waterproof and other subway and building engineering fields. But there is little information about the shear mechanical properties of water-soluble polyurethane in concrete. The new type of water-soluble polyurethane as an adhesive material, the shear mechanical properties of concrete under the composite action of pressure and shear are studied in this paper. A diagram of the relation between shear stress and horizontal displacement is drawn. And the relationship between the maximum static friction and the dynamic friction and the relationship between the shear stress and the vertical stress are obtained. It provides a scientific basis for the application of new high performance water-soluble polyurethane in a large range of engineering.

1. Introduction

The construction of the subway is entering a period of unprecedented superiority [1]. The problem of waterproofing is an important task in the construction of the subway [2]. The waterproofing task runs through the construction and operation of the whole subway construction, and it is related to the fate of the construction project [3]. Therefore, it is of great significance to choose a reasonable waterproof material. The waterproof mainly involves the waterproof and bonding of the concrete interface, and the adhesion of the interface has a direct effect on the waterproof effect. Usually, the concrete bonding interface will occur cracks or excessive deformation after working for some time [4-6]. And spalling will occur in the repair and strengthening of concrete structure [7]. These phenomena cause the function and security of the whole structure to be damaged again [8-9]. Therefore, the selection of suitable concrete interface treatment material has always been a concern of the engineering community. Water soluble polyurethane is a kind of adhesive and water stop material for wet base. It can be used as a repair material, waterproof material, or as an interface treatment agent for the deformation joint of a building. So it can be widely applied to subway engineering [10].

Water-soluble polyurethane material is a new type of single composite polymer grouting material [11]. One of its prominent features is that it can react with water and solidify under any condition. So the slurry will not be diluted with water. Another feature is that the consolidation body has a variety of forms due to its different composition. It can be a hard plastic body, and it can also be a good stretch of rubber. In addition, most of the chemical serous consolidation bodies have poor elastic toughness and low reaction activity at low temperature, which are limited to the stable cracks in the grouting. The polyurethane chemical pulp is very active, and the consolidation body has good elasticity and strength. It is an ideal material to solve this kind of engineering problem.



The bond surface of concrete is a weak surface which will affect the resistance performance of the whole structure. Therefore, it is necessary to study the mechanical properties of bond. The shear performance of the concrete bonding surface is the most important factor affecting the stability of the concrete structure. In this paper, the mechanical properties of the concrete bonded surface under the compacted shear stress state are tested, in order to provide a theoretical basis and scientific basis for the further effective use of high performance water-soluble polyurethane to solve the waterproofing problems of subway and other projects.

2. Experiment

2.1. Experimental materials

Portland cement (PO32.5R) known as Qinling brand produced in Shaan'xi province was used in this study. The indicators were in agreement with the Chinese national standard of GB50010-2010. Sand was medium-sized in the Xi'an Bahe River. The fineness modulus was $\mu_f=2.7$. The graded aggregate with a nominal particle size of 5 mm~20 mm was used. Water-soluble polyurethane prepolymer is provided by Shaanxi gold stone concrete technology development Co., Ltd. And all the indexes meet the standard requirements JC/T864-2000. The main component of the curing agent is the polyether that can react with -NCO or the inorganic compound with crystalline water, and the curing agent Mocha (MOCA), to ensure that the polyurethane has very high mechanical strength and ensure enough time in the construction.

2.2. Experimental schemes

In this experiment, there were 5 groups of concrete specimens. And there are 3 concrete specimens in each group. The mixture ratio of specimens is given in Table 1.

Table 1. The proportioning of concrete (kg/m^3)

Type	Cement	Sand	Aggregate	Water	W/C	Sand rate	Slump/cm
Ordinary concrete	300	548	1371	180	0.5	40%	5mm

The shape and size of the concrete specimens in the shear test are shown in Figures 1~2 and the installation of the equipment are shown in Figure 3.

