Load and wear experiments on the impact hammer of a vertical shaft impact crusher

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Abstract. Impact hammers are important components of impact crushers, and are often short-lived due to the high-impact nature of their use. Wear-resistant alloys are welded to the surface of impact hammers to prolong their service life. In this paper, a simulation model of the rotor and impact hammers in impact crushers was designed to utilize the Discrete Element Method (DEM). The wear-resistant alloy on each impact hammer was divided into twenty-two action regions. The load distribution on each alloy block is affected by the structural and manufacturing parameters of the impact crusher. The wear distribution of the impact hammer was measured by shape morphology according to relative impact crushers. The results demonstrated that the real measurements of wear distribution on the impact hammer were similar to simulated load distribution measurements on the same surface. The study of load distribution of impact hammers by DEM established a theoretical foundation on which to base the optimal design of impact crushers.

1. Introduction
With the rapid development of infrastructure and real estate in China, the demand for concrete is increasing quickly, of which sand is a necessary component, and a limited natural resource. It is inevitable that artificial sand will eventually replace natural sand to a large extent in the future of concrete manufacturing. Rock breakage is the key technology in artificial sand manufacturing systems, widely achieved by use of vertical shaft impact crushers (VSI) [1, 2], which consist of a rotor, crushing chamber, and center distributor plate. High silicon dioxide content in the raw materials used to create artificial sand leads to high hardness of the material, and the rocks must be accelerated to a high speed in order to be broken into artificial sand materials. High hardness and high speed are the two most important aspects that affect the contact parts of VSI, and which result in the fast and significant wear and tear of VSI parts. The highly priced wear-resistant parts must be changed frequently because of excessive wear and tear caused by strong impact [3, 4], which decreases the efficiency of sand production and machine reliability, and increases production costs. It is necessary to study the internal relationships between the wear of VSI and related parameters to improve the performance and efficiency of VSI [5].

A vertical shaft impact crusher has two operating modes: rock-to-steel and rock-to-rock. Rocks are accelerated by a quickly rotating rotor. They are then broken into pieces in the crushing chamber [6]. In order to improve the crushing effect, many manufacturers equip the rotor with impact
hammers at the edges of rotor outlets, which are usually covered with carbon tungsten alloy blocks to extend their service life [7]. This study primarily investigates the impact load of a unit area on carbon tungsten alloy blocks by the Discrete Element Method (DEM). The internal relationship among rotor structure, manufacturing parameters and impact load is studied by simulation. Optimized manufacturing parameters and VSI structure are obtained by simulation so as to extend the service life of the impact hammer. Comparison between simulation results and practical measurements are in agreement, demonstrating that DEM is an efficient method to decrease the production costs and development cycle of artificial sand manufacturing.

2. Crusher simulations

2.1. Establishment of 3D rotor model

The VSI rotor primarily consists of a trail plate, impact hammer and center distributor plate. Impact hammers withstand strong impact loads, which leads to severe wear and tear. Therefore, this paper analyzes the wear and load distribution of the impact hammer. The VIS rotor used in this study has five channels, and the 3D solid model of the rotor is shown in figure 1(a). There are 22 colored sections made of carbon tungsten alloy at the edges of the channels, on the surface of the impact hammer. Each colored section is a carbon tungsten alloy block; each carbon tungsten alloy block represents an action unit. The 3D solid modeling IGS data (i.e. STEP data) was imported into the Discrete Element Modeling (DEM) software. Figure 1(b) displays the rotor model as it appears in the DEM analysis software. The shape of the particle used in the DEM model was spherical, which can reduce simulation time. The rotor in figure 1(a) was simplified in the DEM simulation model shown in figure 1(b). A particle factory was established in the DEM simulation model.

