

# Energy Consumption Analysis of Particle Crushing on Structural Contact Surface under High Pressure Shear

Junkun Tan <sup>a</sup>, Jiaqi Guo

School of civil engineering, Henan Polytechnic University, Jiaozuo 454003, Henan, China

<sup>a</sup>tanjunkunde@126.com

**Abstract.** The experimental study on the energy relationship between the coarse sand with different water content and the concrete interface with different hardness and roughness is carried out, through the high stress direct shear apparatus. Experimental results show that the growth rate of shear energy dissipation of sand - structure contact surface is slowing down with the increase of roughness, even negative; The shear energy dissipation of concrete with different hardness decreases first and then increases with the increase of water content, The crushing energy consumption is the lowest when water content is 16%; The shear energy dissipation at different moisture content increases with the increase of the contact strength of concrete structure.

## 1. Introduction

The three law of thermodynamics is the empirical law put forward on the basis of experiments, and it mainly focuses on the concepts of heat, power, energy and other concepts. The energy balance of the three laws of thermodynamics can provide a solid foundation for scientific research and development, and in recent years, it has also been applied in the study of sand- concrete structure contact surface. Wang Wei [1] based on the principle of macroscopic thermodynamics, on the assumption of energy dissipation, established the governing differential equations of contact stress ~ strain relation from the microscopic point of view. Zhao Guangsi [2] studied the energy effect in particle crushing process by high pressure straight shear test, and the results show that particle crushing is linearly related to plastic work, and it is confirmed by the test. In this paper, the shear energy relationship between sand and the contact surface is further studied based on the direct shear test.

## 2. Test introduction

### 2.1. Test scheme

Under the condition of normal stress 4MPa, conducted 27 groups shear test of contact surface with different influence factors, arranging the moisture content of 8%, 16%, 24%, the concrete strength of C30, C40, C50, rough type prism height of 0mm, 2mm, 3mm. The classical particle crushing theory suggests that the crushing material is related to the input energy of particle crushing. In this section, an unified evaluation index shear energy dissipation is adopted, and study the influence to shear energy dissipation under different conditions. The formula is:



$$W = \int_0^S \tau ds \quad (1)$$

In the formula: the increase slows, and the augments has been small compared to the previous one when the contact shear stress between sand and concrete is at 10mm, so the shear displacement  $S$  takes 10mm.

The test used the coarse sand with the maximum dry density  $d_{max}=1.750\text{g/mm}^3$  and particle size less than 2mm, and its characteristic particle size and characteristic parameters are shown in table 1.

**Table 1** characteristic particle size and characteristic parameters of coarse sand

Soil property	d10	d30	d50	d60	Cc	Cu
Coarse sand	0.09	0.30	0.43	0.53	1.85	5.79

## 2.2. Test method

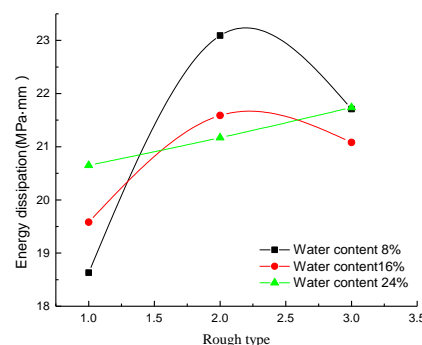
In order to study the effect of different water content and roughness interface on particle crushing under high stress straight shear condition, selected the coarse sand which meets the test requirements according to the requirements of document [3]. When used, first filtered out the sand with a particle size greater than 2mm and dried putting in the air, then putted it in the oven and baked for an hour at  $106^\circ\text{C}$ , then took 400g drying sand into test tray, added some water according to the test requirement, to prepare four sand samples with water content of 0%, 8%, 16% and 24%. Rough surfaces are fabricated according to document [4] using concrete with C20, C30, C40 strength. Each kind of concrete strength was used to design prismatic table which had 1mm, 2mm, 3mm three kinds of roughness.

