Paper

High Temperature Hardness and Wear Resistance of Alumina-Dispersed High-Chromium Cast Iron PM alloys Prepared by the MA-SPS Process

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SYNOPSIS

The MA-SPS (mechanical alloying followed by spark plasma sintering) process was adopted to further improve the high temperature properties of a newly developed 36Cr white cast iron (a eutectic Fe-36Cr-9Ni-5Mo-0.45Si-2.2C alloy). α -Al₂O₃ powder with a mean diameter of 0.4 μ m was used as reinforcement for the MA material, and the volume fractions of Al₂O₃ in the composites were 10% and 30%. The results show that the microstructures of the MA materials were greatly refined compared to those of the conventionally solidified ingot and that their high temperature hardness and high temperature abrasive resistance were considerably improved. Also found was that the increase in the volume fraction of the Al₂O₃ powder increased both the hardness and the abrasive resistance of the composite materials.

KEY WORDS

alumina-dispersed high-chromium cast iron, mechanical alloying, spark plasma sintering, high temperature hardness, high temperature abrasion resistance

1 Introduction

High Cr white cast irons (HCWCIs) containing a large amount of carbides with high hardness are commonly used for wear resistant applications in the mining and minerals industries, steel making plants, etc.¹⁾ The excellent wear-resistance of these materials results mainly from the hard carbides dispersed in an austenite matrix. Generally, the HCWCIs are designed to consist of a strengthened austenite matrix with uniformly dispersed hard carbides. In recent studies, we have successfully developed a eutectic 36Cr cast iron which exhibits excellent wear- and oxidation-resistance at elevated temperatures²⁾. In the present study, mechanical alloying followed by spark plasma sintering (MA-SPS) process and the composite technique are adopted to further improve the high temperature properties of this newly developed material. This paper describes the hardness, abrasion resistance of both the MA materials and its composites at elevated temperatures.

2 Experimental procedure

The eutectic 36Cr alloy employed had a chemical composition of Fe-36Cr-9Ni-5Mo-0.45Si-2.2C (mass%), and the reinforcement was the α -Al₂O₃ powder with a mean diameter of 0.4 μ m. As shown in Fig. 1, the fabrication process of the MA materials was: pre-mixing the element

powders with the Al₂O₃ powder (the volume fractions of the Al₂O₃ powder were 0, 10 and 30%) using a V-type blender for homogeneous dispersion of each powder followed by the MA process with a planetary-type ball mill for 200 h in argon atmosphere, and then consolidation by spark plasma sintering at 1373 K by uniaxial pressing at 50 MPa to form coin-shaped specimens (ϕ 32 $\times$ 6 mm). The conventionally solidified 36Cr ingot and a widely used hypoeutectic 25Cr cast iron ingot (Fe-25Cr-0.5Ni-0.5Mo-2.9C) were also

Fig.1 Fabrication procedure of MA materials.

prepared for comparison.

The structure of the mixed powders at different MA times was analyzed with an X-ray diffractometer. The Vickers hardness of the test materials was measured at room temperature, 773, 873, 973 and 1073 K under a load of 49 N in argon gas atmosphere. The high temperature wear test was performed using a newly designed low stress abrasive tester described elsewhere³⁾. This tester consists of a symmetric Π -shaped specimen holder that is rotated in a stainless steel tank filled with silica sand (average particle size = 1 mm), and an electrical furnace surrounds the tank to heat the abrasive sands, as shown in Fig. 2³⁾. The testing materials and its comparative sample (25Cr cast iron ingot), of a size of $20 \times 20 \times 5$ mm, were placed at the respective branches of the holder, leaving a 20×20 mm face of each specimen to be exposed to abrasion. During the experiments, the rotation speed of the specimen holder was 200 rpm (the specimens' speed was 1.36 m/s), the wearing time for each measurement of the mass loss was 20 h (the total wearing time was 80 h), and the testing temperature was 923 K. The silica sand was exchanged with new material every 20 h. The final results of the abrasion test were given by the volume loss of the specimens as a function of the wearing time.

3 Results and discussion

The XRD patterns of the elements during the MA process of the 36Cr composition specimen are shown in Fig. 3. It shows that the peak of the C element disappears at the very early stage of the MA process (within 5-h MA time), showing the solution of C in the Fe and/or Cr, while the peaks of the Ni and Mo elements disappear at the later stages. At the 100-h MA stage, only a broad peak of Fe and Cr is observed. Furthermore, the peaks of the Fe and Cr disappear, and an amorphous-like broad pattern occurs

after a 200-h MA process.

