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# The Research on Characterization of Crushability for Foundry Sand Particles

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## Abstract

In this paper, crushability of foundry sand particles was studied. Three kinds of in-service silica sands in foundry enterprises selected as the study object, and foundry sand particles were subjected to mechanical load and thermal load during service were analyzed. A set of methods for simulating mechanical load and thermal load by milling and thermal-cold cycling were designed and researched, which were used to characterize the crushability for silica sand particles, the microstructure was observed by SEM. According to the user's experience in actual application, the crushability of Sand C was the best and then Sand B, the last Sand A. The results indicated that mechanical load, thermal load and thermal-mechanical load can all be used to characterize the crushability of foundry sand particles. Microscopic appearances can qualitatively characterize the crushability of foundry sand particles to a certain extent, combining with the additions and cracks which are observed on the surface.

**Keywords**: Foundry sand particles; Load; AFS grain fineness; Crushability

## 1. Introduction

Brittle material refers to a material that cannot exhibit visible plastic deformation cracked. Common brittle material includes ceramic, concrete, glass, stone, cast iron, masonry and gangue concrete. Crushing refers to the process that a bulk material which is crushed into small pieces or powders by exerting a mechanical external force to overcome intermolecular cohesion forces, and it depends on its mechanical property, including brittleness and strength.[1,2] In some certain fields, they may prefer more obvious crushing effect, while some prefer less. Foundry silica sand particles indicate a tendency to be crushed during the service[3,4]. Thus in order to characterize the crushability, ensure the particles are within the stated size range, it has important significance for relevant researches to provide the foundation for reasonable exploitation and utilization of molding sands.

Kjaemsli, Hall et al.[5] extended that particles that has irregularly-shaped, roughened surface may be more easily broken down into smaller particles under certain sustained stress. Lee et al.[6] revealed that a certain content ratios of before and after particle diameter can characterize crushability by extensive isotropic loading and proportional tension-torsion loading tests.. Liu Chongquan et al.[7] proposed WB expression between particles crushing of calcareous sand and shear dilating coupled role. Meanwhile, he established the evaluation indicator (Br) of particles crushability and energy formula. Xu Yongfu et al.[8] raised that particles crushability can be described by fractal theory. At the same time, fractal dimensions can calculate crushing probability. Taking a wide view of the domestic and foreign related researches, some innovative methods of characterization were proposed, though complex, laborious and time consuming in practice. In addition, results in the past have been not systematic and the focus of these researches were concentrated on calcareous sand, gangue, concrete and rockfill, there were seldom researches on the crushability of silica sand.

Based on the foundry sand service process, in connection with mechanical load, thermal load and thermal-mechanical load, characterization of crushability for silica sand particles was studied. And creative thinking that crushability of sand was characterized by AFS grain fineness was put forward. This work was important for molding and recovering used sand in the practice casting manufacturing process.

# 2. Characterization methods design and experiments

## 2.1. Foundry sand service condition analysis and characterization methods design

Representative test samples, three kinds of silica sands, were selected from foundry factories, and they were identified by Sand A, Sand B and Sand C respectively. Each of three kinds of samples was in-service foundry silica sand. Based on the user's experience in actual application, the crushability of Sand C was the best and then Sand B, the last Sand A.

The molding sand service process as shown in Fig. 1, the foundry sand must be mulled to prepare molding sand. Common types of mixers include roller mixer, paddle mixer and vibrating mixer, etc., which will result in mechanical load acted on sand particles. The temperature of the sand mold will be rapidly raised to several hundred degrees or even over one thousand degrees during the casting process, thus, thermal load repeatedly being applied to sand particles. Except the above-described service process, within the used sand reclamation thermal load or mechanical load is generated by hot-reclaimed or vibration type reclamation technology.