2.2. Simulation parameters for DEM simulations

Before simulation, parameters must be set in the DEM software. Some model parameters were obtained from design manuals and previous literature [8-11]. The rotor material was set as steel, Poisson’s ratio = 0.28, shear modulus = 7.5e+7 Pa, and rotor density = 7800 kg/m³. The crushed material was set to granite. The material properties of the crushed particles were set as follows: Poisson’s ratio = 0.25, shear modulus = 1.4e+7 Pa and density = 2800 kg/m³. The particle-particle coefficient of restitution was set to 0.45, and particle-geometry coefficient of restitution was set to 0.5. The particle-particle sliding friction coefficient was set to 0.545, and particle-geometry sliding friction coefficient was set to 0.5. The particle-particle rolling coefficient and the particle-geometry rolling friction coefficients were set to 0.3. According to the particle size distribution of the practical rocks, the distribution of particle size in the simulation was set to normal distribution. A cylinder factory coaxial to the rotor was created to simulate the feed hopper, and the initial velocity of the particles was set to zero.

3. Simulation experiments of load on impact hammer
An impact hammer consists of 22 carbon tungsten alloy blocks, which are welded to the steel surface by specialty technology. A simulation test was created to determine the maximum impact load area among the 22 carbon tungsten alloy blocks. This was accomplished by analyzing the influences of various practical manufacturing and structural parameters on the impact load of each block.

3.1. Determination of the active zone
In order to determine the greatest wear area, the 22 carbon tungsten alloy blocks were labeled by number, as shown in figure 2. The rotating speed of the rotor was set to 1550 r/min, the particle feeding rate was set to 7.5 kg/s and the particle size range was set to 0-13 mm with normal distribution. After the simulation test, the number of collisions between particles and carbon tungsten alloy blocks were counted. Comparing the collision numbers of the 22 blocks, the block with the greatest number of collisions was chosen as the load analysis object to investigate by a series of simulation tests with varying parameters. Table 1 displays the numbers of collisions on each of the 22 blocks; blocks 5, 6, and 7 experienced more collisions than others, which is consistent with the actual processing results.

![Figure 2. Action regions on impact hammer.](image)

Table 1. Simulated number of particle collisions on action regions of impact hammer.

| Region Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|
| Collisions number | 25 | 284 | 711 | 933 | 1022 | 1013 | 1017 | 984 | 363 | 53 | 8 |
| Region Number | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| Collisions number | 5 | 37 | 65 | 67 | 51 | 56 | 78 | 86 | 64 | 15 | 1 |

3.2. Relationship between manufacturing parameters and load on the impact hammer
A series of simulation tests was conducted on the 22 blocks. Rotor speed, particle size distribution, and feeding rate were manipulated to investigate the relationship between manufacturing parameters and the total force on each carbon tungsten alloy block. The simulation results are shown in figures 3-5. As was illustrated by Table 1, the impact loads on blocks 1-11 were stronger than on blocks 12-22. Therefore, analytical results primarily investigated the influences of different parameters on blocks 1-11. First, simulation tests were conducted with three different rotating speeds: 1440, 1550, and 1700 r/min. The feeding rate was set to 7.5 kg/s, and particle size ranged from 0-13 mm with a normal distribution. After the simulation, the total forces exerted on the first 11 blocks were separately imported to DEM software. Figure 3 illustrates the relationship between rotating speed and total force on each carbon tungsten alloy block. As shown in figure 3, total force increases with increasing rotor speed. Additionally, the total force on blocks 5, 6, 7, and 8 are far larger than exerted on other blocks, indicating that more significant wear and tear would occur on these blocks.

Next, simulation tests were conducted with three different feeding rates: 6.5, 7.5, and 8.5 kg/s. The rotor speed was set to 1550 r/min, and particle size was set to the same value as in the previous three tests. Figure 4 shows the relationships between different feeding rates and the total force exerted on each of the 11 blocks. Figure 4 demonstrates that total force exhibits no obvious increase with increasing feeding rate, and different feeding rates result in different maximum impacts on load blocks. Finally, simulation tests were conducted with three different particle sizes: 5.5, 6.5 and 7.5
mm. As shown in figure 5, different particle sizes significantly influence the force exerted on block 5, 6, and 7, particularly on block 7.

