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Short communication

Dry sliding wear in injection molded 17-4 PH stainless steel powder with nickel boride additions

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Abstract

Dry sliding wear behavior of injection molded 17-4 PH stainless steel powder with nickel boride additions has been studied on a pin-on-disc wear tester using an alloy steel pin and disc of hardness 63 HRC. The PIM alloys in the as sintered as well as in the precipitate-hardened conditions were investigated for their wear behavior. Wear rate was found to be initially decreased with the increasing nickel boride amount. Optical microscopy and XRD analysis were preformed to characterize the basic microstructures for all samples. SEM observations of the worn surfaces revealed plastics deformations with delamination of surface layers by subsurface cracks as the mechanism in the as sintered and precipitate-hardened conditions.

Keywords: Dry sliding wear; Powder injection molding; Sintering

1. Introduction

Powder injection molding (PIM) is a powder metallurgy process currently used for the production of complicated and near-net-shape parts of high performance materials. This technique basically combines the advantages of the plastic injection molding with the versatility of the traditional powder metallurgy, producing highly complex part of small size, tight tolerance and low production cost. The process overcomes the shape limitation of traditional powder compaction, the cost of machining, the productivity limits of isostatic pressing and slip casting and the defect and tolerance limitations of conventional casting [1,2]. Mechanical properties of a well-processed powder injection molded material and indistinguishable from cast and wrought material. The PIM process is composed of four sequential steps: mixing of the powder and organic binder, injection molding, debinding (binder removal), and sintering. If it is necessary, secondary operations such as heat and surface treatments after sintering can be performed [1].

Material removal is expressed as area, volume or mass and is termed as wear amount and wear rate. This is related to the path or duration of load. The reciprocal value of wear amount is termed as the wear resistance. Economic life of many structural parts is limited by wear. Therefore, wear resistance is as important as yield strength or fracture toughness values. When some material is removed from the sample due to contact with a hard surface, the worn material is known as ductile materials [3–10]. Subsurface deformation and hard phases influence the wear behavior.

The alloy 17-4 PH is a precipitation-hardenable martensitic stainless steel. Due to its high strength and good corrosion resistance, 17-4 PH has widespread applications, especially in medical, automotive, military and aircraft components. Many 17-4 PH components can be manufactured as cost-effectively by powder injection molding, a net-shape forming process with an advantage of shape complexity material utilization and high final density. This alloy is, however, hard to be machined. Therefore, it has been attempted applying to a near net-shape production technique such as metal PIM to this useful material [11–14].

The friction and wear behavior of metallic parts by PIM has not been studied so far. Earlier investigations on PM or PIM 17-4 PH focused on the effect of powder characteristics, sintering atmosphere, temperature and time, heat treatment, residual carbon content on microstructure, corresponding microstructural characterization, mechanical and corrosion properties [2,11,12]. Although they found to be poor corrosion performance in comparison with the corresponding wrought material because of the

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porosity left in the final product, mechanical properties were somewhat improved with increased sintering parameters.

In several investigations, boron as a sintering additive has been used to achieve higher sintered density in stainless steels at lower sintering temperatures [13–17]. Different boron additions can be selected for full density and higher performance, because of low melting temperature, excellent wetting characteristics and an extremely low solubility in solid. Due to these attractive characteristics, intensive research efforts have been dedicated to the study of several iron-based alloying systems [18] including stainless steels. In several studies was observed that additions of boron as FeB, Fe_2B, NiB, CrB_2 to iron and stainless steels resulted in greater densification [13–18]. Full density and a noticeable improvement in the mechanical properties were obtained by the addition of 200 ppm of boron to martensitic stainless steel [16]. The addition of 0.5 and 1 wt.% elemental boron powder to 316L stainless steel powders increased theoretical density, mechanical properties and corrosion resistance [15]. The boron additions effect on melting and densification characteristics, and distortion of PM stainless steel [13–16]. 0.20 wt.% FeB powder to 17-4 PH stainless steel powders improved the final density to the theoretical values. As a consequence, a noticeable improvement in the mechanical properties is obtained [17].

