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Wear Behaviour of Iron Matrix Composite Reinforced by ZTA Particles in Impact Abrasion

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Abstract. Zirconia toughened alumina (ZTA) particles reinforced high chromium cast iron composites (ZTA/Iron composites) were prepared by a two-step processing method, i.e. mixing particles by the molten metal and cohering by high pressure, which based on the squeeze casting process. The impact wear resistance under different impact energies were investigated using dynamically loaded abrasive wear tester at room temperature. For comparison, the wear tests of high chromium cast iron were also carried out under the same conditions. Worn surfaces of the samples were observed under scanning electron microscopy equipped with an energy dispersive detector. The results showed that the composites have better impact wear resistance than that of high Cr cast iron regardless of impact energy level, and the wear resistance of the two materials all decrease with the increase of the impact energy. The main wear mechanisms of the high Cr cast iron were micro-cutting and fatigue peeling, while the wear of composites occurred through micro-cutting of the matrix (lower impact energy) and breaking and shedding of the reinforced particles (higher impact energy).

1. Introduction

Wear is one of the three most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering. According to Eyre estimates, abrasive wear comprises roughly about 50% of industrial wear situations [1]. And among various abrasive wear, impact abrasive wear is an extremely bad wear condition in the practical application, which resulting in the materials shows the rapid wear and extremely short life. Compared with the conventional metal wear-resistant materials, particles reinforced iron matrix composites have attracted more and more attentions due to their high wear resistance and excellent comprehensive properties [2, 3]. Meanwhile, these composites can bring the excellent characteristics of reinforcement and matrix into full play, have become one of the development directions of high performance structural materials [4-6]. With more and more composites components were applied into the impact wear conditions in various industries, it would be of great importance to study the impact wear properties of particles reinforced iron matrix composites.

In this paper, high Cr cast iron matrix composites reinforced with ZTA particles were prepared by a two-step processing method [7], i.e. mixing particles by the molten metal and cohering by high pressure, which based on the squeeze casting process. The method belongs to green casting, which eradicate the pollution of moulding sand existed in the traditional casting process, as well as has a lower cost. The wear behaviour of the composites in impact abrasion conditions was investigated. The present work highlights the influence of impact energy on the wear characteristic and the wear mechanism of ZTA/ Iron composites.

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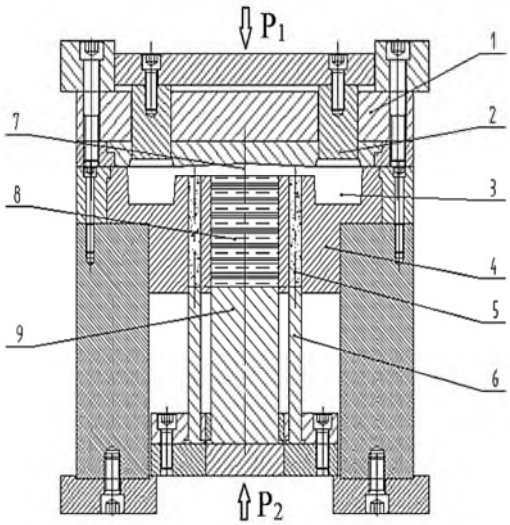
2. Experimental materials and methods

Commercial ZTA particles (containing 60 wt.% Al_2O_3 and 40 wt.% ZrO_2) were used as the reinforcements while micro-alloying high chromium cast iron was chosen as the matrix of the composite material, and the chemical composition of high Cr cast iron matrix are presented in Table 1. The ZTA reinforced particles with an average size of 2-4 mm possessed a micro-hardness of 1500-1700 HV, a density of 4.0 $g \cdot cm^{-3}$ and a melting point of 1890°C.

Table 1. The chemical composition of high Cr cast iron matrix (wt.%).

Element	C	Si	Mn	Mo	W	Ni	Cr	Fe
Content	2.8-3.0	0.8-1.0	1.8-2.0	0.7-1.0	0.9-1.3	0.3-0.5	25-27	Bal.

