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Modern Investigation of Different Failure Modes in Al/Sic Metal Matrix Composites

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Abstract: Metal matrix composites, especially particle reinforced composite generally fails due to matrix yielding, interface deboning (cracking) and particle fracture. These failure modes generally dominating as a single mode (or) combined effect. The composite strength and other properties strongly depend on the nature of interface bonding. The interfacial strength plays vital role in deciding strength of composite. The main function of interface region is to transfer the load from matrix to reinforcement. Interface failures such as reinforcement stress, matrix stress, composite stress, load transfer between matrix to reinforcement and interface strength, were evaluated by mathematical model for various volume fractions of reinforcement at different load conditions.

Keywords: Metal Matrix Composite, Failure criteria, Interface strength.

I. INTRODUCTION

Metal matrix composites (MMCs) generally ceramic particles reinforced composite exhibit higher specific strength and stiffness over monolithic alloys and have been used extensively in aerospace industry. However, the ductility of these materials is significantly reduced compared to unreinforced alloys, and the use of these materials in potential applications is hindered by their poor fracture toughness. Hence, designing composite against the failure criteria is essential which requires fundamental understanding of failure modes of MMC, Further the ways to minimize these failure modes. Thus, characterization of the fracture in MMCs has recently become a focus for research. Studies on fracture behavior of particulate-reinforced MMCs have been focused mainly on the particle/matrix interface. Relatively little work about the effect of the reinforced particle on the fracture properties of MMCs has been reported. Results suggest that the selection of a high-strength reinforcement material may be an alternative way to optimize the fracture properties of MMCs.

The interface between the matrix and the reinforcement plays a crucial role in determining the properties of MMCs. The fracture behavior is also dependent on the strength of interface. A weak interface results in a low stiffness and strength but high resistance to fracture whereas a strong interface produces high stiffness and strength but often a low resistance to fracture i.e. brittle behavior.

II. MATHEMATICAL MODEL

The basic equations to find the stress inside the reinforcement and matrix for the simple composite model, which allows to account for the volume fraction of reinforcement on the overall behavior is given by Babout et al.,(2004)

$\sigma_r = \sum a + \mu^* E_p$ ....(1)

$\sigma_m = \sum a + (V_r \mu^* E_p) / (1 - V_r)$ ....(2)

Where

$\sum a$ - Applied load

E_p - Plastic deformation in the matrix

V_r - Volume of fraction of reinforcement

μ^* - Depends on the elastic properties of reinforcement and matrix.

The calculation of the factor which depends on the elastic properties of reinforcement and matrix can be obtained using the equation (3).

$\mu^* = 2 V_r$ □□ $(\mu_m \mu_r) / (\mu_r -$ □ $(\mu_r - \mu_m))$ ….(3)

This Eshelby accommodation factor □ is given by Brown et.al (1975)

□□ = (7-5v) / 15(1-v)

Where

μ_m, μ_r - Shear modulus of matrix and reinforcement respectively
 - Eshelby accommodation factor
v - Poisson ratio
For quantifying the stress reduction in the reinforcement Babout et al. (2004) suggested to account for a progressive interfacial damage by introducing a so called damage function (Φ)

$\sigma_r = (\sum a + \mu^* E_p)(1 - \Phi)$ …….(4)

The modulus correction factor to account for elastic inhomogeneity which depends on the shape of the inclusion and on the ratio of shear modulus is

$D = \mu^* / (\mu^* - \quad (\mu^* - \mu)$ ……. (5)

The composite stress can be found based on the law of mixture i.e., given by Ding et al, (2002) is given by

$\sigma_c = (1 - V_r)\sigma_m + V_r \sigma_r$ ……. (6)

The stress transfer from matrix to reinforcement often called as load transfer stress which can be obtained by using the equation (X.D.Ding et al 2002)

$\sigma_{TR} = (\sigma_c - \sigma_m) / V_m$ ……. (7)

Where
V_m = Volume of matrix
$_c$ = Composite stress
$_r$ = Length of the SiC

III. MATERIAL PROPERTIES

The Al-SiC composite was treated as an isotropic perfectly elastic - plastic material following the generalized Hook's law. The mechanical properties of Al/SiC were given in the table.1.

Matrial	Elastic modulus (GPa)	Poisson ratio	Shear modulus (GPa)
Matrix (Al)	68.3	0.3	26
Reinforcement (SiC)	431	0.25	179

IV. REINFORCEMENT STRESS FOR DIFFERENT PLASTIC DEFORMATION OF MATRIX

The figure.1 shows the graph between reinforcement stress and the plastic deformation of matrix. The reinforcement stress is obtained for various plastic deformation of the matrix with different volume fraction of reinforcement under the different load condition. It was found that the reinforcement stress increases as the plastic deformation of the matrix and the volume fraction of reinforcement increases.

