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# Modelling particulate erosion–corrosion regime transitions for $Al/Al_2O_3$ and $Cu/Al_2O_3$ MMCs in aqueous conditions

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**Abstract**

Very little research effort has been directed at development of models of erosion–corrosion of composite materials. This is because, in part, the understanding of the erosion–corrosion mechanisms of such materials is poor. In addition, although there has been a significant degree of effort in the development of models for erosion of MMCs, there are still difficulties in applying such models to the laboratory trends on erosion rate.

In this paper, the methodology for mapping erosion–corrosion processes in aqueous slurries was extended to particulate composites. An inverse rule of mixtures was used for the construction of the erosion model for the particulate MMCs. The corrosion rate calculation was evaluated with reference to the matrix material.

The erosion–corrosion maps for composites showed significant dependency on pH and applied potential. In addition, the corrosion resistance of the matrix material was observed to affect the regime boundaries. Materials maps were generated based on the results to show the optimum composite composition for exposure to the environment.



*Keywords:* Erosion–corrosion; MMCs; $Al/Al_2O_3$; $Cu/Al_2O_3$; Maps; Models

## 1. Introduction

In studies of erosion–corrosion of composite materials, there have been few attempts to model the process [1–5]. This is despite the fact that composite materials may offer an improvement in erosion resistance in comparison to conventional alloys. Increasing the volume fraction of re-inforcement, either in the form of fibres or particulates, increases the stiffness of the material [1–5]. The overall hardness is thus increased as a result; however, the fracture toughness as a result of incorporation of ceramic material into the matrix is decreased, a factor which may have a negative effect on the erosion resistance in fracture-dominated conditions [1–5].

There have been puzzling results on the solid particle erosion and abrasion of composite materials that can be linked to the transition between ‘ductile’ and ‘brittle’ erosion behaviour of the composite material. For the solid particle erosion of Ni–Cr/WC based MMCs, there was a minimum in the erosion rate at intermediate volume fractions [4,5]. Above this threshold value, the erosion rate increased with increasing volume fraction of hard particles in the system. This unexpected increase in erosion rate was attributed to the transition to a brittle fracture-dominated erosion regime. In such cases, the addition of hard particles into the matrix proved to be deleterious because here fracture of the re-inforcement was the dominant wastage mechanism.

Such observations had been made in earlier work on the abrasion of $Al/Al_2O_3$-based composites [1]. Here, a minimum was established for the relative wear rate of the composite material as a function of volume fraction. Further work on the effect of impact angle of such materials showed that changes in impact angle and erodent composition shifted the peak wear rate, as a function of increasing re-inforcement volume fraction, indicating that the wear of composites can change significantly, depending on the MMC and the erosion conditions [3].

In the development of models for erosion of MMCs, there have been various attempts to base them on the inverse rule of mixture criterion, accounting for erosion methodologies for the ductile matrix and brittle re-inforcement [6]. However, the inverse rules of mixture approaches have well

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recognized limitations. Scattergood (in a study of an Al/SiC system) points out that there may be a threshold volume fraction of re-inforcement below which the inverse rule of mixture approach does not apply; however, based on experimental work by Wang and Hutchings [3] and Stack and Pena [4,5], it seems that this threshold volume fraction is dependent on the contact conditions, as defined by the particle and target parameters.

Erosion of particulate MMC is likely to occur by plastic deformation of the matrix and dislodgement of the reinforcing particles as a whole or in the form of fractured particles. Research has shown [7,8] that the size of the plastic zone formed in an eroded sample of a particulate MMC was less than that of the corresponding monolithic material; in this study, the rate of erosion of the composite was higher than that of the base alloy and the rate increased with increases in particulate content. This differs from other results, where a minimum in erosion rate as a function of increasing re-inforcement volume fraction was observed [3,4].

Composite-based materials are increasingly been used in erosion–corrosion environments [9]. However, there has been virtually no work to model such processes, despite the probable widespread applicability of such a model. In this work, the erosion–corrosion performance for a range of Al and Cu /$Al_2O_3$ composite-based materials was modelled using an inverse rule of mixture erosion model. Erosion–corrosion mechanisms and wastage maps were generated from these models. In addition, materials performance maps for erosion–corrosion resistance were generated using this approach. Current limitations in terms of the applicability of the erosion models used, in addition to possible extensions of the erosion–corrosion algorithm developed, are addressed as part of this study.