An intermediate frequency induction furnace was used for the high Cr cast iron melting, and the tapping temperature was higher than 1600°C. The mould, especially the ceramic and metal cavity, was preheated to 220-260°C using a self-made preheater made by electric heating tube, moreover, the particles contained by crucible were preheated to 1100°C in a resistance furnace. The schematic diagram for fabricating ZTA/Iron composites by two-step processing method was shown as figure1, and the experimental procedures are as follows, firstly, added preheated ZTA ceramic particles and poured molten metal into the ceramic and metal cavity to full, respectively. Then making the upper and lower mould closed and locked at the specific pressure of 115MPa, followed by an external pressure of 125MPa was exerted to drive the ceramic and metal pressure head with a filling speed of 150mm/s, thus made the particles and molten iron from ceramic cavity and metal cavity continuous pushed into the mould filling runner. When the molten metal flows over the ceramic cavity, its kinetic energy and viscosity were utilized to achieve the uniform dispersion of ceramic particles, meanwhile, formed the solid-liquid mixture wrapped with particles to fill the workpiece cavity. After then, the mixture in the workpiece cavity achieved solidification and feeding at the supplement pressure of 130MPa offered by workpiece pressure head. Finally, released the pressure of ceramic, metal and workpiece pressure head, opened the mould and removed the composites workpiece.



(1) upper mould; (2) workpiece pressure head; (3) workpiece cavity;
(4) lower mould; (5) ceramic particles; (6) particles pressure head;
(7) mould filling runner; (8) molten metal; (9) metal pressure head

Figure 1. Schematic diagram for fabricating ZTA/Iron composites.

The ZTA/Iron composites were designed for industries involving impact loads. Therefore, the impact–abrasion wear tests were carried out to better assess the performance of the composites in service. Meanwhile, the single high chromium cast iron was selected as the reference material for the wear tests to compare with ZTA/Iron composites in the purpose of evaluating the wear properties of composites.

The wear tests were performed on a dynamically loaded abrasive wear tester (MLD-10, produced by Zhangjiakou Cheng Xin Testing Equipment Manufacturing Co. Ltd., China) at room temperature, the schematic representation was exhibited in figure 2(a), the impact–abrasion wear of the samples is realized with the non-stop rotating of the lower sample and the vertical reciprocating motion of the upper sample. The wear (upper) sample were cut into 10 mm × 10 mm × 30 mm size, as shown in figure 2(b), and the surface of 10 mm × 10 mm was mechanically polished for impact-abrasive wear tests. The cylindrical contrast (lower) sample was made of 45# steel (58HRC) with the size of 50 mm in diameter and 20 mm in length, which was quenched at 840°C in water and tempered at 300°C for 1h. The wear surfaces of the tested samples were observed and examined by the scanning electron microscopy (SEM, Hitachi S-4800) equipped with an energy dispersive detector (EDS, Vantage).

During the test, the wear sample is fixed on a clamping chuck which connects with a hammer. The impact frequency of wear sample was 150 times/min and the wear tests were performed for 60 minutes. The rotation speed of contract sample was 200r/min, the impact energy is set at 2 J, 3 J and 4 J, respectively. Refined quartz sands are used as the abrasive material (with particle size of 10-20 mesh, density of 2.6 g/cm^3 and hardness value of 800 HV–1200 HV), the SEM micrograph of abrasive particles as shown in figure 2(c). The wear tests were repeated three times with new samples for each test condition to ensure the reliability, and each sample was subjected to pre-wear for 30min before the formal tests. The wear mass loss was measured every 10 minutes in the tests, before and after each test, the wear sample was cleaned ultrasonically, dried and then weighed by a precision electronic balance with an accuracy of 0.0001g, and take the average value of three measurements as the results.

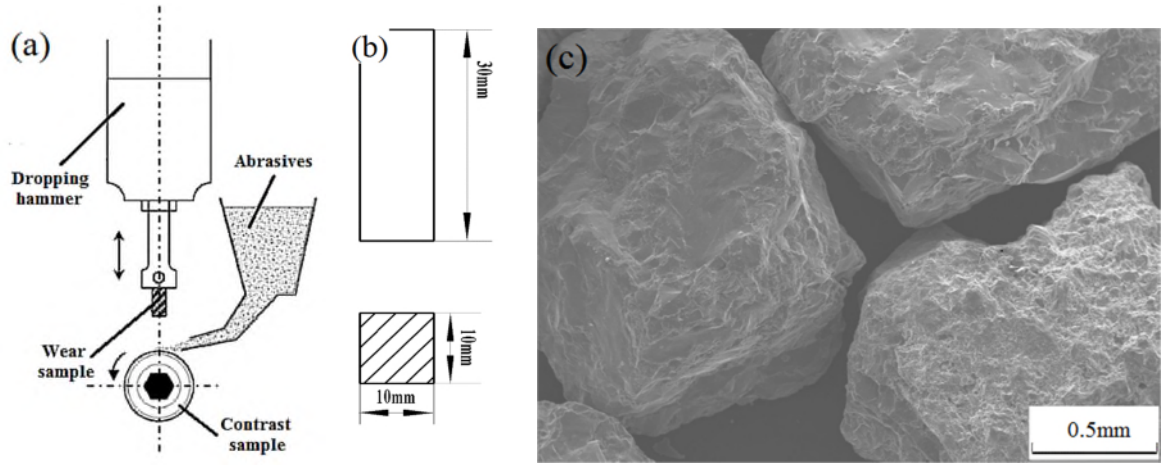


Figure 2. (a) Schematic of MLD-10 wear tester; (b) Size of wear (upper) sample; (c) the SEM micrograph of quartz abrasive particles.