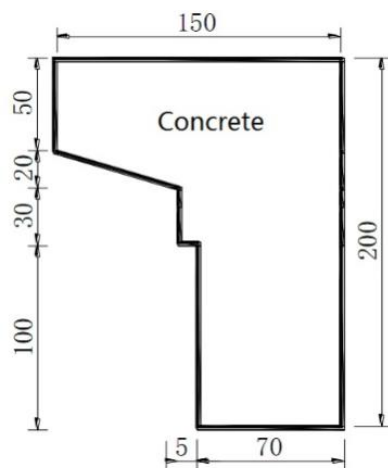


Figure 1. Specimen size



Figure 2. Specimen smeared with polyurethane

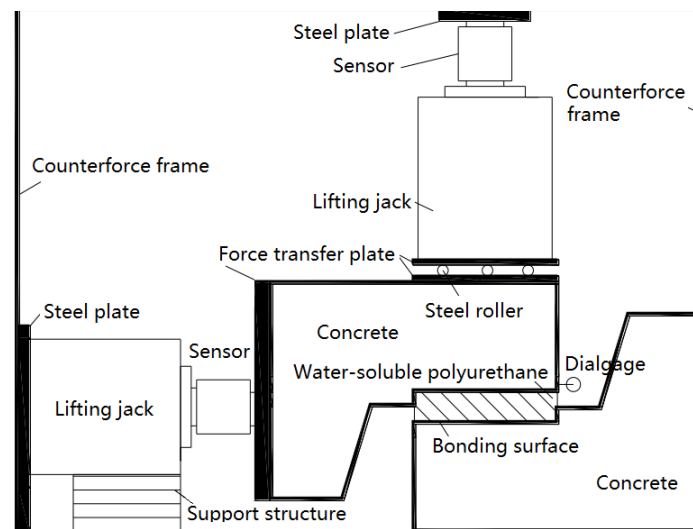


Figure 3. Shear test equipment

The specimens were with the standard curing. And specimens were demolded after 3 day. Then they were placed in the shade. There was no water in the surface of specimen. Make sure that the surface is dry.

The treatment of polyurethane joint could be done as follows: the two components are mixed proportionately and fully stirred. The polyurethane embedded in the seams should be sealed without breakage or hole. The concrete surface should be flat with a scraper after being caulked. Then put the specimen in the cool room for 14 days.

2.3. Experimental equipment

- (1) Hydraulic jack: it is used to apply vertical action and horizontal shear force.
- (2) BZ2206 static resistance strain instrument: it is used to measure the stress and strain under load.
- (3) Auxiliary equipment: tension sensor, steel plate, steel roller, counter force frame, dial gauge etc.

3. Results and discussion

During the shear test, the destruction of the polyurethane which was bonded between concrete and concrete was not sudden. When the polyurethane reaches the yield strength, the horizontal displacement increased rapidly, but the growth of the horizontal thrust was slowly. After moving a section of displacement, the thrust was stable with the increase of displacement. At this time, the numerical value of the horizontal thrust was reduced to the corresponding rolling friction resistance that was, the actual shear resistance of the polyurethane bonded concrete was obtained. The average results of the three specimens were summarized as shown in Table 2.

Table 2. The summary of test data

vertical stress (MPa)	proportional limit state		yield limit state		failure limit state		maximum displacement (mm)	residual deformation (mm)	rolling friction (mm)	maximum static friction (KN)
	shear stress (MPa)	Displacement (mm)	shear stress (MPa)	displacement (mm)	shear stress (MPa)	displacement (mm)				
0.095	1.94	0.079	4.97	0.112	6.210	0.126	7.313	3.477	0.183	0.212
0.116	2.75	0.086	5.79	0.132	7.067	0.145	10.563	5.097	0.223	0.246
0.137	3.29	0.092	5.80	0.142	7.343	0.154	9.083	4.290	0.284	0.285
0.158	3.60	0.104	6.63	0.145	8.287	0.161	11.080	5.113	0.340	0.344
0.185	3.92	0.117	7.49	0.178	9.240	0.194	10.120	5.903	0.420	0.455

In this paper, the relations between shear stress and horizontal displacement under different vertical pressure were given in Figure4~8.

