Wear 270 (2011) 439–445

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

A note on threshold velocity criteria for modelling the solid particle erosion of WC/Co MMCs

B.D. Jana, M.M. Stack*

Department of Mechanical Engineering, University of Strathclyde, James Weir Building, 75 Montrose St., Glasgow G3 6DD, United Kingdom

ARTICLE INFO

Article history:
Received 4 August 2010
Received in revised form 2 December 2010
Accepted 9 December 2010
Available online 15 December 2010

Keywords:
Solid particle erosion
MMCs
Model
Threshold effects

ABSTRACT

The threshold velocity for erosion of a ductile material is considered as the velocity required for initiation of plastic deformation in the substrate. For a brittle material, it defines the velocity required to nucleate a median crack in the elastic/plastic interface beneath the indentation. By invoking models for the solid particle erosion of ductile and brittle materials from the literature, together with a set of criteria based on threshold velocity calculations for erosion of the individual components, various predictions of erosion behaviour of WC/Co MMCs have been made. Qualitative agreement was found between the model predictions and various trends of the solid particle erosion behaviour of WC/Co cermets in the literature. The implications of the findings in addressing some of the puzzling trends of the solid particle erosion of MMCs in the literature, and how such insights may result in a reconsideration of some "classical" solid particle erosion relationships, are addressed in this paper.

1. Introduction

The purpose of this work has been to model the erosion of a metal matrix composite, by considering threshold criteria for erosion of the ductile and brittle phases of the composite, Figs. 1–2, in the composite, Fig. 3. In the literature, there has been some confusion on the effect of increasing reinforcement on the erosion of metal matrix composites MMCs [1–5]. Such effects are discussed in the context of the analysis of the model below and various trends observed for the solid particle erosion of metals and ceramics.

Early work on the erosion of WC/Co cermets showed a monotonic decrease in erosion rate with an increase in the volume fraction of reinforcement at normal impact at 133 m s^{-1} and with 10 μm silica particles [6], Fig. 4; in another study, for erosion of a similar material, at 40 m s^{-1} and with 100 μm SiC particles, the erosion rate increased up to a critical point whereupon it commenced to decrease again [7], Fig. 5. For the data, reported in [7], Fig. 6, the effect of impact angle showed that at lower values, i.e. 15° and 30°, a monotonic reduction in erosion with this variable was observed, thereby suggesting that as the normal component of velocity was increased (as is the case with an increase in impact angle), the trends in erosion with impact angle were reversed.

Considering, the erosion of ceramics and metals separately, some surprisingly similar observations have been made to the behaviour for metal matrix composites above. For ceramics, i.e. the erosion of soda lime glass, a monotonic increase in erosion with impact angle has been observed for larger particles sizes, Fig. 7, i.e. 21 μm, unlike the behaviour observed for the smaller 9 μm particles [9]. For erosion of mild steel for 50 μm angular SiC particles, Figs. 8 and 9, a peak in erosion was initially obtained up to 30°. This was followed by a decrease in erosion above such impact angles, Fig. 8. When the particle size was increased by a factor of 2 to 95–105 μm, using crushed glass beads as the erodent, a monotonic increase in erosion was observed [9], as a function of increasing impact angle. (In this study, the change in erosion behaviour was attributed to a perceived change in shape, citing the crushed glass particles as spherical and the SiC particles as angular in shape. However, the fact that the particle size was increased by a factor of two in the former case was neglected in the analysis of the results.)

For MMCs, other studies have also observed such puzzling trends. In some cases, i.e. in the erosion of Ni–Cr–WC based MMCs, the addition of reinforcement particles resulted in a reduction in erosion rate up to a critical volume fraction. Above such volume fractions, an increase in erosion rate with increasing volume fraction was observed [10].