3. Results and discussion

The text of your paper should be formatted as follows: Relative wear resistance β was used to evaluate the impact wear properties of ZTA/Iron composites, which can be obtained through the following process.

First the abrasive volume ΔV was calculated as:

$$\Delta V = \frac{m_1 - m_2}{\rho_m f_m + \rho_c f_c}$$

where ΔV is the abrasive volume; m_1, m_2 is the weight loss before and after abrade, relatively; ρ_m, ρ_c is the density of high chromium cast iron and ceramic particle, relatively; f_m, f_c is the volume fraction of high chromium cast iron and ceramic particles in the composites, relatively.

Then the relative wear resistance β was achieved through the following equation:

$$\beta = \frac{\Delta V_m}{\Delta V_c}$$

where β is the relative wear resistance; ΔV_m is the abrasive volume of reference matrix (high chromium cast iron) sample; ΔV_c is the abrasive volume of ZTA/Iron composites sample.

The test results of wear samples under different impact energies were shown in figure 3. It can be seen that the cumulative volume loss of the single high Cr cast iron and composites all have a greater change in the different impact energies, and the wear properties both decrease with the increase of impact energy. However, the impact abrasive wear property of the composites all superior to that of the high Cr cast iron in various impact energy. Figure 4 shows the relative wear resistance of composites with high Cr cast iron, it has been calculated that the relative wear resistance of composites is 1.84, 1.43, 1.1 times higher than the high Cr cast iron when the impact energy is 2, 3, 4 J, respectively, which indicates that the wear resistance of composites is more excellent in the condition of lower impact energy.

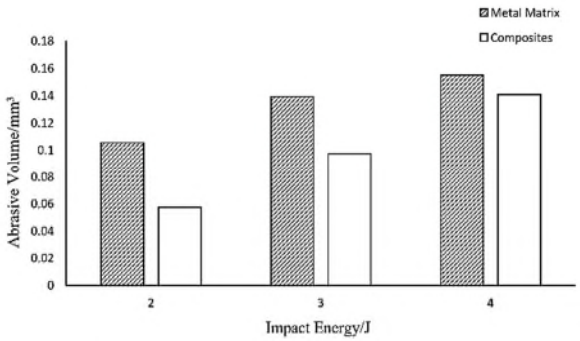


Figure 3. Wear test results of composites and matrix under different impact energies.

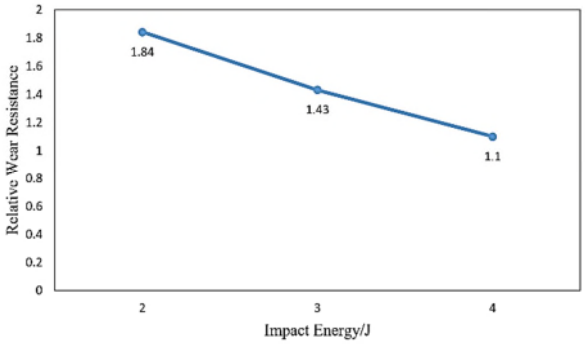


Figure 4. The relative wear resistance of composites under different impact energies.

In the condition of impact abrasive wear, the materials not only bearing tangential sliding wear of the abrasive, but also subject to an impact action in the normal direction. The abrasive piercing the surface of the material in the normal action, then cutting the materials under the action of tangential force.

The quartz sand is hard abrasive compared with the high Cr cast iron, the serious cutting and rolling effect will be produced on high Cr cast iron under the external load. The wear morphology of high Cr cast iron samples were shown in figure 5, it can be seen obvious micro-cutting marks (A in figure 5(a)) from the wear surface when the impact energy is lower (2J), which demonstrates that the wear mechanism is dominated by micro-cutting in the lower energy. The local stress of the material increased with the increase of the impact energy, leading to the appearance of the cracks and developing into the fatigue peeling (B in figure 5(b)). Meanwhile, the abrasive particles will be embedded into the wear surface (figure 5(c)) with the increase of the impact degree.