Fig. 4 shows the appearances of the MA powders after a 200-h MA process and the mixed powder. The MA powders exhibit the peculiar surface to mechanical alloying, i.e., the trace by which pulverization and adhesion were repeated is observed. Although the shape of the MA powder without the Al_2O_3 particle is relatively rounded, that of the MA powder with 30 vol.% Al_2O_3 addition is sharp, because the addition of the Al_2O_3 powder suppresses the re-adhesion of pulverized powder. The particle sizes of the MA powders decrease with increasing Al_2O_3 content, and the particle size tends to be classified into two sizes, fine particle and coarse one. The particle size of the MA powder of $V_f = 0\%$ is in the range of $10 - 30 \mu\text{m}$, and the average particle diameter is $20 \mu\text{m}$. The particle size of the MA powder containing 30 vol.% Al_2O_3 is distributed over the range of $3 - 20 \mu\text{m}$, and the average particle diameter is $6 \mu\text{m}$.

Fig. 5 shows the microstructures of the test materials. Compared with the conventionally solidified 36Cr and 25Cr ingots which have respectively typical eutectic and hypoeutectic microstructures, the MA materials exhibit an extremely refined microstructure. In the composite specimens, the Al_2O_3 powder is homogeneously dispersed, and no obvious defects have been found in each of the MA specimens.

Fig. 6 shows the Vickers hardness of the test specimens as a function of the testing temperature. All the MA materials are harder than the conventionally solidified 36Cr ingot at each test temperature. The increase in the Al_2O_3 content considerably increases the hardness of the composite materials. At 1073 K, the hardness of the

Fig. 2 Schematic view of high temperature abrasion tester: (a) vertical section of the tester, (b) cross section of the specimen holder.

Fig. 3 XRD patterns of element powders at various MA times.

Fig.4 Appearances of MA powders (a, b and c) and mixed one (d).

Fig.5 Microstructures of MA materials (a and b), 36Cr ingot (c) and 25Cr one (d).

Fig. 6 Relationship between Vickers hardness and testing temperature for MA materials, 36Cr ingot and 25Cr one.

Fig. 8 Effect of Al₂O₃ content in metallic matrix on wearing rate at wearing temperature of 923 K.

Fig. 7 Volume loss as a function of wearing time for MA materials, 36Cr ingot and 25Cr one at wearing temperature of 923 K.

composite specimen of V_f=30% is determined to be 580 HV5 that is equivalent to the RT (room temperature) hardness of the monolithic MA specimen and that is by far greater than the RT hardness of the conventionally solidified 36Cr ingot.

The volume losses of the specimens in the abrasive test at 923 K are shown in Fig. 7. The volume losses of the 36Cr materials prepared by two different processes, conventionally ingot metallurgy and MA-SPS processes, are extremely smaller than that of the 25Cr ingot, showing the excellent abrasive resistance of the former. Also shown

is that the MA process obviously improves the wear resistance of the 36Cr specimen; the average wear rate (the slope of the curve, dV/dt) of the 36Cr MA alloy is about 70% of that of the conventional 36Cr ingot, i.e., the MA alloy has 1.4 times higher wear resistance than the 36Cr ingot. The wear resistance of the composite materials is further improved with increasing content of the Al₂O₃ reinforcement. A linear relationship between the wearing rate of the MA materials and the content of the Al₂O₃ powder is clearly described in Fig. 8. The wearing rate of the composite of V_f=30% is only half of that of the monolithic MA specimen.

Fig. 9 shows the worn surface morphology of the specimens after abrasion at 923 K for 80 h. The worn surface of the 25Cr ingot shows a relatively rugged surface, which depends on the microstructure. The primary γ -phase is worn out more compared with the eutectic phase, because the γ -phase is softer than the eutectic phase at the test temperature. The 36Cr ingot also presents a worn surface with the ruggedness, whereas the MA materials have outstanding smooth worn surfaces compared with those of the 25Cr and 36Cr ingots. The composite specimen of V_f=30% exhibits an extremely smooth and refined surface.

4 Conclusions

The MA-SPS process and the composite technique have been used to further improve the high temperature properties of a newly developed 36Cr white cast iron. The following conclusions can be drawn from this work:

Fig.9 Worn surfaces of MA materials (a and b), 36Cr ingot (c) and 25Cr one (d) after wearing at 923 K for 80h.

- (1) The monolithic 36Cr MA material prepared by the MA-SPS process is by far harder than the conventionally solidified 36Cr ingot at each test temperature. The hardness of the MA material can be further improved by forming a composite of it with the Al_2O_3 powder. The higher the content of the Al_2O_3 powder, the greater is the high temperature hardness of the composite materials.
- (2) At the test temperature of 923 K, the monolithic 36Cr MA material exhibits greater abrasive resistance than the conventionally solidified 36Cr ingot. The wear rate of the former is only 70% of that of the latter. The composite process further improves the high temperature abrasive resistance of the 36Cr MA material. The wear rates of the composites decrease linearly with increasing Al_2O_3 content.

- (3) The 36Cr composite material containing 30 vol.% Al_2O_3 exhibits the remarkably smooth and refined worn surface compared to the 25Cr and 36Cr ingots after the abrasion test for 80 h.

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