SOLID PARTICLE EROSION MODELS FOR TITANIUM AND ALUMINUM METAL MATRIX COMPOSITES

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Abstract: *Solid particle erosion behavior in composite materials is difficult to estimate due to the complex structure and interactions between the continuous and discontinuous phases. This paper refers to the semi-empirical mathematical correlation between the solid particle erosion rates of metal matrix composites and the erosion rates of the matrix alloys. Two well known examples were used to create correlation functions for aluminum and titanium matrix composites. Both correlation functions are in good accordance with the experimental datasets from the literature. Also, the functions are non-dimensional which means they can be used for volumetric as well as mass erosion rate measurements. A final benefit of the proposed models is that they can be used in conjunction with conventional erosion models such as the models of Hutchings, Sundararajan or Wallace, to provide semi-analytical erosion estimations. Further work will have to integrate new experimental data in order to extend the models database.*

Keywords: *metal matrix composite, solid particle erosion, semi-empirical mode, curve fitting*

1. INTRODUCTION

Because of the mechanical and thermal loadings to which the aeronautical propulsion systems are subjected, composite materials make up a small percentage of the turbine engine components. Although phenolic and epoxidic matrix composites have been used, in conjunction with metal alloys, for fan blade fabrication Matheny A.P. (2009), in the hotter parts of the turbine engine, only metal matrix composites (MMCs) can be used as alternatives to conventional metal alloys D.R. Pank & J, Jackson(1993).

In order to reinforce metals, particularly aluminum alloys, with carbon fibers, the fibers must be coated with a thin layer of nickel or titanium boride. The process is complex and provides the fibers with a microscopic layer of nickel or titanium boride which helps the bonding of the fibers to the metal matrix. A patent describing MMC fabrication for aerospace applications was obtained by Bell et al. (2003).

Other fabrication technologies may be found in Evans et al (2003). Wiest (1992) makes a good synthesis for the mechanical properties of aluminum based MMCs, more properties of MMCs are found in Kainer (2003).

The usefulness of MMCs in aerospace applications is derived from their mechanical advantages over conventional materials as shown by Stuart (1992) and Singerman & Jackson (1996) .

More recent studies regarding the application of MMCs in the aeronautical field are described in Vaidya et al (2006) and, for more general purposes in Rawal (2001) .

2. THE MMC EROSION MODELS

As stated in the introduction, metal matrix composites are more commonly found in the fabrication of turbo-machineries than other types of composite materials. This is due to their thermo-mechanical properties which are superior to both the base alloy and phenolic or esteric matrix composites.

In the following sections, we interpret some of the most relevant experimental data found in the literature in order to obtain a mathematical model for estimating the erosion rate for airborne solid particles on titanium and aluminum matrix composites.

The interpretation of the experimental data in the literature is based on the observation that MMCs display a slightly higher erosion rate than the matrix alloy. Therefore a correlation function was derived in both cases below, linking the MMC erosion with that of the matrix alloy – which can be estimated through conventional erosion models such as Hutchings (1981), Sundararajan (1991) or Wallace et al (2000).

In order to obtain the mathematical correlation equation, a non-linear regression method was used, similar to the ones described in Baker (2008), Bethea et al. (1985) or Geaghan (2012).

2.1 The titanium matrix composite with aluminum fibers

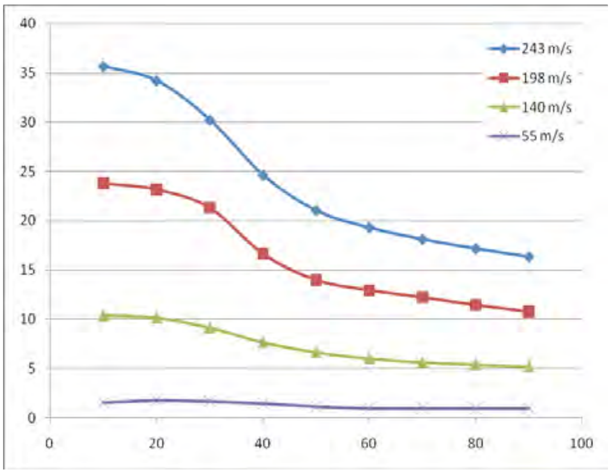
As seen in Wilson & Ball (1990) and Tua et al(1998) , by reinforcing composite materials with various fibers, the solid particle erosion rate increases.

In their paper, Tua et al.(1998) presents a series of experiments in which he describes the erosion of an AC4C titanium matrix composite reinforced with un-oriented Al18B4O33 aluminum fibers. Figure 1 presents a comparison between the erosion rate for the composite and for the base alloy (which makes up the matrix). It can be observed that, although similar in shape, the maxima of erosion rate for the composite is obtained at approximately 30º angle of impact. This tendency diminishes at low impact velocities.

Due to their similarities, the two graphs may be correlated through a mathematical function. This will permit the estimation of erosion rate of a MMC based on the known erosion rate of the alloy which makes up the matrix. Since, at this point, the theoretical know-how of calculating erosion rates for metals is superior to that of composites, this correlation function could be considered a step forward.

