Quantifying the Role of Ellipsoidal Inclusion Spacing on the Performance of Particulate Composite

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Abstract— **Particulate composites have been extensively investigated since 1980 for applications where light weight structures with high strength and fatigue resistance were required. Particulate composites utilize ellipsoidal inclusions as reinforcement members to provide strength to the composite. The size of inclusion, its dimensions, and spacing between two adjacent inclusions determines the properties of composite. Hence we need to understand if two inclusions are closely spaced is there a certain optimum spacing beyond which the benefit of having inclusions lapses. The proposed study intended to investigate role of ellipsoidal inclusions on the performance of particulate composites. The objective of the project is to understand the role of inclusions in the characteristics of the composites. Also, to analyze and optimize dimensions or the particle size of the ellipsoidal inclusions and it's spacing, in order to achieve highest strength and fatigue life. The proposed study is to be carried out by finite element analysis procedure and validating it with tensile test key-results of the test specimen.**

Keywords – Composites, Nonlinear Finite Element Analysis, Optimization

I. INTRODUCTION

Composite material is basically artificially made material constituting of two or more materials combined together at macroscopic level in which one forms as the reinforcement and other as matrix. The main difference between composite and alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, whereas, in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents [1]. The properties of the composite are superior and possibly unique in some specific respects to the properties of individual components. These materials generally have wide range of applications viz. automobile, electronics, machine components, medical, aircrafts, space satellites etc. Some composite material found their way into commercial applications very quickly if costs could be controlled or were not an issue.

Today, organizations face a lot of external environment pressure such as technological and economic changes; they have to spend a large sum of money in research and development to improve the properties of composites used on their products. Due to this, composites are being used more and more. The essence of the concept of composites is that the load is applied over a large surface area of the matrix. Matrix then transfers the load to the reinforcement, which being stiffer, increases the strength of the composite.It is important to note that there are many matrix materials and even more fiber types, which can be combined in countless ways to produce just the desired properties.More and more applications will occur as the world's inventors use their imagination and cunning to improve old products and to create new products. [2]

Various shapes and arrangements of particle used are spherical, ellipsoidal with random arrangement, aligned ellipsoids, aligned spherical of different sizes. At present many research work had been carried out on the composites of various types, and present study is based on the particulate composites in which ellipsoidal inclusion or particle is reinforced with matrix. The optimum spacing between inclusions is intended to investigate with the help of finite element analysis considering the strain hardening should be taken into account.

II. LITERATURE SURVEY

Wei Yueguang (2001) [1] carried out research on particulate composites to investigate the relationship between particle size, young's modulus, particle aspect ratio, particle volume fraction and strain hardening exponent of the matrixmaterial. Two types of particle shapes included are elliptical and cylindrical for which cell models are developed. Concluding remarks states that composite strength depends upon particle size, shape, young's modulus and strain hardening while decreasing the particle size, increases strength resulting weak dependency on particle aspect ratio and particle shape. Rashid K. Abu Al-Rub, Mahmood Ettehad (2011) [2] this paper presents inter-particle size effect on deformation behavior of metal matrix composites with use of strain gradient plasticity theory and finite element method. It is shown that decreasing particle size and particle spacing helps to improve strengthening of composites. However decreasing the free path inter-particle spacing does not lead to largest strengthening. It also states that inter-particle size and

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spacing are dependent on strain gradient hardening and geometrically necessary dislocations. NikhileshChawla, Yu-Lin Shen (2001) [3] reviews research papers on mechanical behavior of particle reinforced metal matrix composites. This paper studies the tensile, fatigue and creep behavior of particulate metal matrix composites including salient features of experimental as well as analytical and computational characterization of the mechanical behavior of metal matrix composites. Particulate in metal matrix composites increases the tensile, ultimate, creep resistance and fatigue resistance with decrease in particulate size. Also there is increase in ductility of the composite due to decrease in the composites.Shao-Yun Fu, Xi-QiaoFeng, Bernd Lauke, Yiu-Wing Mai (2008) [4] discusses on the effects of particle size, particle/matrix interface adhesion and particle loading on the stiffness, strength and toughness of such particulate–polymer composites are reviewed. To develop high performance particulate composites, it is necessary to have some basic understanding of the stiffening, strengthening and toughening mechanisms of these composites. A critical evaluation of published experimental results in comparison with theoretical models is given.The applicability of existing models, both phenomenological and empirical/semi-empirical, to describe the experimental results for polymer-based particulate composites are discussed.

