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Short communication

Surface fatigue processes at impact wear of powder materials

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Abstract

The problem of the fatigue strength of wear resistant materials is significant both from the theory and practical point of view. In abrasive wear two different mechanisms of material removal occur either separately or simultaneously. At abrasion and low-angle abrasive erosion, microcutting is dominating and the main criterion for materials selection is hardness. At abrasive impact wear and high angle abrasive erosion by irreversible deformation, direct fracture and low-cycle fatigue mechanism are dominating and materials fracture toughness is important.

The aim of this work is to determine and compare fatigue behaviour at abrasive erosion and abrasive impact wear as well to study surface fatigue of the high-tech powder materials—PM/HIPed tool steels and conventional wear resistant steels. An attempt to find correlation between abrasive erosion and abrasive impact wear rates with materials surface fatigue resistance was made.

Keywords: Powder materials; Wear; Erosion; Impact wear; Surface fatigue

1. Introduction

The estimation of the fatigue strength of wear resistant materials, particularly powder materials containing pores, defects or inhomogeneities, is important both from the theory and practical point of view. These materials are related to so-called "structurally brittle" materials and their behaviour at different wear conditions may be unpredictable.

High surface hardness of traditional materials does not always provide the wear resistance required for faultless operation of machine parts and tools under the conditions of abrasive erosion and impact wear. Removal of material in wear is caused by impact and cyclic loading and high contact pressure as a result of direct fracture or fatigue processes. Thus, toughness and fatigue properties of materials are as important as their hardness parameters.

It is well-known that there is a substantial difference between ductile and brittle materials when the weight loss in erosion is measured as a function of the impact angle. Ceramic materials are considered sufficient to reduce scratching and micromachining surface damage exposed to low-angle impacting particles because of their high hardness and stiffness. At the high angle of impact, the exposed surface should be able to withstand repeated deformation and more elastic materials with higher toughness, such as steels, are usually preferred to cermets in which cracks propagate rapidly and lead to material removal. At abrasive erosion and impact wear, where a wide range of impact angles are applied, the contradicting properties of material—hardness and fracture toughness are required. Composite materials, special reinforced metal-matrix composites and so called "double cemented" metal-matrix structures allow a partial solution of this problem [1].

If material hardness exceeds that of an abrasive, erodent particles can hardly cause a plastic flow in the hard target. The degree of elastic penetration and therefore the energy transmitted to a surface depends on the elastic modulus and, if the latter is high, less elastic penetration occurs. Therefore, as compared to abrasive hardness, the modulus of elasticity is one of the most important parameters influencing the wear resistance in the case of harder materials [2]. Under these conditions, particle impacts may cause a low-cycle fatigue failure of the reinforced metal-matrix and hard phase particles.

If the hardness of an abrasive exceeds that of a material, the following processes take place: penetration of erodent particles into the material surface, microcutting or ploughing, failure of hard phase particles resulting in the detachment of small chips.

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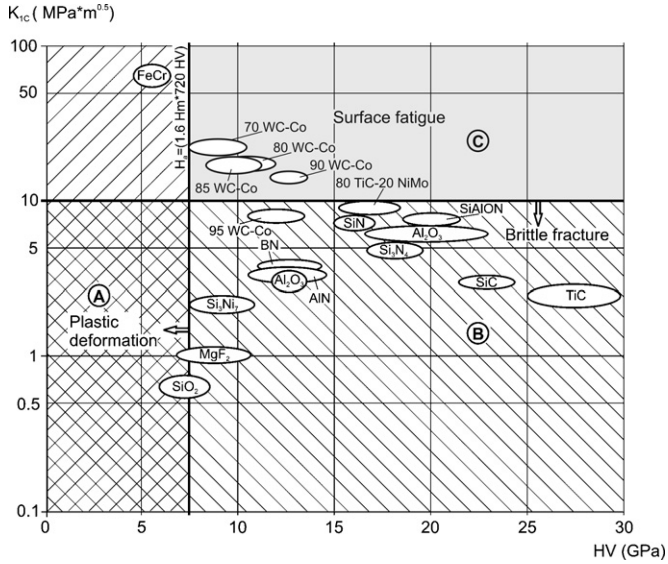

Fig. 1. Erosion wear mechanisms of wear resistant materials (toughness K_{1C}; hardness HV map). Prevailing mechanism of wear: (A) plastic deformation, (B) brittle fracture, and (C) surface fatigue [3].