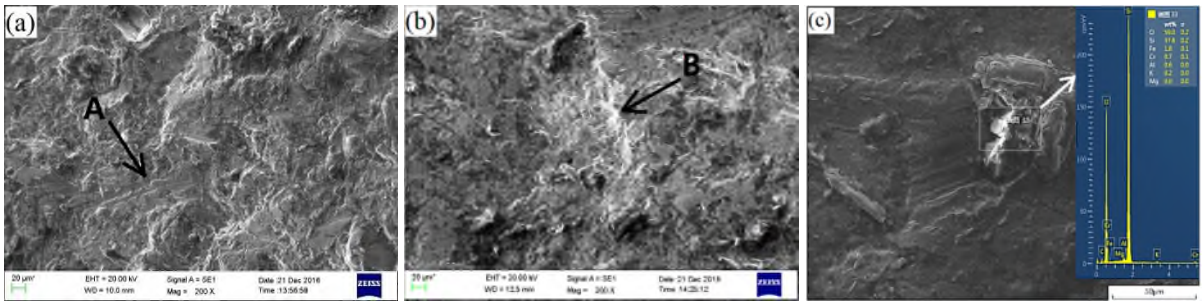


Figure 5. The wear morphology of high Cr cast iron (a) lower impact energy; (b) higher impact energy; (c) The abrasive particles embedded into the wear surface.

When the ZTA ceramic particles were introduced into the high Cr cast iron matrix, the impact wear resistance of the composites depends on the synergistic effect of the metal matrix and reinforced particles. On the one hand, the good supporting role of the metal matrix ensured the ZTA particles hard to fall off in the wear process. On the other hand, the hardness of ZTA particles is much higher than that of the quartz abrasive, which can resist the cutting effect of abrasive on the metal matrix, thus

protecting the matrix. However, the wear resistance of the composites will be greatly influenced by whether the reinforced particles break or fall off under the impact action. The wear morphology of composites samples was shown in figure 6, it can be seen that the stress of the particles is small and the fracture is not obvious when the lower impact energy (2.0J) is applied. The ZTA particles are protruded from the matrix during the wear process (figure 6(a)), reduced the contact area of the matrix with abrasive particles and made the matrix hard to cut and wear, so that the wear resistance of the composites is much better than that of the high Cr cast iron. When the impact energy is 4J, the cracks appeared within particles due to the larger stress, and the cracks in different directions further extended, leading to breaking of the particles (C in figure 6(b)), even shedding of the entire particles (D in figure 6(c)). In this case, the ZTA particles lose their protective effect on the matrix, resulting in a greater wear of the composites.

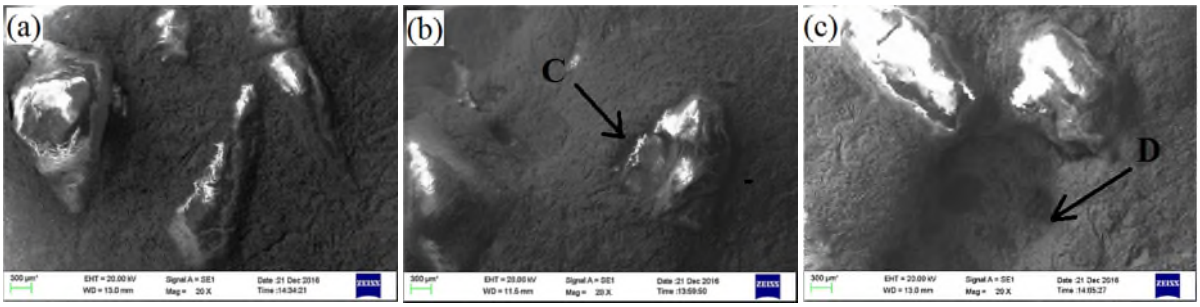


Figure 6. The wear morphology of ZTA/Iron composites (a) lower impact energy; (b) Breaking of the particles in the higher impact energy; (c) shedding of the particles in the higher impact energy.

4. Conclusions

(1) A high Cr cast iron matrix composite reinforced with zirconia toughened alumina (ZTA) particles 2-4mm in size was prepared by a two-step processing method.

(2) The composites have better impact wear resistance than that of high Cr cast iron regardless of impact energy level, and the wear resistance of the two materials all decrease with the increase of the impact energy.

(3) The wear of high Cr cast iron occurred through micro-cutting and fatigue peeling under the lower and higher energy, respectively. While the wear mechanism of ZTA/Iron composites appears as micro-cutting of the matrix in the lower impact energy and breaking and shedding of the reinforced particles in higher impact energy.

5. References

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