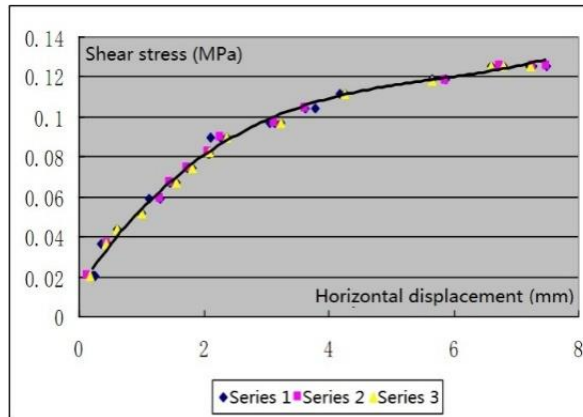


Figure 4.Vertical force $N=1.424\text{KN}$

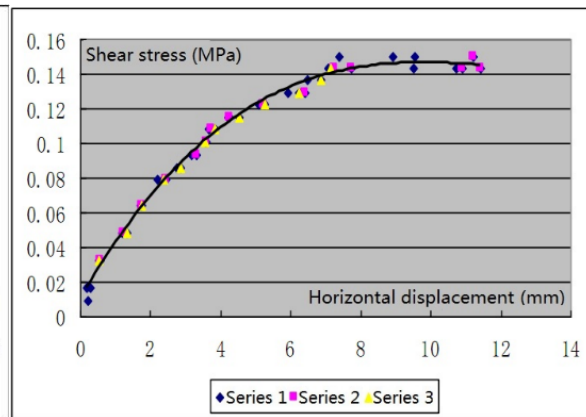


Figure 5. Vertical force $N=1.734\text{KN}$

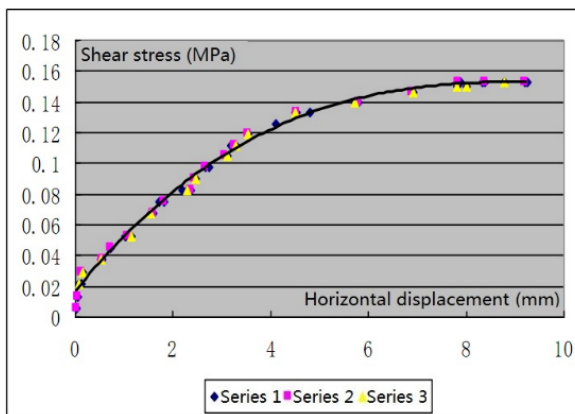


Figure 6.Vertical force $N=2.05\text{KN}$

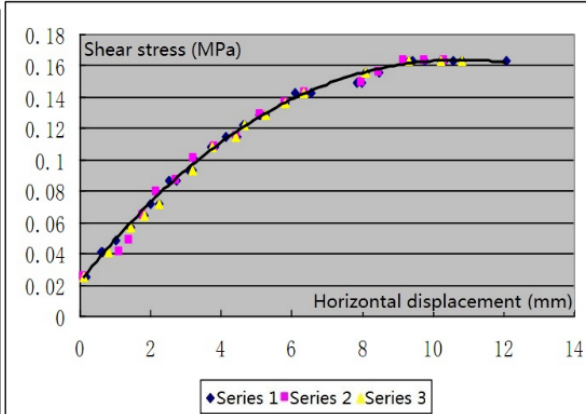


Figure 7.Vertical force $N=2.37\text{KN}$

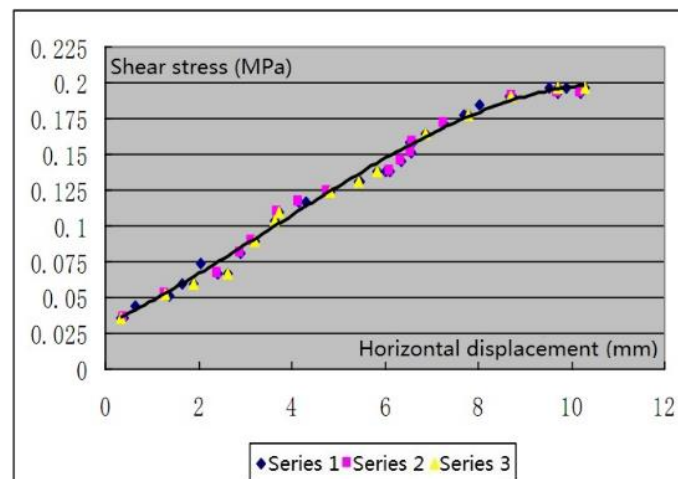


Figure 8.Vertical force $N=2.771\text{KN}$

3.1. The relationship between the maximum static friction Q and the vertical force N

From the relation curve of shear stress and horizontal displacement, we could see that the shear deformation had an initial rigid segment under the vertical pressure of different sizes. That was, the bond face was subjected to a certain shear stress. The bond surface began to shear deformation after

overcoming the static friction force. The frictional force at this time was the maximum static friction force. The test results were calculated by the least square method, and the relationship between the maximum static friction force and the vertical pressure was obtained as follows:

$$Q = 0.1452N.$$

The diagram was shown in Figure 9.

3.2. The relationship between shear stress τ_f and vertical stress σ

According to the test, the shear stress, the maximum displacement and the rebound deformation value of each specimen are obtained. And the relation curve between τ_f and σ was given in Figure 10. Considering the discreteness of the values of the 15 concrete specimens, the experimental data were calculated by least squares regression analysis, and the relationship between shear stress and vertical stress is obtained as follows:

$$\tau_f = 0.6891\sigma + 0.0608.$$

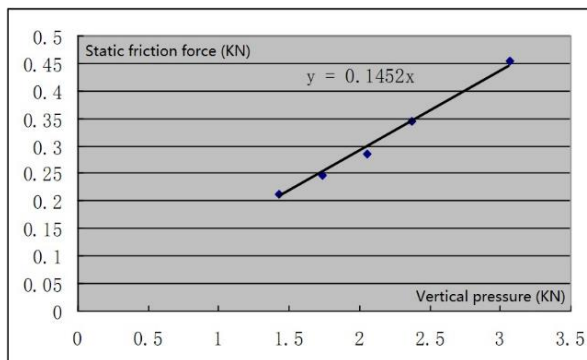


Figure 9. The relations of $Q \sim N$

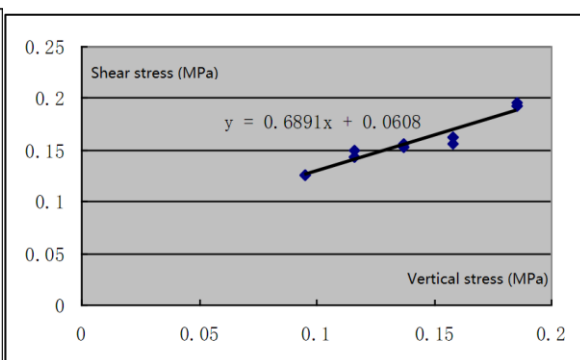


Figure 10. The relations of $\sigma \sim \tau_f$

3.3. The relationship between shear stress τ_f and horizontal displacement Δu

Figure 4- figure 8 showed that the force process of polyurethane under different vertical forces could be divided into three stages: elastic stage, transition stage and plastic slip stage.

a. elastic stage: When the roughness reached a certain degree, the shear deformation had an initial rigid segment. The static friction must be overcome first and then the shear deformation of bond surface occurred. At the beginning, the curve was elastic, and the stress increased fast, but the total deformation was very small. When the value reached 59% ~ 66% of the failure shear stress, the polyurethane reached the limit state of proportion and entered the next stage.

b. transition stage: This stage was from the elastic deformation zone to the plastic sliding zone. With the acceleration of the deformation and the decrease of the slope of the curve, the velocity of deformation was quicker and the slope of the curve was reduced in this stage. When the value reached 89% ~ 93% of the failure shear stress, the polyurethane reached the yield limit state.

c. plastic slip stage: After the stress of polyurethane was yield, the slip amount increased rapidly. When the peak stress was reached, the slip amount of the bond surface increased continuously under the condition that the stress was basically unchanged. The specimen was eventually destroyed. The shear stress of the damaged state of the specimen was obtained. The curve can be attributed to the approximate vertical and horizontal shear horizontal displacement. It was shown in Figure 11. The relationship curve between shear stress τ_f and horizontal deformation Δu belonged to plastic failure type. The line segment OA was linearity range. The line segment AB was quadratic curve. Point c corresponded to the peak value of τ_f . The point A was called the ratio limit, point b was called the yield limit, and point c was called the failure limit, which all were constant value.

Seen from Figure 11, the value of τ_f increased significantly when Δu was small. After the curve passed the B point, the value of τ_f raised slowly with the increase of shear deformation. At this time,

this relationship reflects the good bonding between water-soluble polyurethane and concrete. When the damage limit was reached, the peak value kept constant with the increase of the displacement.

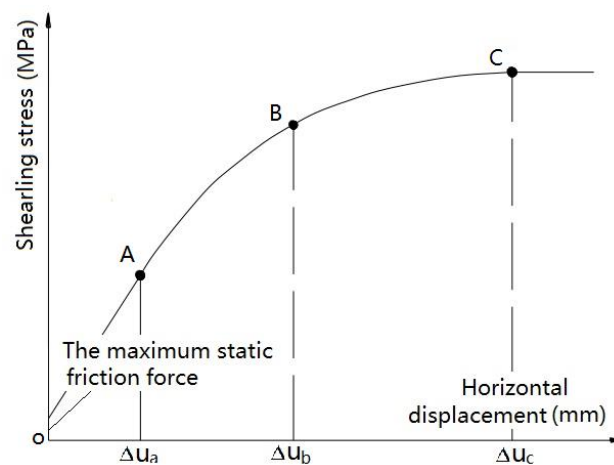


Figure 11. Relationship between shear stress and horizontal deformation

4. Conclusions

(1) The research shows that the water-soluble polyurethane material has a stable performance under normal temperature conditions and has a strong adhesive property, which is easy to be popularized and used in waterproof engineering and structural maintenance and transformation.

(2) Under different vertical pressure, the relationship curve between shear stress and horizontal displacement shows that the shear deformation has an initial period of rigidity. After that, when the certain size of shear stress on the bonding surface overcomes the static friction and the concrete was forced to shear deformation, that is the maximum static friction force. And maximum static friction is bigger than rolling friction.

(3) The $\tau_f \sim \Delta u$ curve real reacts the bond characteristics of water-soluble polyurethane, which has the obvious peak and residual deformation; Also the $\tau_f \sim \sigma$ relationship in the deformation cracks of concrete water soluble polyurethane has been got, it provides reference for water soluble polyurethane to deal with cracks, expansion joints and settlement joints of various buildings and underground concrete works.

(4) When construction, the wet requirements on the concrete surface of the water-soluble polyurethane is much lower than oily polyurethane. As long as there is no water on the concrete base surface, the sufficient bonding strength can be achieved. So it can have the lower construction difficulty and the quality of the project is easy to be ensured.

5. Acknowledge

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