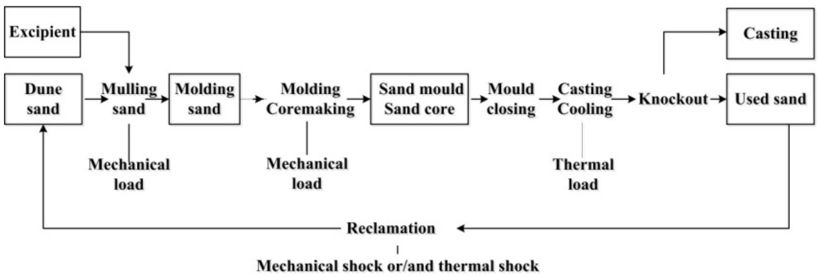



Fig. 1. The foundry sand service process

## 2.2. Characterization methods design

### 2.2.1. Simulation experiments of crushing for foundry sand particles service process

In order to simulate the crushing for particles in the actual production process, the following experiments were conducted in the laboratory. A planetary ball mill was used to simulate the mechanical load during the mulling sand and Vibration-reclaimed used sand. Thermal-cold cycling experiments were conducted in a box type resistance furnace, which simulated the thermal load repeatedly being applied to sand particles within the casting and hot-reclaimed used sand.

Chongqing Sand A, Chongqing Sand B, Sicuan Sand were selected as representative silica sands from enterprises, identified by Sand A, Sand B and Sand C respectively. Microscopic appearances were observed firstly. Then, every sample was individually tested by mechanical load, thermal load and thermal-mechanical load.

Mechanical load: Sand A, B and C were weighed 50g in respective, then it was screened and weighed. The sample was collected and weighed soon afterwards. Finally, Based on the process parameters of milling sand in foundry enterprise, it was milled for 40 minutes in the planetary ball mill, the reason why we chose 40 minutes was that after repeated experiments, 10 minutes of milling time were too short, we found that the particles sizes differences of sands selected from different areas were insignificant before and after the 10 minutes of milling, so it was not suitable to distinguish the difference of the sand particles crushability. During the mulling sand process, sand particles were usually crushed relatively mild and slow, 40 minutes of milling was a strengthening experimental of crushing, which could cause that sand particles were greatly crushed within a short time, so 40 minutes of milling was a relatively suitable time to characterize the difference of crushability, and then screened and weighed again.

Thermal load: Repeating the above weighing and Screening process. Thereafter, heati with a box type resistance furnace at 650°C for 1 hour. After that, cooled to room temperature in the air and replaced into the furnace again. The test was set up with 10 replications, and the recovered specimen was Screened and weighed again.

Thermal-mechanical load: Repeating the above weighing and Screening process. The thermal load mentioned above was repeated 10 times. Finally, the specimen was milled for 40 minutes in a planetary ball mill, and then screened and weighed again.

### 2.2.2. Microscopic appearances

Microscopic appearances of three kinds of sands particles were observed by using FE-SEM, and the differences were analyzed to obtain the relationship between the microscopic appearance and crushability. And a method using the microscopic appearance to characterize the crushability was put forward.

### 2.2.3. The evaluation method of variations for the particles sizes

A series of simulation experiments combined with practical engineering were designed. The crushing effect of particles corresponded to the variation of grain size. The larger the variation of grain size became, the better the crushing effect was obtained. In order to evaluate the variation of grain size before and after load, AFS(American Foundry Society) grain fineness was put forward, the variation of AFS grain fineness, that is, the variation of grain size.

Recovering specimen particles were put into the electromagnetic jolt sand screener to screen after different loads. Based on the correspondence between AFS grain fineness and mesh numbers of the screener, the mass of sand on every mesh number can be converted to the AFS grain fineness. Formulae for calculating as follows:

$$\text{AFS grain fineness} = \frac{x}{\sum x_i} \times \lambda \times 100\% \qquad (1)$$

Where x corresponds to the mass of sands on every mesh number, Σ xi is the total sum of mass on all meshes , λ is the corresponding coefficient shown in Table 1.