Volume fraction of reinforcement increases with decreased in volume of matrix. Therefore, when applied load increases more load easily transferred to the reinforcement and the stress induced in the reinforcement get increased while stress gathering capability of matrix get reduced.

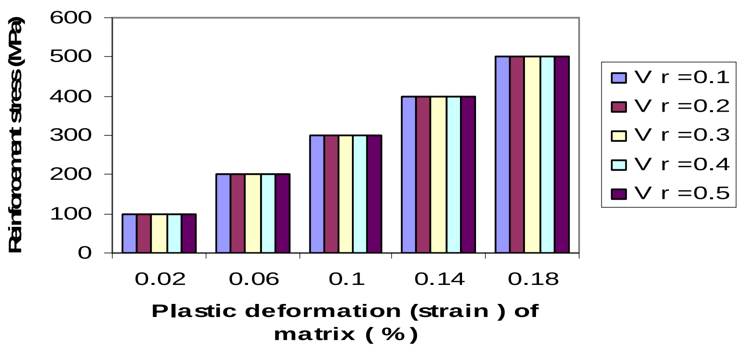

Figure 1 Reinforcement stress for different plastic deformation of matrix (Vr =volume fraction of reinforcement

V. MATRIX STRESS FOR DIFFERENT PLASTIC DEFORMATION OF MATRIX

The Figure 2 shows the graph between matrix stress and the plastic deformation of matrix. The matrix stress is obtained for various plastic deformation of the matrix with different volume fraction of reinforcement under the different loading condition. It was found that the matrix stress increases as the plastic deformation of the matrix and the volume fraction of reinforcement increases in undamaged condition

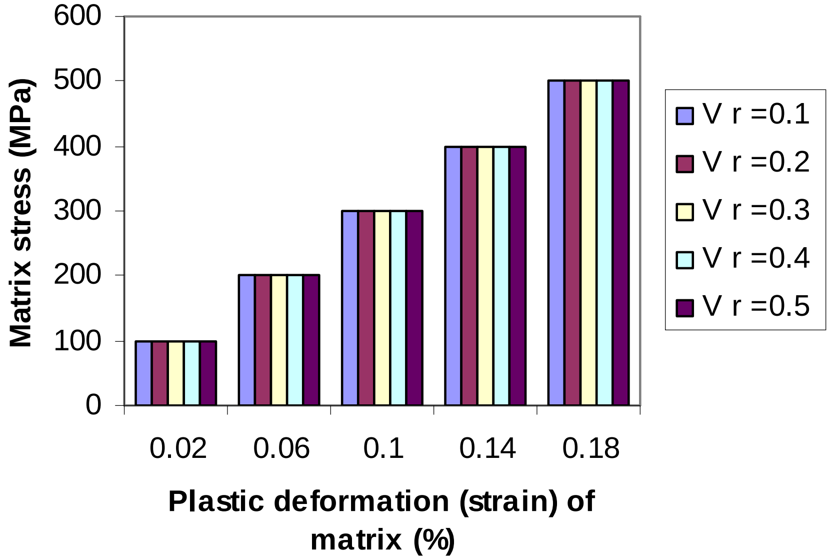

Figure 2 Matrix stress for different plastic deformation of matrix

VI. COMPOSITE STRESS FOR DIFFERENT PLASTIC DEFORMATION OF MATRIX (WITHOUT DAMAGED)

Figure 3 shows the graph between composite stress for Al/SiC and plastic deformation of matrix. The composite stress is obtained for various plastic deformation of matrix with different volume fraction of reinforcement under the different loading condition. It was found that the composite stress increases as the plastic deformation of matrix increases with respect to increase in reinforcement content.

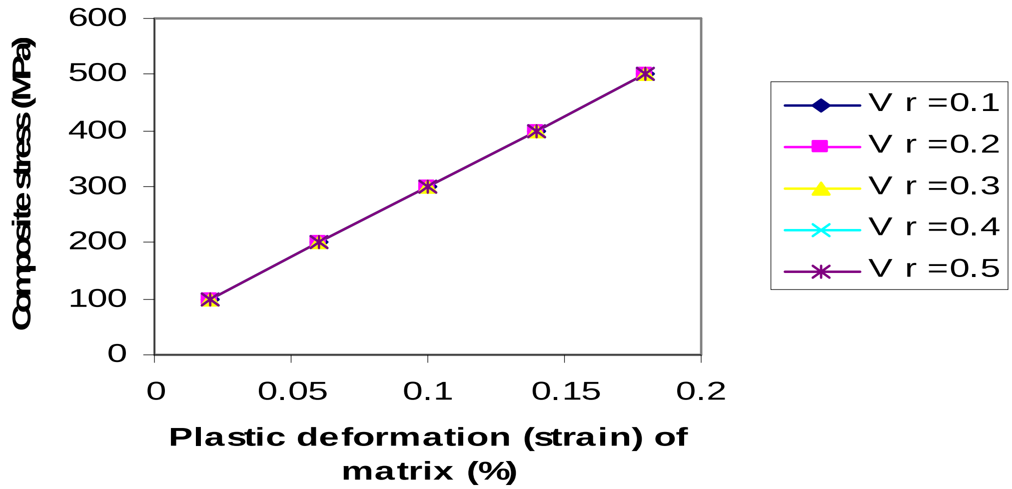

Figure 3 Composite stresses for different plastic deformation of matrix (Vr = Volume fraction of reinforcement) (wihout Damaged)