In the current case, the existing experimental data were synthesized in Table 1. Based on this, the data was then subjected to an iterative non-linear regression algorithm in order to produce the correlation function:

$$E_{r(MMC)}/E_{r(Alloy)} = -1\cdot10^{-7}\,\alpha^4 + 3\cdot10^{-5}\,\alpha^3 - 2\cdot10^{-3}\,\alpha^2 + 6\cdot10^{-2}\,\alpha + 0.670 \qquad (1)$$



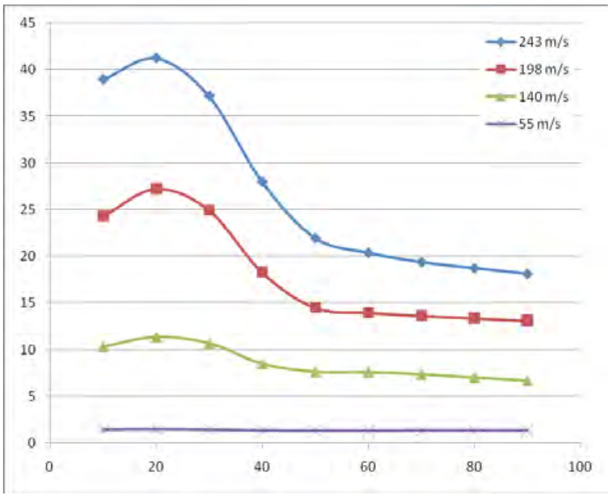


Fig.1. The erosion behavior of the Titanium alloy (top) and the Titanium alloy matrix composite (bottom)

A significant advantage of the proposed equation is that it is no longer confined to the dataset that generated it. This means that it does not refer to a volumetric erosion rate (such as the one described in the experimental paper), instead it is non-dimensional. Therefore it can be used, independently, with any available erosion rate pre-existing or acquired, without any other transformations or corrections.

Table 1. Sample data set used for correlating the solid particle erosion behavior of the Ti alloy and the Ti alloy matrix composite

	243 m/s		198 m/s	
Alfa	MMC	Ti	MMC	Ti
10	38.95	35.68	24.29	23.8
20	41.24	34.21	27.24	23.18
30	37.19	30.24	24.94	21.32
40	28	24.65	18.29	16.65
50	21.98	21.04	14.49	14
60	20.39	19.32	13.95	12.97
70	19.4	18.12	13.63	12.24
80	18.75	17.18	13.36	11.46
90	18.14	16.34	13.1	10.79

2.2 Aluminum matrix composite reinforced with particles

Wilson and Ball (1990) present in their paper, various studies regarding the mechanical properties of a MMC with aluminum 6061 alloy matrix (1%Mg, 0.6%Si, 0.2%Cu, 0.2%Cr) reinforced with 20μm silicon carbide particles. The experimental data provided was also interpreted in a similar manner. The same tendency was observed, in that the MMC eroded more than the base alloy.

After a new iterative process of non-linear regression, a curve fit was obtained for correlating the alloy in question with its MMC.

The following equation links the erosion rate of the MMC to that of the base alloy as a function of the angle of impact of the erodent particles.

$$E_{r(MMC)}/E_{r(Al)} = 2.26\cdot\alpha/(10.9+\alpha) \quad (2)$$

By comparison, the aluminum alloy composite tends to have a relative erosion rate higher than the titanium MMC relative erosion rate. This is a clear indication that the nature and geometry of the reinforcing structure plays a key role in the erosion rate of MMCs.

In Fig. 2, the experimental and mathematical equation are superimposed in order to show the accuracy of the model.

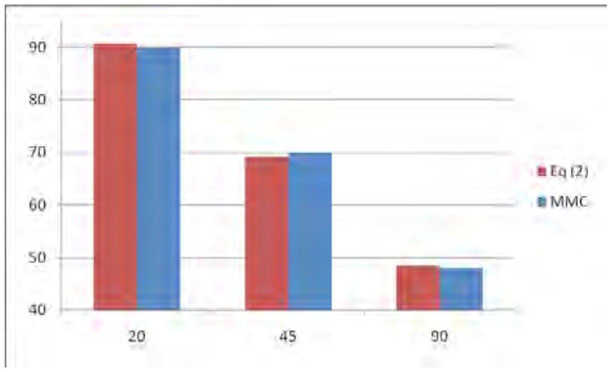


Fig.2. Sample experimental data and analytical correlation function for the Al 6061 MMC

3. CONCLUSIONS

The work described in this paper refers to the mathematical interpretation of existing experimental data, found in the specialized literature, in the field of solid particle erosion of metal matrix composites.

Estimating composite material erosion is a difficult technical problem, most recent studies being focused mainly on experimental data rather than theoretical models. The difficulty of developing a purely theoretical model lies in the complex fiber-matrix interaction.

The proposed model presumes that the matrix alloy has a solid particle behavior which can be predicted by the classical existing erosion models. Furthermore, by comparing the experimental results found in the literature, correlation functions have been developed – through non-linear regression. In this way, the theoretical predictions of classical erosion models may be linked to the erosion rate estimation for a metal matrix composite. The mathematical equations proposed are simple enough to be integrated in CFD solvers in order to estimate erosion rates for various mechanical components such as MMC blades of turbo machineries.

Further work should incorporate more experimental data as well as the accumulated know-how resulted from the application of the proposed methods.

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