Yi Hua and LinxiaGu (2012) [5] this paper presents the thermo-mechanical behavior of 2080 aluminum alloy reinforced with SiC particles using the Mori–Tanaka theory combined with the finite element method. The influences of particle volume fraction, stiffness, aspect ratio and orientation were examined in terms of effective Young’s modulus, Poisson’s ratio and coefficient of thermal expansion of the composite. The overall material properties of the composite were insensitive to the particle aspect ratio beyond certain limit. The particle orientations significantly impacted the effective material properties of the composite, especially along the longitudinal direction.

III. PROBLEM DEFINITION

Many research works has been carried out on particulate composites utilizing ellipsoidal inclusions as reinforcement members to provide strength to the composite. Currently, the research work carried out on particulate composites finds out the relation between inclusion sizes, volume fraction on the strength of the composite. The effect of inclusion spacing in particulate composite has not been studied yet. The size of inclusion, its dimensions, and spacing between two adjacent inclusions determines the properties of the composite. Hence we need to understand if two inclusions are closely spaced is there a benefit in terms of strength, or is there a certain optimum spacing beyond which the benefit of having inclusions lapses.

IV. OBJECTIVES

- To understand the role of inclusions in the characteristics of the composites.
- Analyzing and optimizing the spacing between inclusions to provide maximum strength to the composites.
- Understand the FEA procedure for particulate composite in order to compare it with theoretical procedure.

V. MATERIAL DESCRIPTION

The composite material used, consists of epoxy resin as matrix and E- Glass fiber in ellipsoidal shapes as reinforcement material. Glass fibers are the earliest known fibers used to reinforce materials.Over 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced. Epoxies make an excellent matrix material because of their versatility and excellent adhesive properties.

Table I MaterialProperties of Composite

Material Name	Young’s Modulus (GPa)	Poisson’s Ratio
Epoxy Resin	183	0.3
E- Glass Fiber	2.30	0.41

VI. MODELING OF COMPOSITE

The composite model needed for the analysis purpose is created with ANSYS Design Modeler tools, using the specified dimensions. The model is created in microns, so as to simulate it with real life conditions. The total 5 layers are created with 4 inclusions in each layer, with fixed spacing between inclusions.

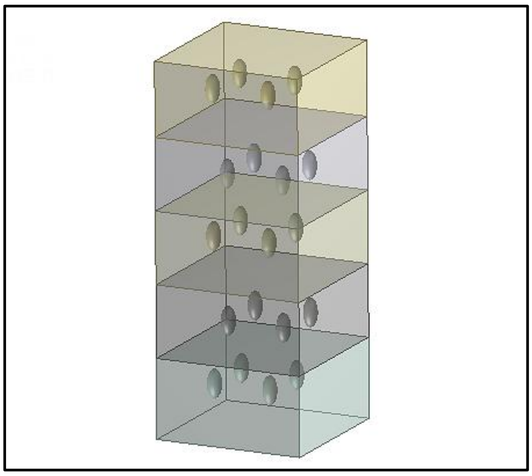

Fig.1 3D Model of composite

The shape of the inclusions used for the research is ellipsoidal, whose major radius is 30 mm, while minor radius is half of the major. The spacing between the inclusions is three times the major radius and alternate layers grid will be offset to centroid of the spacing of the level 1 grid. The gap of the outer surface from the top level of the ellipsoidal inclusion is 50 mm, while it is 60 mm for the bottom level. The different inclusion spacing used for the analysis purpose is 108, 114, 120, 126, 132 microns.

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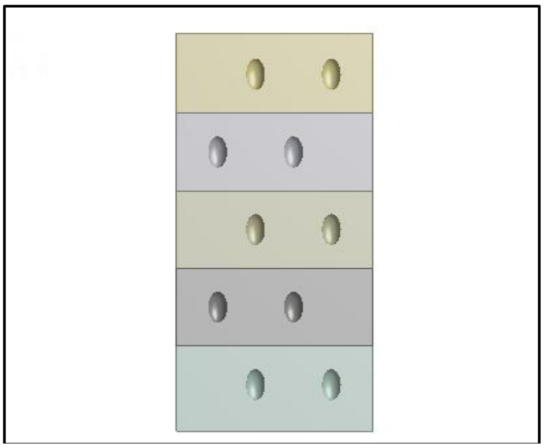

Fig.2 Side view of model showing layer offset

VII. FINITE ELEMENT ANALYSIS

Finite element analysis is a technique, which discretizes the model into finite number of elements and nodes. It is actually a numerical method employed for the solution of structures or a complex region defining a continuum. This is an alternative to analytical methods that are used for getting exactsolution of analysis problems. Finite element analysis involves solving partial differential equations, the primary challenge is to create an equation that approximates the equation to be studied, but is numerically stable, meaning that errors in the input and intermediate calculations do not accumulate and cause the resulting output to be meaningless.