**Figure 3.** Relationship between rotation speed and total load.

**Figure 4.** Relationship between production speed and total load.

**Figure 5.** Relationship between particle size and total load.

**Figure 6.** Changed structural parameter of rotor.

3.3. **Relationship between structural parameters and load on the impact hammer**

In a vertical shaft impact crusher, the main factors which influence the velocity of particles from the channel outlets are the length and setting angles of trail plates. Rotor models of different setting angles and trail plate lengths in 3D software (Solid Works) are shown in figure 6. The trail plate length of
VSIs was originally 122 mm, with an install angle of 0°. Simulation tests were conducted with different trail plate lengths $L_1$, $L_2$ and $L_3$, which were 112 mm, 122 mm and 132 mm, respectively, as shown in figure 6(b). The feeding rate was set to 7.5 kg/s, rotor speed was 1550 r/min, and particle size ranged from 0-13 mm with normal distribution. Figure 7 shows the relationship between different trail plate lengths and the total force exerted on each of the 11 blocks. As shown in figure 7, the impact load on the carbon tungsten alloy blocks decreased with increasing trail plate length. When the trail plate length increases, particles take longer to travel, which increases the friction action time between the trail plate and the material particles? The kinetic energy of the particles declines, and the velocity of the particles that hit the impact hammer drops accordingly. Shorter trail plates can cause a stronger impact load on block 7.

Simulation tests were then conducted with increasing install angles. The simulated install angles of the trail plate were $\theta_1=0^\circ$, $\theta_2=30^\circ$, $\theta_3=40^\circ$, and $\theta_4=50^\circ$. Figure 8 shows the relationship between the install angle of the trail plate and the total force exerted on each of the 11 blocks. When the installation angle was 0°, the motion path of the particles was perpendicular to the trail plate, causing the particles to hit the impact hammer without much friction. With the increasing install angle of the trail plate, the friction on particles coming from the trail plate would increase, and the particles’ kinetic energy loss would increase accordingly, and the impact load from particles on the carbon tungsten alloy blocks would decrease. Designing different installation angles according to different rocks sizes can not only ensure an optimal crushing effect, but also decrease the impact wear and tear on the trail plate.

4. Analyses and experiment comparison of throwing material hammer

In order to verify the actual wear distribution characteristics of the impact hammer, real experiments were conducted using the same type of VSI. In the field experiment, the rotation speed of VSI was 1440 r/min, rotor diameter was 1660 mm, the rotor weight was 2000 kg, and the crushing chamber diameter was 3070 mm. After 10,000 hours of crushing, the impact hammer was removed from the VSI. Figure 9(a) shows the scanned picture of the carbon tungsten alloy blocks on the impact hammer. In the simulation process, rotor size identical to that used in the actual VSI in the field experiment. The feeding rate was 7.5 kg/s, rotor speed was 1440 r/min, particle size ranged from 0-13 mm with normal distribution, the install angle of the trail plate was 0°, and trail plate length was 122 mm. Figure 9(b) shows the result of the simulation experiments: the distribution and number of collisions between the particles and the impact hammer. The axes represent the length of the hammer, width of the hammer and the number of particle collisions, respectively. The gradient projection in figure 9(b) demonstrates the impact load distribution of the hammer. Figure 9 demonstrates that the actual and simulation experiments shows similar results: blocks 5, 6, 7, 8 and 9 demonstrate greater impact loads than other blocks, and the wear and tear on blocks 1-11 are generally greater than on blocks 12-22. Results verify that the impact load distribution and actual wear distribution of the hammer were consistent. The DEM and load distribution can be used to optimize structural and
manufacturing parameters of VSI and prolong the service life of impact hammers. Figure 9 shows a comparison of the actual wear and load distribution on the impact hammer by simulation.

![Figure 9. Really wear distribution compare with simulation load distribution of hammer.](image)

**5. Conclusions**

In this paper, a geometrical model of a vertical shaft impact crusher is created, and 22 carbon tungsten alloy blocks on the impact hammer were labeled. First, DEM was used to study the impact load on the carbon tungsten alloy blocks on the surface of the impact hammer. Secondly, the effects of rotor speed, feeding rate and particle size on load distribution were studied by simulation. Next, the influence of the length and installation angle of the trail blade on the load distribution of the impact hammer was investigated by simulation. Finally, comparing wear and tear on the impact hammer by actual experiments and simulation, it is found that actual wear and tear distribution and the simulation load distribution produce similar results. The simulation of the influences of various parameters on load distribution is an efficient way to optimize the crushing effects of VSI. Meanwhile, optimal parameters can improve the service life of the impact hammer by DEM simulation, which provides a strong tool to optimize the design of vertical shaft impact crushers.

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