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Applicability of Rule of Mixtures to Metal Matrix Particle Composite Material

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ABSTRACT

The mechanical properties of composite material in particulate form can be obtained by the sphere model. Resultsobtained by the present method are compared and experimentally the equations are correct. The longitudinal modulus gives an equally good prediction when compared to the other methods. Also the transverse modulus of elasticity show better results experimentally.

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INTRODUCTION

Particulate matrix composite materials possess high mechanical properties. The macroscopic mechanical properties are high important in design of the composite materials. The effective and high valued mechanical properties are obtained by the use of rule-of-mixtures considering the micromechanical properties of the matrix and reinforcement. The cylinder model method is summarized by Tsai, Hann, Jones and Cox.

The particle reinforced composite materials mechanical properties can be analyzed by the use of rule-of-mixtures by Step-By-Step (SBS) method under the assumption that matrix and the reinforcement material are isotropic materials.

The volume fraction of particle is given by

where a and b are the radii of the reinforcing and matrix material respectively. The composite of P_2 is obtained using the sphere model. The particulate volume fraction of the composite at step 2 increases to the following equation (2)

$$V_{p2} = v_{p1} + (1 - v_{p1})v_{p1} = v_{p1} + v_{m1}v_{p1} \; --- (2)$$

Where $v_{m1} = 1$

Similarly the composite at step 3 can be composted and its property P_3 can be obtained by the same manner. The total particulate volume fraction is given by

$$V_{p3} = v_{p1} + (1 - v_{p1})v_{p2} = v_{p1} + v_{m1}v_{p2} \; --- (4)$$

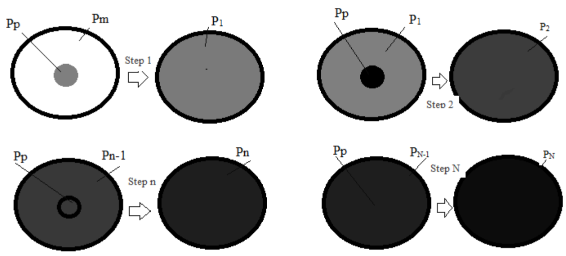

Fig. 1: showing the particulate mixing process in matrix material in step by step process with continuous addition of particulate material into the matrix material.

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After n times, the composite with the property P_n can be obtained, and the total particulate volume fraction is given by

$$V_{pn} = v_{p1} + v_{m1} v_{p(n-1)}$$
$$V_{pn} = v_{p1} + v_{m1}(v_{p1} + v_{m1} v_{p(n-2)})$$
$$V_{pn} = v_{p1} + v_{m1}[v_{p1} + v_{m1}(v_{p1} + v_{m1} v_{p(n-3)})]$$
$$V_{pn} = v_{p1} + v_{p1}v_{m1} + v_{p1}V_{m1}^2 + v_{m1}^3 v_{p(n-3)} - - - (5) \ldots\ldots$$
$$= v_{p1}(1 + v_{m1} + V_{m1}^2 + v_{m1}^3 + \cdots + V_{m1}^{n-1})$$
$$= 1 - V_{m1}^n$$

Hence we have

$V_{pn} = 1 - (1 - \mathrm{l}$ (6)

finally if $V_{pN} = V_p$ after N step combinations, the property of the composite becomes P_c approximately equal to P_N where N is given by

$N = \frac{\mathrm{ln}}{\mathrm{lr}}$ (7)

On the entire matrix area the relation between N, V_{p1} and V_f can be derived as

The formulae for the elastic moduli and thermal expansion coefficient of the particle-reinforced composite can be derived as finally

$$K_n = K_{n-1} + \frac{(3K_{n-1}+4G_{n-1})(K_{p1} - K_{n-1})V_{p1}}{(3K_{n-1}+4G_{n-1}) + 3(K_{p1} - K_{n-1})V_{m1}} - - - \quad (9)$$

