Microstructure based modeling of angular impact on a martensitic steel and a metal matrix composite

Anssi Laukkanen[2)*], Matti Lindroos[1)], Marian Apostol[1)], Veli-Tapani Kuokkala[1)], Kauko Östman[1)], and Kenneth Holmberg[2)]

[1)] Tampere Wear Center, Department of Materials Science, Tampere University of Technology, P.O. Box 589, FI-33101 Tampere, Finland
[2)] VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT Espoo, Finland
[*]Corresponding author: anssi.laukkanen@vtt.fi

1. Introduction

Hard martensitic steels and metal matrix composites have been proven to be reasonably resistant to abrasion. Partly due to the high yield strength of the martensitic steels, they can endure great deal of stress during the contact before plastic flow occurs at a larger scale. Shear localization, however, may occur due to active slip in favorable orientations, eventually leading to the formation of wear particles. Similarly, because the metal matrix composites usually consist of hard and wear resistant particles in a binder phase forming a strong compound, the stress concentrations in the microstructure are a result of its morphologically complex character. The shape, distribution, mechanical properties and quantity of hard phases all affect the wear behavior of the composite. Especially when the materials are exhibiting high strain rate deformation during an impact event, the stress concentrations may lead to a premature failure.

This paper presents a study of high strain rate angular impact behavior of a wear resistant steel and a metal matrix composite. Experimental work focuses on the deformation and optically visible surface changes in the microstructure. Numerical simulations are aimed to produce a more comprehensive understanding of the stress-strain behavior of the descriptive microstructures during the impact event. Common constitutive models are implemented in the simulations based on the characterization of the microstructures to capture the anisotropic deformation behavior.

2. Materials and methods

Impact resistant 500 HB martensitic steel and a 750 HB metal matrix composite were tested with High Velocity Particle Impactor (HVPI). Round tungsten-carbide projectiles with a diameter of 9 mm were fired with compressed air. The WC projectiles were chosen for their rigid nature during the impact to avoid significant plasticity of the projectiles. The single impact incident was monitored with a high speed camera setup and a piezoelectric force sensor. The samples were fixed in the angular positions of 15, 30 and 60 degrees. Several high energy impact velocities were studied between 45 and 115 m/s.

The microstructures were characterized with electron microscopy employing the electron back scatter diffraction (EBSD) technique for identifying the material grain structure and crystal orientations. The microstructurally representative volume element (RVE) blocks for finite element analysis were generated based on the EBSD data. For the martensitic steel an adapted stochastic tessellation approach was utilized to capture its lath-like appearance. For the metal matrix composite, a cherry-pitting algorithm incorporating particle clustering was applied. The macroscopic high and low strain rate stress-strain behavior was determined using the compressive Hopkinson split bar technique and quasi-static compression tests. In micro-scale the features were tested with nano- and micro-indentation techniques to define the small scale yield behavior.

The impact craters were studied with optical and electron microscopy to reveal changes, damage and deformation mechanisms in the microstructures.

3. Results and discussion

The numerical results are in agreement with the deformation behavior observed in the experimental tests. The material loss and deformation were dependent on the impact angle in both materials, which was confirmed by different stress-strain states in the simulations. In the metal matrix composite, the distribution of stress within the microstructure is dependent on the particle networks in the matrix during the impact event. This indicates that the particles are acting as brittle initiation sites for cracks that may develop around the hard phases, leading to complete fracture. The compressive residual stresses in the composite, however, indicate improved resistance against continuous impacts if fracture initiation does not occur.

The martensitic steel exhibits formation of shear bands in the microstructure near the heavily deformed craters in the experiments. The shear band formation is directly linked to the anisotropic slip within individual laths, their particular morphology and local misorientation. These shear bands may be responsible for the initiation sites of wear particles during repeated impacts and are considered to be the most important microstructural mechanism with respect to failure initiation and propagation mechanisms. However, at the same time the steel exhibited work hardening, which on the other hand can increase its resistance to impact-abrasion. The numerical results demonstrate a correlation between the material microstructure, mechanisms of deformation, and the behavior of the materials under dynamic impact-wear type conditions. The results act as a basis for further microstructure based improvements of the material performance.