Since the erosion of brittle grains is primarily caused by a mechanism involving the initiation and propagation of microcracks, one expects that the fracture toughness of the material will affect the erosion rate. The toughness–hardness map of wear resistant materials proposed in Ref. [3] is shown in Fig. 1. It was demonstrated, that the wear of materials with low fracture toughness (below 10 MPa $m^{0.5}$ by erodent, silica) is caused mainly by the brittle fracture (area B), the wear of materials with low hardness (less than abrasive hardness) is caused mainly by microcutting (area A). At higher hardness and fracture toughness, surface fatigue is dominating (area C).

Attempts to correlate the solid particle erosion rates of composite materials with experimental and materials parameters were made in [3,4]. In the proposed models, hardness and fracture toughness emerge as the main material parameters that control erosion; high hardness increases resistance to plastic deformation while high fracture toughness increases resistance to fracture. Depending on the intensity of the impact processes, the contact can lead to reversible or irreversible deformation in the surface area of the basic body. The reversible impact process generates only stresses in the target surface layer, which lie below the yield strength. Consequently, they are of elastic nature. Due to elastic deformation, material removal can be caused by fatigue. Nevertheless, this wear component at abrasive erosion is many times lower than that caused by irreversible deformations however considerable at impact wear. The process of material removal starts after a relatively low deformation, i.e., contacts between abrasive particles and the target. Thus, in abrasive wear, one of the mechanisms of material removal is surface fatigue wear.

Fatigue performance of wear resistant materials under cyclic loading and monotonic loads has been tested by different researchers [5,6]. It has been found that the fracture at adhesive wear and fatigue in hardmetal-type material start similarly – predominantly in the binder phase (extrusion–intrusion mechanism), in contrast to abrasive erosion and sliding wear [5]. To test the surface fatigue of wear resistant materials a special study

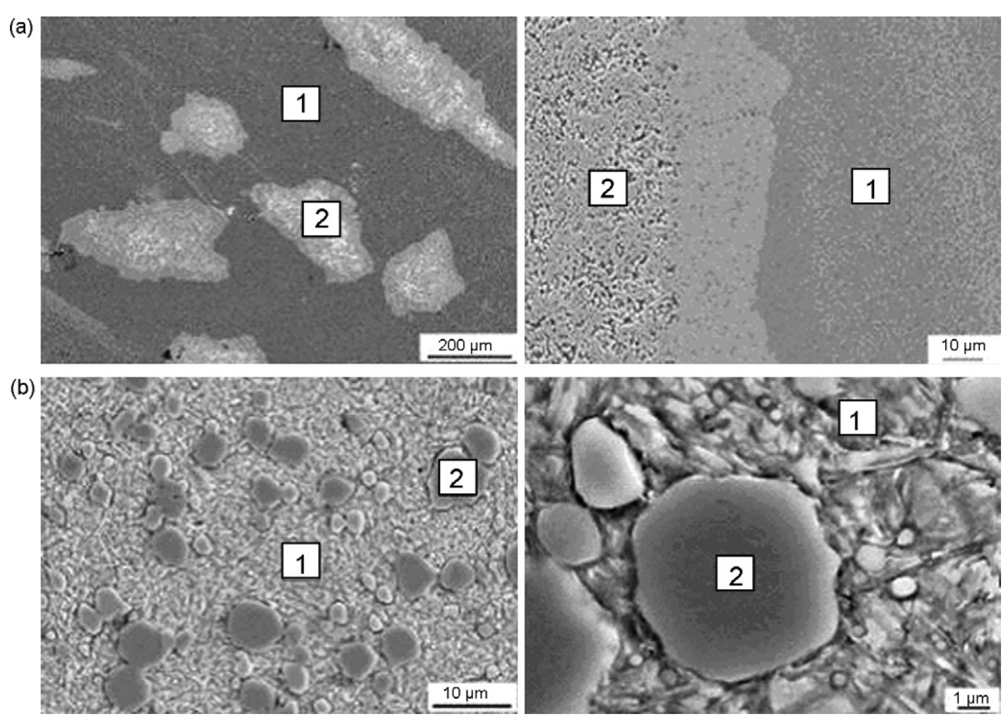

Fig. 2. Microstructures of the studied powder materials: (a) MMC ((1) (Cr-steel + VC); (2) WC particles); (b) Weartec® ((1) Cr–Mo–V-steel; (2) VC particles) at different magnifications.