And the Rigidity modulus is given by

$$G_n = G_{n-1} - \frac{5(3K_{n-1} + 4G_{n-1})(G_{n-1} - G_p)G_{n-1}V_{p1}}{(9K_{n-1} + G_{n-1} + 8G_{n-1}^2) + 6(K_{n-1} - 2G_{n-1})V_{p1}} - - - (10)$$

$$\alpha_n = \alpha_{n-1}V'_{m1} + \frac{K_{p1}(3K_{n-1} + 4G_{n-1})\alpha_{p1} + 4(K_{n-1} - K_{p1})\alpha_{n-1}G_{n-1}V'_{m1}}{(3K_p + 4G_{n-1}) - 4(K_{n-1} - K_{p1})G_{n-1}V_{p1}} V_{p1} - - - (11)$$

Where $V'_{m1} = 1 - \mathrm{l}$ (12)

The youngs modulus and poisons ratio are given by the equation $E = \frac{9KG}{3K+G}, \nu = \frac{E}{2G} - 1 - - - (13)$

And the volume fraction of the n particles is given by $V_{p1(n)} = \frac{V_{p1}}{1+(n+1)V_{p1}} - - - (14)$

Method of production of Aluminum Alumina Silicon Carbide particulate composite material:

Addition of high-strength matrix material to a weaker ceramic material has been successful and often the resultant composite has proved to be of good properties. The use of reinforcement with almost same modulus of elasticity may take care of the problem to some extent and presents pre-stressing of the matrix in the ceramic matrix is being increasingly resorted (Tsai, S.W. and H.T. Hann, 1980).

When ceramics have a same thermal expansion coefficient of that of the reinforcement materials, the resultant composite have a superior level of strength (Christensen, R.M., 1979; K.S. Raghuram, Dr. N.V.S.Raju; Laxmi, N., et al., 2015; Jaya Santhoshi Kumari, Y., et al., 2015). In that case, the composite will develop strength within ceramic at the time of cooling resulting in good settlement and cohesiveness of the particulates within the matrix. Micro cracking cannot result in a composite with tensile strength lower than that of the matrix.

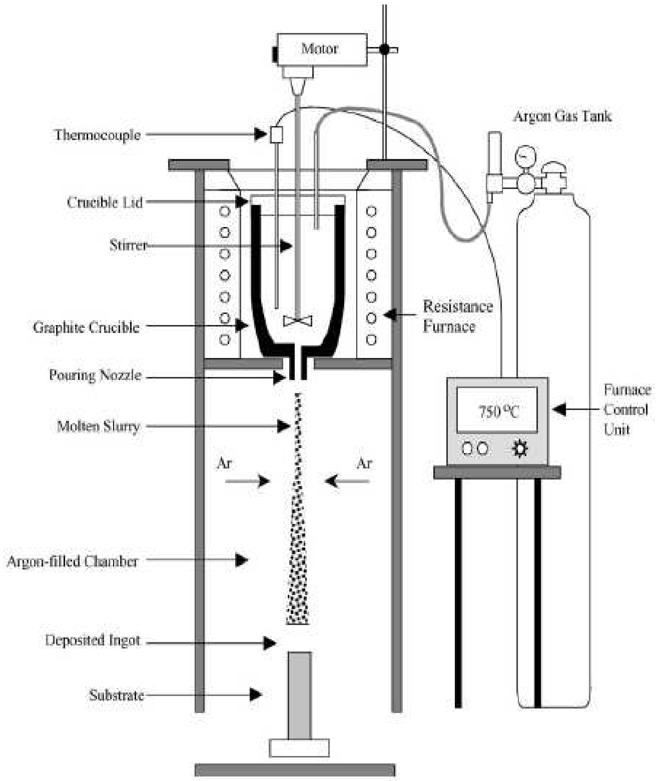

Fig. 2: showing the drop down stir casting process with argon gas.