Selecting straight shear apparatus with an output stress of up to 4MPa, in the test, set the normal stress 4MPa, and the shear rate of the shear test 1mm / min. When the shear stress-displacement curve appears platform or when the shear displacement is greater than 12mm, stop shearing, and collect interfacial shear stress, relative shear displacement and other test data to save. After shearing test, take the coarse sand near the contact surface of concrete structure, and the sand was dried and sieved, recorded the particle size weight data after sieving, to draw the gradation curve.

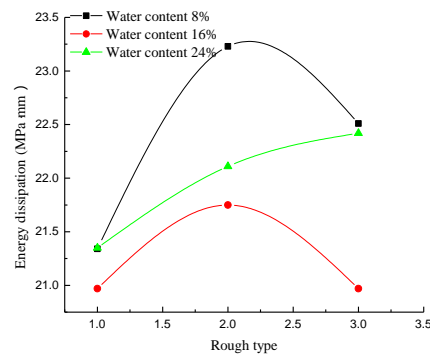
## 3. The influence factors relationship of shear energy dissipation on peak intensity of shear stress

### 3.1. The relationship between roughness and shear energy dissipation

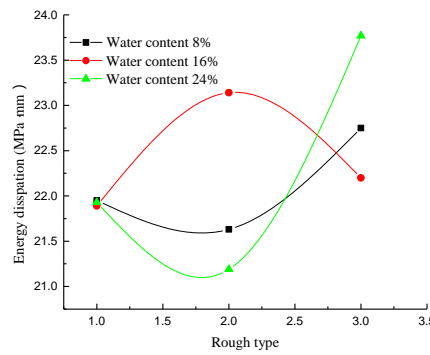
Collect the experimental data to draw experimental data curve using data processing software Origin , the drawing curve of roughness and shear energy dissipation is as follows:



**Fig. 1** Relationship between shear energy dissipation and different roughness types at various moisture content when concrete strength is C30



**Fig. 2** Relationship between shear energy dissipation and different roughness types at various moisture content when concrete strength is C40



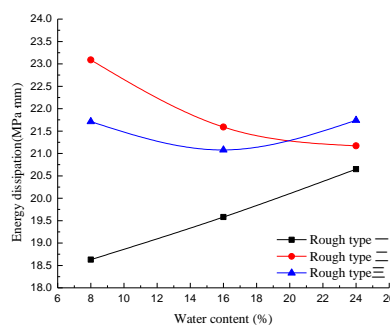
**Fig. 3** Relationship between shear energy dissipation and different roughness types at various moisture content when concrete strength is C50

From the analysis of Figure 1, 2, 3 shows:

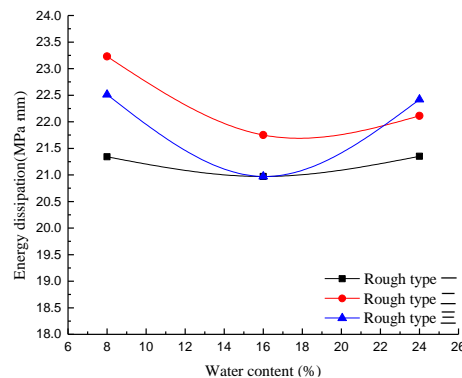
The shear energy dissipation of the sand-structure contact surface is as follows: With the increase of roughness, the decrease rate of shear energy dissipation becomes slower, even negative. When the sand- structure contact surface is sheared, the external energy is transformed into elastic energy storage and friction energy dissipation between particles, when the shear dilatancy occurs, it does external work and particle crushing energy consumption, and the frictional energy consumption and crushing energy consumption of the particles are much larger than those of other concentrated energy dissipation methods.

### 3.2. The relationship between water content and shear energy dissipation

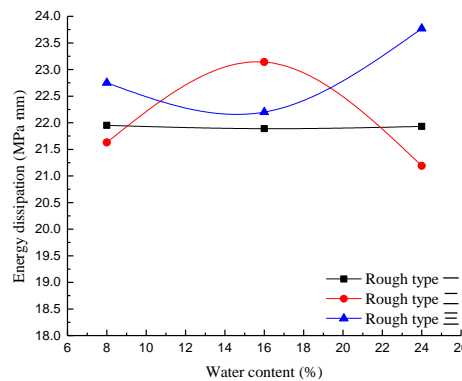
The relationship curve between water content and shear energy dissipation is as follows.