Such trends, for metallic and ceramic materials, have to some extent been addressed in the solid particle erosion literature through analysis of threshold effects of impact velocity and particle size on the erosion mechanism [11–16]. A threshold particle size for erosion of ductile materials was derived by Shewmon [11], where he pointed out that particles sizes below a nominal threshold value were incapable of removing material through plastic work. Lawn

* Corresponding author. Tel.: +44 141 5483754; fax: +44 141 5525105.
E-mail address: margaret.stack@strath.ac.uk (M.M. Stack).

0043-1648/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2010.12.001

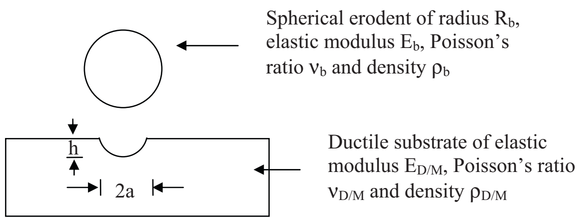

Fig. 1. Schematic diagram of an erosion event by a spherical indenter on a ductile surface.

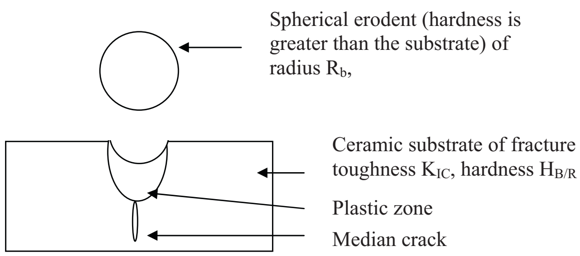

Fig. 2. Schematic diagram of an erosion event by a spherical indenter on a brittle substrate surface causing the formation of median cracks in the surface.

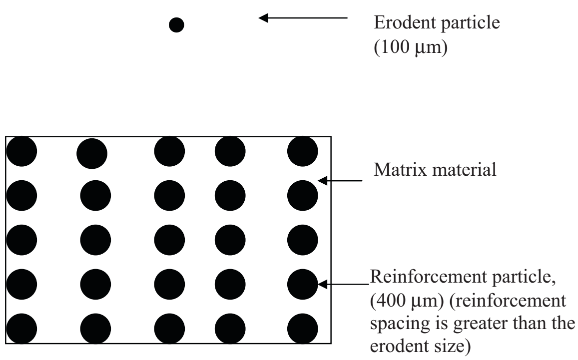

Fig. 3. Schematic diagram of the erosion processes of a particulate reinforced MMC as represented in the mathematical model.

and co-workers [12–14], and Swain and Hagan [16] identified particle size as playing a key role in the indentation fracture mode of a brittle material. Impacting particles greater than 1 mm in diameter were thought to cause Hertzian cracking, whereas impacts below this size were thought to result in plastic deformation and formation of median cracks. In other work, Hutchings [17] generated erosion maps for ceramics, using threshold velocity criteria, and indicated the importance of particle size and velocity on the erosion rate transitions for these materials. However, what has not been attempted to date, is to use such threshold velocity criteria for the ductile and ceramic phases of an MMC to model the erosion behaviour.

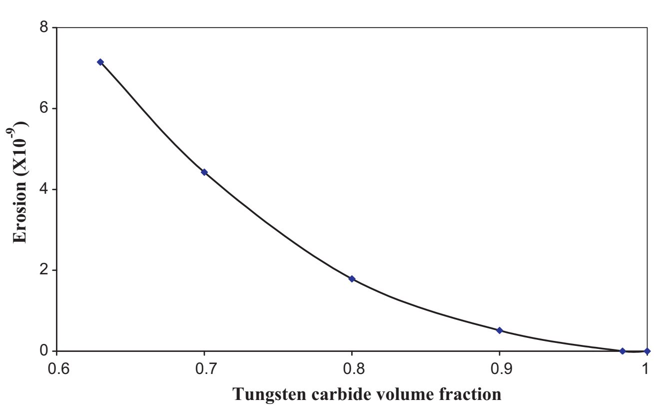

Fig. 4. Erosion rate versus volume fraction of WC for a WC–Co cermet, following impact by a slurry of 10 μm silica particles in oil at 133 m s^{-1} and impact angles of 90° [6] (threshold velocity for erosion of Co is 0.21 m s^{-1}, and WC is 2651.6 m s^{-1}, according Eqs. (9) and (13), respectively).