Fig. 3: showing the precission Universal Testing Machine

Fig. 4: showing the impact testing machine

Results and Analysis:

$$a\frac{\partial^2\varphi}{\partial x^2}+b\frac{\partial^2\varphi}{\partial x\partial y}+c\frac{\partial^2\varphi}{\partial y^2}+d\frac{\partial\varphi}{\partial x}+e\frac{\partial\varphi}{\partial y}+f\varphi+g+ \quad (15)$$

The particulate composite material, there are two independent moduli of elasticity. They are longitudinal Youngs Modulus an

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Table 1: showing the Densities of various metals in M.K.S.Units

Metal	g/cm^3
Aluminum	2.70
Zinc	7.13
Iron	7.87
Copper	8.96
Silver	10.49
Lead	11.36
Mercury	13.55
Gold	19.32

Table 2: showing the properties of Alumina (Al_2O_3)

Molecular Weight (g/mol.)	101.94
Apparent Density (g/cm^3)	0.7- 0.9
Loose Bulk Density (g/cm^3)	~0.83- 1.01
Boiling Point (°C)	a=2040
Specific Surface Area (m^2/g)	0.5- 50
Thermal Conductivity (cal/s-cm-°C)	0.004- 0.10
Mohs Hardness @20°C	9.0
pH	7 -9
Specific Gravity	3.4- 4.0
Crystallography	hexagonal

Table 3: showing the % Composition of the particulate material and the tensile strength

% of Al_2O_3 SiC	Ultimate Tensile Strength(Mpa)
pure	112.24
10%	134.46
20%	173.12
30%	192.823
40%	150.24

Table 4: showing the % Composition of the particulate material and the impact test in Joules

% of Al_2O_3 SiC	Impact Strength (J)
pure	2
10%	8
20%	6
30%	4
40%	4

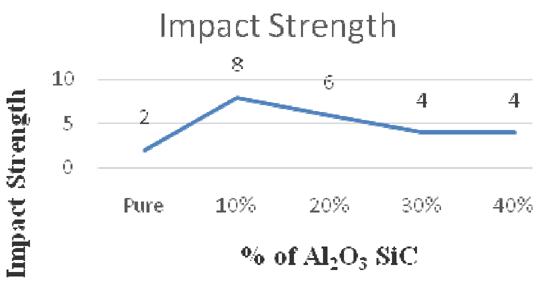

Fig. 5: showing the impact strength vs % Composition of particulate material in 0%, 10%, 20%, 30% and 40% in Aluminum.

Table 5: showing the properties of Al_2O_3

Physical Properties	Metric
Density	2.7 g/cc
Hardness, Brinell	95
Hardness, Knoop	120
Hardness, Rockwell A	40
Hardness, Rockwell B	60
Hardness, Vickers	107
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Elongation at Break	12 %

Elongation at Break	17 %
Modulus of Elasticity	68.9 GPa
Notched Tensile Strength	324 MPa
Ultimate Bearing Strength	607 MPa
Bearing Yield Strength	386 MPa
Poisson's Ratio	0.33
Fatigue Strength	96.5 MPa
Fracture Toughness	29 MPa-m½
Shear Modulus	26 GPa
Shear Strength	207 MPa
CTE, linear 68°F	23.6 µm/m-°C
CTE, linear 250°C	25.2 µm/m-°C
Thermal Conductivity	167 W/m-K
Melting Point	582 - 652 °C
Solidus	582 °C
Liquidus	652 °C

Conclusions:

From the experimental verification, it is obtained by the SBS method that the results are very close to those obtained by the three phase method.

- Strengthening of composites is due to particulate reinforcement, dispersion strengthening, and solid solution strengthening.
- The new Step By Step (SBS) method of rule-of-mixture derived analytically is reliable with the results obtained.
- This method also can be extended to analyze the mechanical and physical properties of the particle reinforced particles.
- The electrical properties, optical properties like scanning electron microscopy can also be calculated by applying the Step By Step method which give the results easier with most accuracy.
- The modulus of Al_2O_3SiC/Al composites tended to be isotropic and was controlled by the amount of Al_2O_3SiC reinforcement.
- The oxide particles produced and unreacted particles of silicon give sufficient improvement in strength and hardness of the composite. The resulting composites show appreciable ductility.

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