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Abrasive wear properties of tool steel matrix composites in rubber wheel abrasion test and laboratory cone crusher experiments

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Abstract

Abrasive wear is the most common type of wear phenomenon in mineral crushing industry. Tool steel matrix-based composites are an attractive choice to combat wear in those conditions because of their excellent abrasion resistance. One purpose of this study is to evaluate the abrasion resistance of such composites having different microstructures. Another purpose is to find out whether the simple dry sand rubber wheel abrasion test (ASTM G 65-91), which is a commonly used and relatively cheap and easy-to-perform test, could be used to rank materials for rock crushing although abrasive wear is not the only type of wear in the real rock crushing conditions. For this purpose Nordberg laboratory cone crusher test was used. Seven different composites were studied. The tool steel of type Ralloy®WR6 was used as a matrix material in all composites. The reinforcement was either cemented carbide (WC–Co), cast tungsten carbide (WC) or titanium carbide (TiC). The composites were manufactured by hot isostatic pressing (HIP).

Abrasive wear properties of all the studied composites are very good. The reinforcement type, size, properties, volume fraction and reinforcement distribution in the matrix all influenced the wear results in both of the tests, but in a different way. Best wear resistance in cone crusher conditions was obtained with cemented carbide (WC–10Co) reinforced Ralloy®WR6 and in dry sand abrasion with WC reinforced Ralloy®WR6. No simple correlations between the dry sand rubber wheel abrasion test results and the cone crusher test results were found. This can be attributed to the different wear mechanics and consequently wear mechanisms in the two tests. In the dry sand rubber wheel abrasion test abrasion and detachment of the reinforcements are the major wear mechanisms while in the cone crusher abrasion with rock sliding and pure indentation are the major wear mechanisms. The differences in wear mechanisms result from differences in abrasives (type, size and hardness) and other wear conditions. It is concluded that dry sand rubber wheel abrasion test should not be used for screening materials for rock crushing applications as far as metal matrix composites are concerned.

Keywords: Steel matrix composites; Cemented carbide; Tungsten carbide; Titanium carbide; Abrasive wear; Cone crusher

1. Introduction

Wear occurs in many different industrial situations, and causes high costs due to equipment failures, replacement of wear parts and downtime during repairs. In addition, the wear influences the quality of the products involved.

Wear can be classified into different modes. One common division is adhesion, abrasion, surface fatigue and tribochemical reaction [1]. These wear modes can be divided furthermore into different wear mechanisms. Abrasion may occur by microploughing, microcutting, microfatigue and microcracking [1]. In the simplest case, only one type of wear mechanisms is present. However, usually several wear mechanisms occur at the same time. For example, in the compressive mineral crusher, abrasion, impact and compressive type of wear are all known to occur [2,3]. Which mechanism will dominate in different case depends, e.g., on the material (ductile or brittle), degree of penetration, and surface hardness [1,4].

In metal matrix composites, two or more different materials and sets of properties are combined. The purpose is to achieve

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materials that have, e.g., good wear resistance combined with high temperature strength or good corrosion resistance [4]. Abrasion resistance of steel matrix composites has been investigated, e.g., in [5]. Abrasion resistance depends on different microstructural parameters such as hardness, shape, size, volume fraction and distribution of the reinforced particles, properties of the matrix and bonding between the matrix and the reinforcements [4–6].

Hot isostatic pressing (HIP) is an attractive processing route for steel matrix composites. In HIP process, a wide range of reinforcement volume fractions and sizes can be used and the distribution of the reinforcement obtained is quite homogeneous [7,8]. In addition, another practical advantage of the powder metallurgy approach is a near net shape manufacturing especially in the case of wear resistant materials, which can be very difficult to machine.

In this study, materials of interest are wear resistant powder metallurgical tool steel matrix composites. The aim of this study is to investigate the abrasive wear performance of the selected metal matrix composites. The wear resistance of the studied materials are tested by dry sand rubber wheel abrasion test (ASTM G 65-91) and Nordberg laboratory cone crusher test. It is also studied if there are any correlations between these tests so that dry sand rubber wheel abrasion test could be used to rank composite materials for rock crushing applications.