VII. COMPOSITE STRESS VS PLASTIC DEFORMATION (STRAIN) OF MATRIX (DAMAGED)

The Figure 4 shows the graph between composite stress for Al/SiC and plastic deformation of matrix for damaged condition. When damage is occurred the composite stress is decreased. The damage function quantifies the stress reduction in the reinforcement due to the extension of the crack at the interface. When the plastic deformation of matrix has reached a critical value, the damage function is equal to 1 and the stress in the reinforcement is totally relaxed

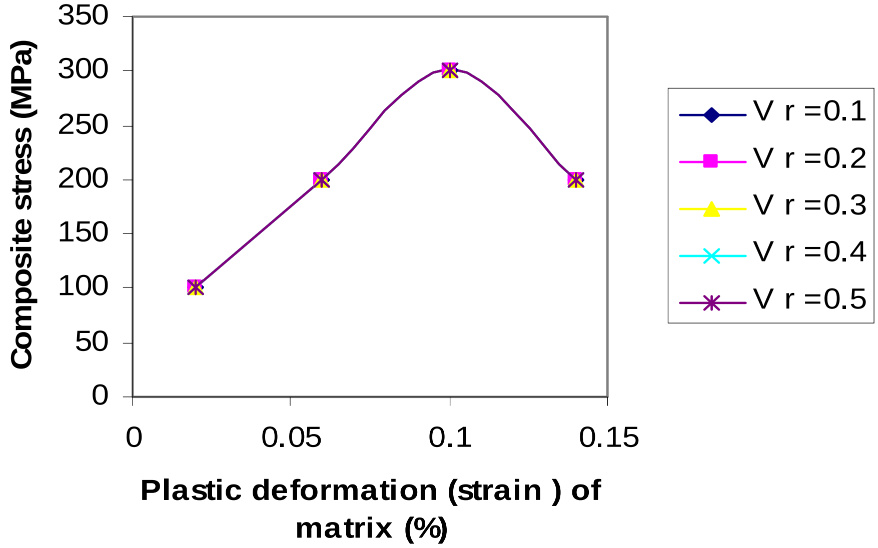

Figure 4 Composite stress Vs plastic deformation (strain) of matrix (Damaged)

VIII. LOAD TRANSFER BETWEEN MATRIX TO REINFORCEMENT FOR DIFFERENT PLASTIC DEFORMATION (STRAIN) OF MATRIX

The Figure 5 shows the graph between load transfer between matrix to reinforcement and the plastic deformation of matrix. The load transfer between matrix to reinforcement is obtained for various plastic deformation of the matrix with different volume fraction of reinforcement under the different loading condition. It was found that the load transfer between matrix to reinforcement increases as the plastic deformation of the matrix with respect to the increased in reinforcement content.

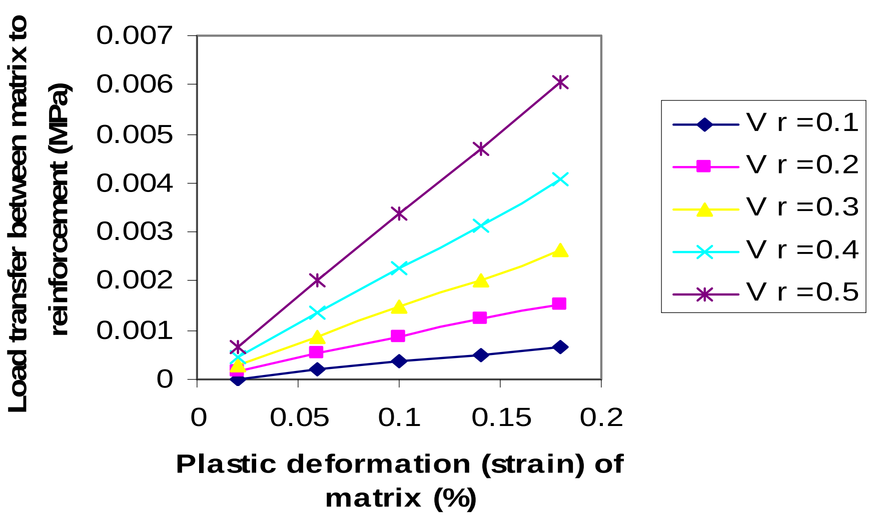

Figure 5 Shows Load transfer between matrix to reinforcement for different plastic deformation (strain) of matrix

IX. RESULTS AND DISCUSSION

Function of mathematical modeling is to calculate interface stress, reinforcement stress, matrix stress, and composite stress. This model also calculates the load transfer between the matrix to reinforcement and ultimate strength of composite. These are calculated by various volume fractions of reinforcement and different load conditions. Which are essential for understanding the mechanical behavior of composite. In Al/SiC composite, SiC deform elastically and Al deforms elastically (or) plastically.