The aim of the present work is to investigate the effect of NiB additions on the wear properties of powder injection molded 17-4 PH stainless steel. X-ray diffractometry (XRD) and metallographic techniques were used to characterize the NiB added as sintered and precipitate-hardened samples. Dry sliding tests were performed in injection molded 17-4 PH stainless steel with and without NiB as sintered and precipitate-hardened conditions. Wear loss was determined for all samples after wear tests. Worn surfaces of as sintered and precipitate-hardened samples were analyzed under scanning electron microscope.

2. Experimental procedures

2.1. Material preparing

In this study, 17-4 PH stainless steel powder was supplied by Osprey Metals Ltd., which was produced by high-pressure gas atomization method with a tap density of 4.2 g/cm^3 and a pycnometer density of 7.5 g/cm^3. The particle size distribution of this powder was D_{10} = 3 μm, D_{50} = 10 μm, and D_{90} = 28 μm. The chemical composition of the powder is given in Table 1. NiB powder used in this study was supplied by F.W. WINTER Inc. & Co. The particle size distribution of NiB powder was D_{10} = 4 μm, D_{50} = 11 μm, and D_{90} = 26 μm. The amount of additive was adjusted to give 0.5 and 1 wt.% NiB in starting mixture was blended in a Turbula mixer for 8 h.

The binder used consisted of 69 wt.% paraffin wax, 20 wt.% polypropylene, 10 wt.% carnauba wax, and 1 wt.% stearic acid. Feedstock was prepared at 175 °C with the binder melted first and then powder blend added incrementally. The powder loading in this mixture was 62.5 vol.%. After cooling, the feedstock was pelletised by hand. These feedstocks were injected using a 12.5 MPa specially made injection-molding machine to produce tensile (MPIF 50) test samples [19]. The melt temperature was 175 °C, the mold temperature was kept at 35 °C and cycle time was 20 s.

Table 1
Chemical composition (wt.%) of 17-4 PH stainless steel powder

Fe	Bal.
Cr	16.2
Ni	4.6
Cu	4.6
Mn	0.54
Nb	0.30
Si	0.30
Mo	0.095
C	0.038
P	0.026
S	0.002

The samples molded using the binder were all thermally debinded in an atmosphere-controlled furnace under high purity H_2 to reduce oxidation with the following schedule: hold at 150 °C for 12 h, 280 °C for 12 h, 390 °C for 12 h, 520 °C for 6 h and at 950 °C for 1 h with heating rates 1 °C/min. After applying this debinding no distortion or other visible reduction in part quality or surface finish was observed.

Sintering of all samples was performed within a vacuum/atmosphere-controlled high temperature furnace of Vacuum Industries. The sintering cycle applied to the samples was as follows: samples were heated to 1100 °C at a rate of 10 °C/min and held at 1100 °C for 5 min, then the samples were heated to various sintering temperatures of 1280 °C at a rate 5 °C/min and they were held at temperature for 45 min. 17-4 PH stainless steel samples without boron addition were sintered at 1350 °C for 1 h. The heat treatment was performed applying a solution treatment in argon for 1 h at 1050 °C, followed by a water quenching and aging treatment carried out in argon for 4 h at 480 °C than cooled in air. Samples were cut from the center of the each sintered and precipitate-hardened tensile test bars by abrasive cutter. Pin of samples is 3.2 mm diameter and 25 mm length. Pin surfaces were ground and polished to a roughness of 0.160 μm R_a.

The densities of the sintered samples were measured by means of the Archimedes water-immersion method. For metallographic examination, samples were cut from the center of the each sintered tensile test bars. A Kalling's reagent, composed of 2 g $CuCl_2$, 40 mL HCl, 60 mL ethanol, and 40 mL H_2O, was used to etch the samples for optical metallography. In order to distinguish the closed porosity from the open porosity, specimens were impregnated with water, a technique which has proven successful for these materials in earlier studies [20]. Oil does not always completely penetrate the open pore system, which results in a measured value of the open porosity that is too low. The pores of sintered materials were studied in polished sections. These samples were vacuum impregnated with epoxy before final polishing to maintain the sharpness of the pore edges. The hardness tests were performed using an Instron-Wolpert Dia Testor 7551 at HRC scale and microhardness tests were performed using a Shimadzu Microhardness Tester. X-ray diffractometry (XRD) was used to characterize the NiB added and heat-treated samples.