2. Materials and test procedures

The metal matrix composites were made by HIP using Ralloy®WR6 tool steel as matrix material. The chemical composition of Ralloy®WR6 was 2.9 wt.% C, 5.25 wt.% Cr, 11.5 wt.% V, 1.3 wt.% Mo, <1 wt.% Mn, <1 wt.% Si, <0.03 wt.% P, <0.03 wt.% S and remainder Fe. This steel contains about 20 vol.% of vanadium carbide after a typical heat treatment cycle. The particle size of used matrix powder was −350 μm. Four different carbides were added to modify the material: recycled cemented carbide (WC–10Co), tungsten carbide (WC), dense coated cemented carbide (WC–Co) and titanium carbide (TiC). Reinforcement contents varied between 17 and 30 vol.% and the particle size between 45 and 425 μm. The compositions of the studied composites are given in Table 1.

HIP processing was carried out at a temperature of 1150 °C and at a pressure of 100 MPa for 3 h. After compaction Ralloy®WR6 matrix composites were austenitized at 1080 °C for 2 h followed with a forced air cooling and a subsequent 2 + 2 h double tempering at 570 °C.

Table 1
The compositions of the studied composites

Composite	Reinforcement	Particle size (μm)	vol.%
17 vol.% WC–10Co MMC	WC–Co	200–400	17
20 vol.% WC MMC fine	WC	45–90	20
20 vol.% WC MMC	WC	250–425	20
30 vol.% WC MMC	WC	250–425	30
30 vol.% WC/Co MMC fine	WC–Co	45–90	30
30 vol.% WC/Co MMC	WC–Co	200–300	30
30 vol.% TiC MMC	TiC	75–250	30

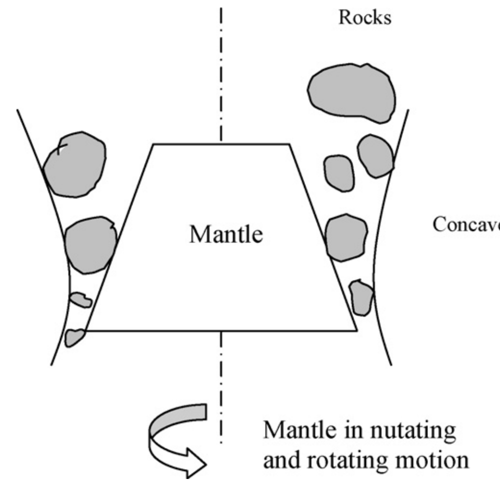

Fig. 1. Principle of cone crusher.

The microstructure of the matrix and the reinforcement, the distribution of the reinforcement and the matrix/reinforcement interfaces were investigated by optical and scanning electron microscopy (SEM). The chemical composition of the matrix/reinforcement interface was determined with an EDS analysis.

The materials were tested for abrasion by dry sand rubber wheel abrasion test made essentially according to ASTM G 65-91 A. The used normal force was 130 N. The abrasion tests were carried out in three parts, each for 1436 m, so that the total wear distance was 4308 m (about 30 min). Nilsiä Quartz sand from Nilsiä Finland (company of SP Minerals) with a particle size of 100–600 μm was used as an abrasive. The sand flow was 470–490 g/min. Two 30-min abrasion tests were done and the averages of the results were counted. In this study the wear resistance was defined as a volume loss in cubic millimetres. The volume loss was defined using the experimental density and the mass loss. The abrasive wear tests were carried out at Helsinki University of Technology, Finland.

The cone crusher tests were carried out at the Metso Minerals' testing laboratory in Tampere, Finland. The small-scale Nordberg laboratory cone crusher, B90, can be classified as a compressive crusher. The stones are crushed in compression in the cavity between the concave and the mantle (Fig. 1). The dimensions of the B90 are: length 765 mm, width 765 mm, and height 720 mm. The total weight of the equipment is 260 kg. The tests were designed to obtain information on the wear rates of the mantle. The feed was granite stone sieved into 10–20 mm size and dried before the tests. The ultimate compressive strength, UCS, of the granite stone is 193.9 MPa. About 2500–4500 kg abrasives were used for each test material and the wear was measured three to six times for each material. More information on the cone crusher test can be found in Ref. [9].

3. Results and discussion

3.1. Microstructure of the composites

Most of the studied materials are double dispersion composites because the matrix of the composites consists of tempered