**Fig. 4** Relationship between shear energy dissipation and different moisture content of various roughness when concrete strength is C30



**Fig. 5** Relationship between shear energy dissipation and different moisture content of various roughness when concrete strength is C40



**Fig. 6** Relationship between shear energy dissipation and different moisture content of various roughness when concrete strength is C50

From the analysis of Figure 4, 5, 6 shows:

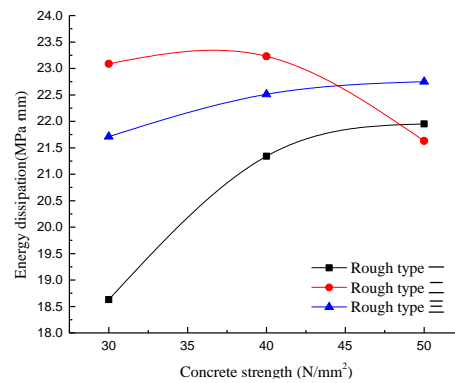
Under circumstance of normal stress being 4MPa, the curves of shear energy dissipation and water content corresponding to different hardness concrete are shown as follows: The curve decreases at first and then increases, which shows that the increase of shear energy dissipation decreases first and then increases, and the crushing energy dissipation is lowest at the moisture content of 16%. This is because the water content has played a certain role in lubrication in the sand - concrete structure of the contact surface on the interval of 8% to 16%, when the particles are sheared, the frictional resistance decreases, and the shear energy dissipation decreases.

### 3.3. The relationship between concrete strength and shear energy dissipation

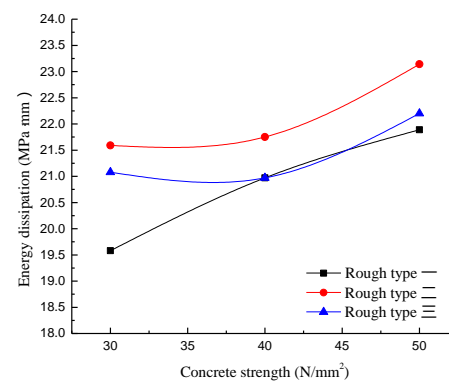
The relationship curve between concrete strength and shear energy dissipation as shown in the following figure:

From the analysis of Figure 7, 8, 9 shows:

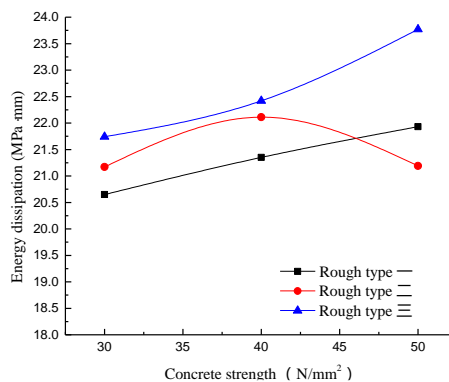
Under the action of high normal stress 4MPa, the shear energy dissipation of the three groups with different water content increases with the increase of the contact strength of the concrete structure, and the shear energy dissipation is the minimum when the concrete strength is C30, the shear energy dissipation is larger when the concrete strength is C40, and the shear energy dissipation is the maximum when the concrete strength is C40.



**Fig. 7** Relationship between shear energy dissipation and different concrete strength of various roughness when water content is 8%



**Fig. 8** Relationship between shear energy dissipation and different concrete strength of various roughness when water content is 16%



**Fig. 9** Relationship between shear energy dissipation and different concrete strength of various roughness when water content is 24%

#### 4. Summary

(1) Under circumstance of normal stress being 4MPa, the decrease rate of the shear energy dissipation of the sand-structure contact surface becomes slower with the increase of roughness, even negative. When the roughness between the rough type one and the rough type two increases, particle crushing energy consumption increased significantly, while the energy dissipation increase velocity decreases when the roughness between the rough type two and rough type three.

(2) The shear energy dissipation of concrete with different hardness decreases first and then increases with the increase of water content and the crushing energy dissipation is lowest at the moisture content of 16%.

(3) The shear energy dissipation of different water content increases with the increase of the contact strength of the concrete structure.

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