## 2. Methodology

### 2.1. Assumptions

(i) Erosion–corrosion occurs on an ideal MMC consisting of spherical ceramic particle re-inforcement in the ductile matrix, Fig. 1.
(ii) Erosion occurs on both the matrix and the brittle re-inforcement phase.
(iii) An inverse rule of mixture analysis is made for erosion of the MMC; the erosion rates of the ductile matrix and the brittle re-inforcement are derived from a model existing in the literature, Fig. 2(a,b).
(iv) The re-inforcement particles are considered to be inert and not to corrode.
(v) The Butler–Volmer equation for estimating corrosion in aqueous conditions is modified for the area fraction of matrix subjected to corrosion.
(vi) Erosion occurs as a result of spherical particles impacting the metal surface at normal incidence and the only force acting on the surface is the contacting force exerted by the metal surface.
(vii) The crater formed due to impact remains in an unrelaxed state and is considered to be a section of a sphere.
(viii) Unless explicitly stated, the rebound velocity is negligibly small, i.e. all the impact energy is dissipated as plastic work.

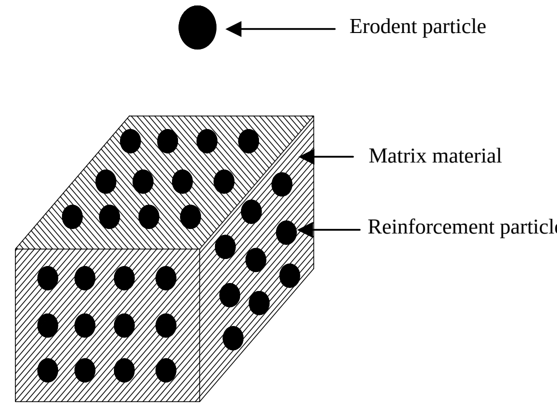


Fig. 1. Schematic diagram of an erosion event for a particulate reinforced MMC.

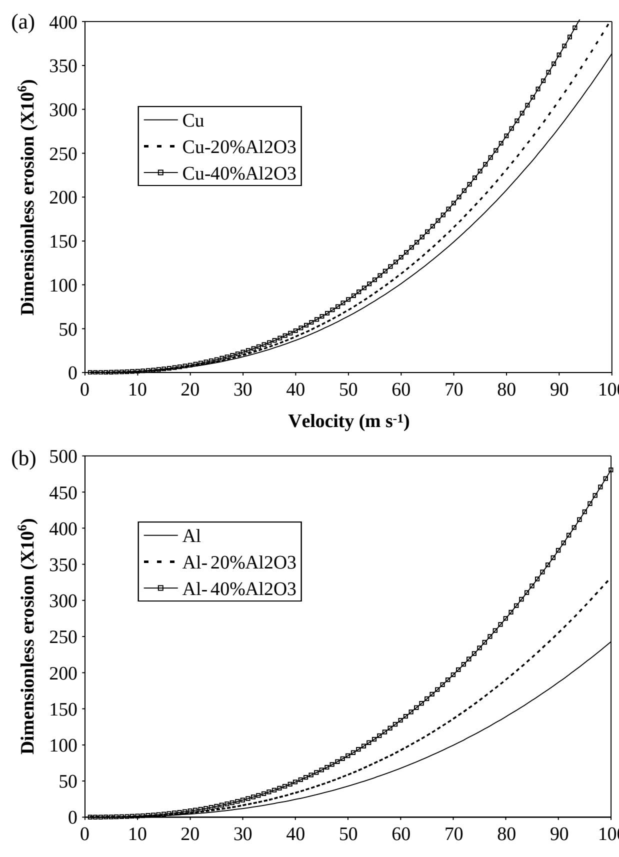


Fig. 2. Dimensionless erosion prediction of (a) Cu/$Al_2O_3$, (b) Al/$Al_2O_3$ MMCs.