Table 1.
The corresponding relation between the AFS grain fineness coefficient and mesh number

| Mesh number | 20 | 30 | 40 | 50 | 70 | 100 | 140 | 200 | Chassis |
|---|---|---|---|---|---|---|---|---|---|
| $\lambda$ | 10 | 20 | 30 | 40 | 50 | 70 | 100 | 140 | 300 |

# 3. Results and analysis

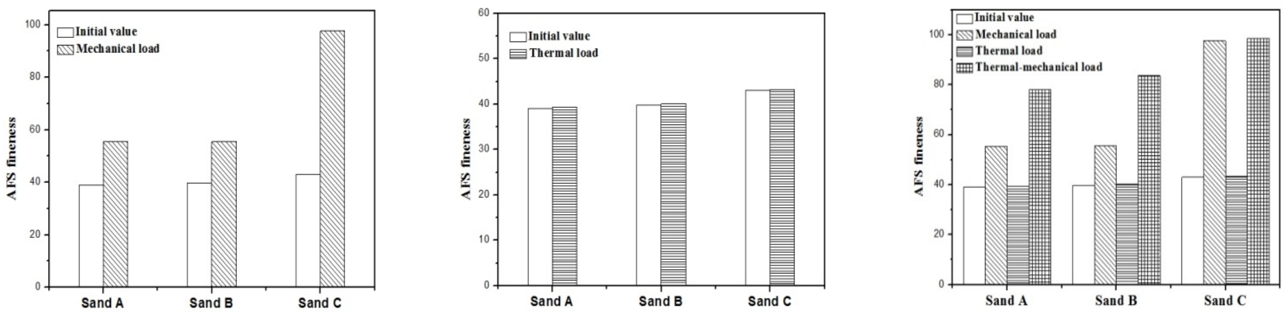
## 3.1. Characterize crushability

Fig. 2 shows the crushability of three kinds of sands particles under different load tests. It can seen from Fig.2 (a) that the AFS grain fineness change rate of Sand A is very near to Sand B, so the crushability of Sand A and Sand B are very close to each other during mechanical load. But Sand C has a lager variation of the AFS grain fineness relative to Sand A and Sand B, so Sand A and Sand B exhibit superior crushing resistance to that of the comparative Sand C. Fig. 2 (b) shows the variation of AFS grain fineness after being submitted to the thermal load test. Clearly, Subtly variations can be observed. Therefore, three kinds of samples are barely crushed under thermal load. In other words, Sand A, Sand B, Sand C have excellent performance for crushing resistance during the casting and hot-reclaimed used sand.

Foundry used sand usually will be recovered and utilized by vibration-reclaimed or hot-reclaimed technology, sometimes two methods may be combined. Thus, thermal-mechanical load may be applied to the sand particles in the actual application. Fig. 2 (c) presents the variation of AFS grain fineness during thermal-mechanical load test. The AFS grain fineness change rates of three kinds of sands were significantly increased compared to the single load test, especially for the single thermal load, but in contrast with the single mechanical load, the AFS grain fineness change rate of Sand C has little change. In other word, Sand A and Sand B crushing resistance for mechanical load becomes worse after being submitted to the thermal load. Consequently, under thermal-mechanical load the relationship between the crushability of three kinds of sands is: Sand C > Sand B > Sand A.

Table 2.
AFS grain fineness, AFS grain fineness change rate for different loads

| Sample | Initial AFS grain fineness | AFS grain fineness/ change rate after mechanical load | AFS grain fineness/ change rate after thermal load | AFS grain fineness/ change rate after thermal-mechanical load |
|---|---|---|---|---|
| Sand A | 39.0 | 55.4/42.1% | 39.4/1.0% | 78.1/100.3% |
| Sand B | 39.8 | 55.5/39.4% | 40.1/0.8% | 83.6/110.1% |
| Sand C | 43 | 97.6/127.0% | 43.3/0.7% | 98.6/129.3% |




(a) (b) (c)
Fig. 2.The variations of AFS fineness under different loads ((a) mechanical (b) thermal (c) thermal-mechanical)