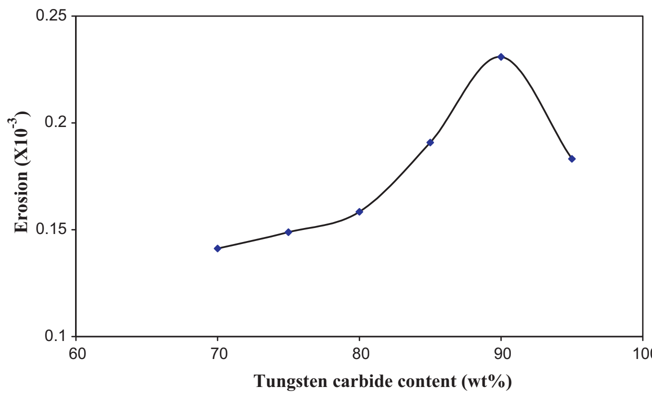

Fig. 5. Erosion rate versus WC content for a WC–Co cermet, following impact by a slurry of 100 μm silicon carbide particles at 40 m s^{-1} and at impact angles of 90° [7] (threshold velocity for erosion of Co is 0.21 m s^{-1}, and WC is 26.52 m s^{-1}, according to Eqs. (9) and (13), respectively).

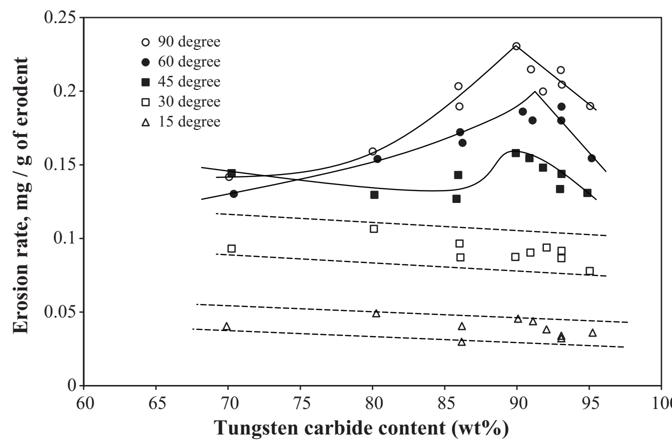

Fig. 6. Erosion rate as a function of WC content for a number of impact angles using 100 μm SiC particles [7].

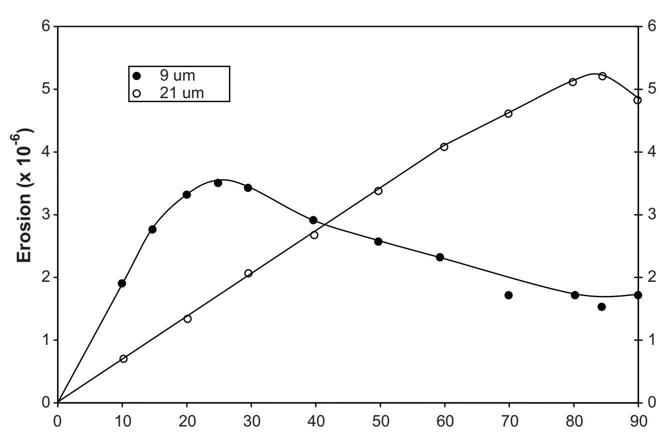

Fig. 7. Dependence of erosion rate on impact angle for soda lime glass eroded by 9 μm and 21 μm SiC particles at 136 m s^{-1} [8].