X. CONCLUSION

From this study the following conclusion can be drawn.

A. The strengthening of composite is depending on the volume fraction of reinforcement.
B. The plastic deformation of matrix initiated by particle fracture and interface decohesion.
C. Composites failures mainly dominated by particles fracture, interface decohesion, volume fraction.

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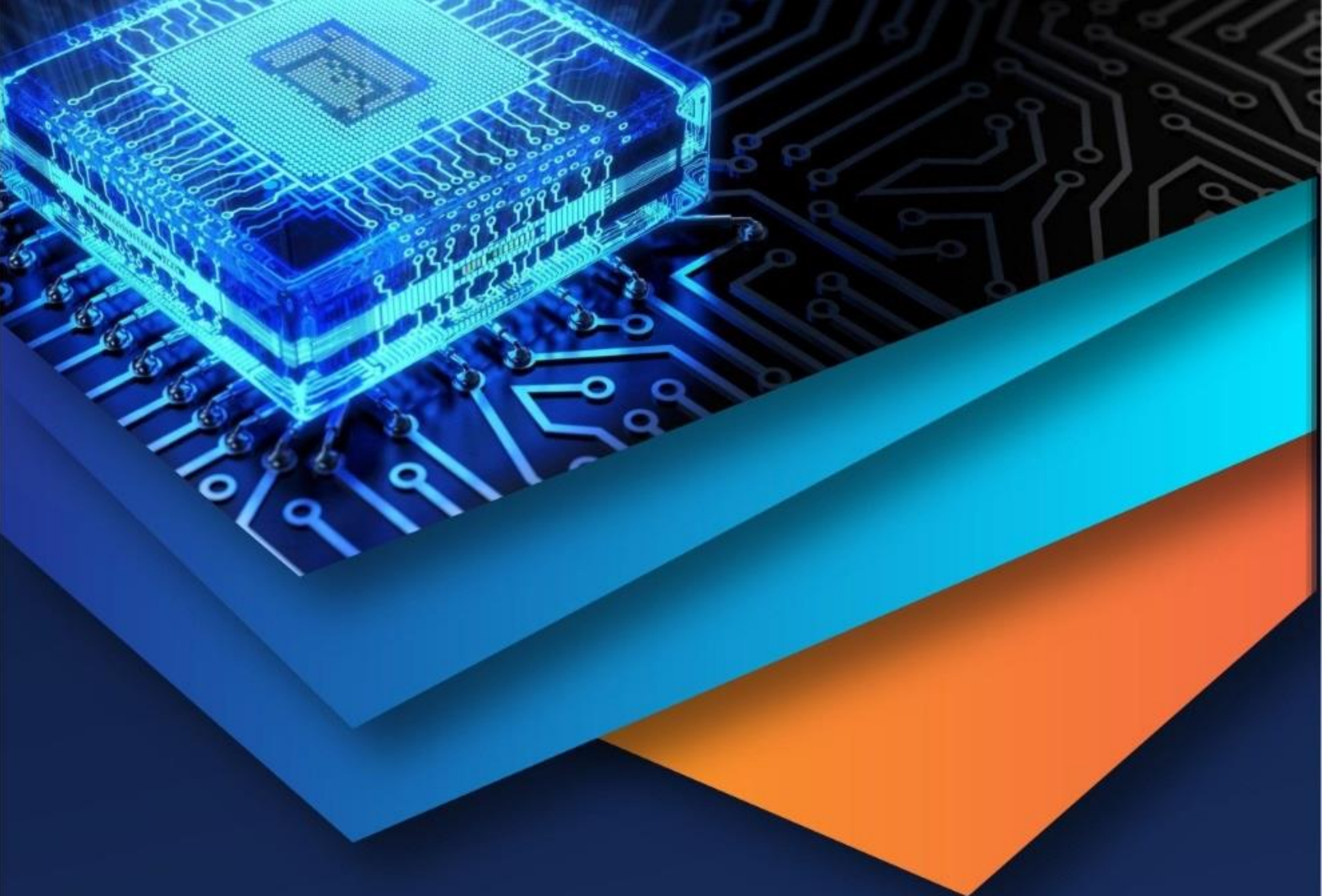

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