### 3.2. Microscopic appearances

As shown in Fig. 3, it can be found that Sand A has higher roundness, and a very small amount of dents and minimal fine additions intersperse on the surface. Sand B exhibits no regular shape and a certain roughness, not only some few cracks and a small amount of additions but also projections and depressions appear on the surface. The shape of Sand C is varied irregularly, many sharp corners additions and cracks are observed, and the larger of the particle size is, the more cracks form on the surface. According to Griffith crack theory, due to micro-cracks or defects presented in solid, a highly concentration of stress will generate at the tip of this crack, which will further lead to brittle fracture. Thus, additions and cracks can result in an easier brittle fracture. It can be qualitatively found that the order of crushability is: Sand C > San B > Sand A. Simultaneously, the result conforms with the user's practical experience. Sand C was easier to be crushed, and it was usually eliminated after just one or two cycle use in the actual foundry process.

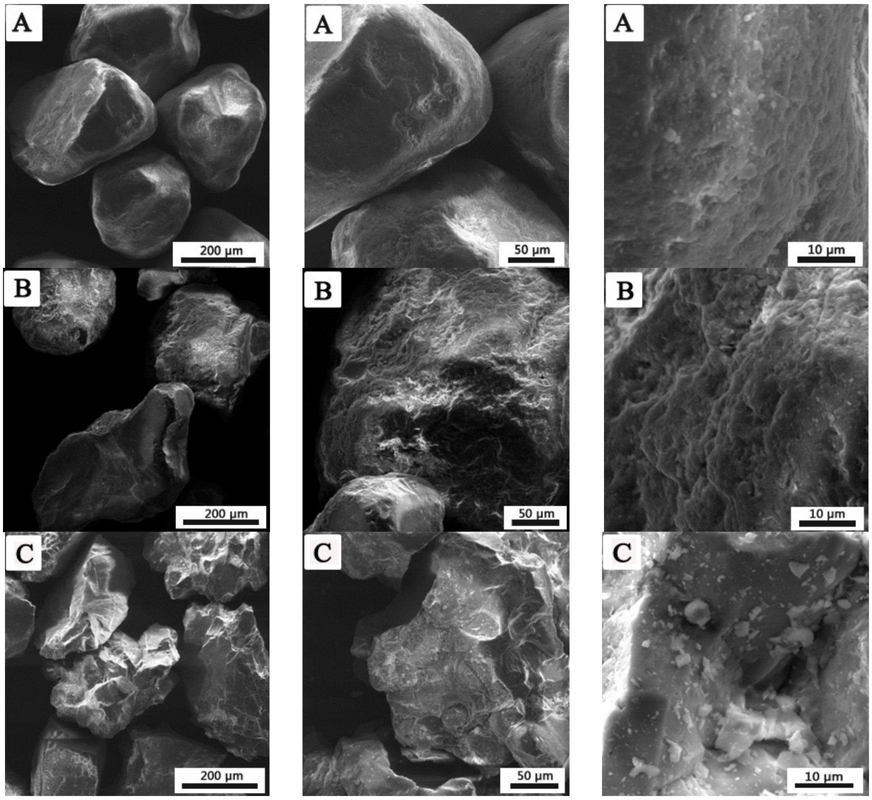


Fig. 3. The SEM images of three kinds of silica sands particles

## 4. Conclusions

Different variations of the particles sizes can be characterized by AFS fineness. Significant variations of the particles sizes can be observed after mechanical load. Subtly variations can be observed after thermal load. Furthermore, undergoing the thermal-mechanical load the variations of the particles sizes were more obvious than that of single load, especially for thermal load. There was a large difference in the variations of the particles sizes between different kinds of particles after the loads described above. Accordingly, mechanical load, thermal load and thermal-mechanical load can be used to characterize crushability, which were especially suitable the comparison of crushability about two or more kinds of particles.

The more additions and cracks from the microscopic appearance of particles were observed, the worse crushability becomes. There was certain relation of correspondence between the additions, the morphology and the number of cracks, the results of different loads and the user's experience, thus, microscopic appearance can qualitatively characterize the crushability to some extent.

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