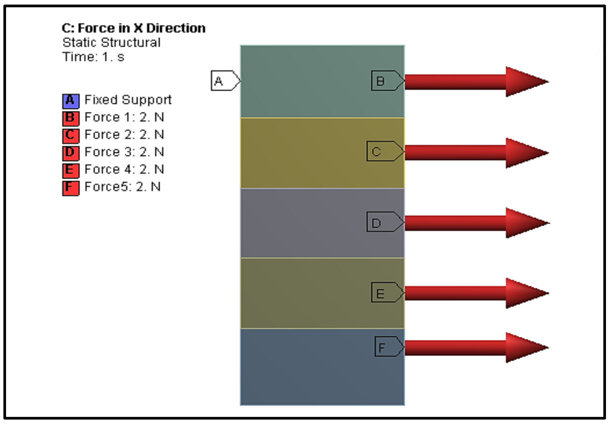

Fig.3 Force in X direction

Meshing is a technique used in finite element analysis in order to divide the problem into finite number of elements. The given problem is meshed with tetrahedron element, with different element sizing. In order to have fine meshing around inclusions, sphere of influence technique is used. The various different element sizing's used in meshing are 4.5, 4.6, 4.7 and 4.8 microns. In engineering most of the problems solved are assumed to have linear relationship between stress and strain. But in real life situation, all the structures are having non-linear relationship between stress and strain. Every material or structure has some kind of non-linearity present in it. Here in this problem, the type of non-linearity involved is contact non-linearity. Nonlinear analysis is carried out on the composite, as contact nonlinearity's exist between inclusion and matrix. The boundary condition involves one fixed support and tensile force at other end. The forces are applied in all three directions and stresses are found out for respective inclusions in each layer.

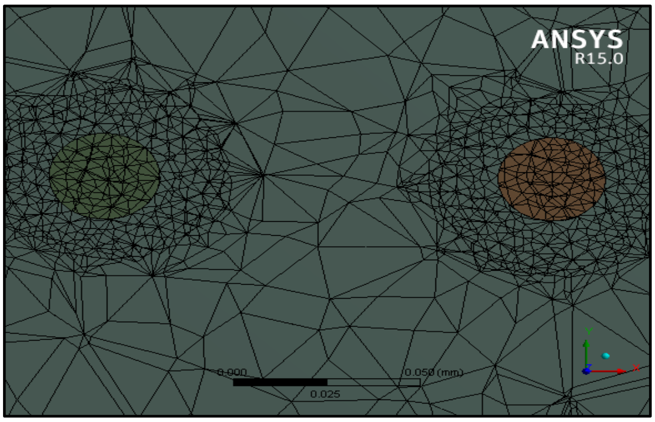

Fig.4 Cut section of meshed model showing meshing of ellipsoidal inclusions

VIII. RESULTS AND CONCLUSION

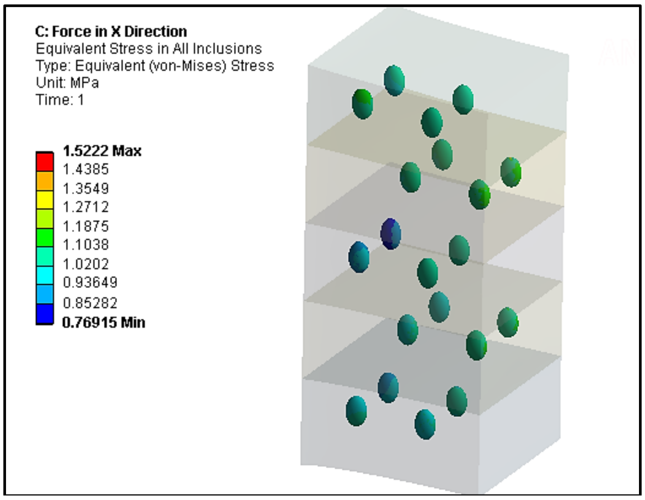

Fig.5 Equivalent Von-Mises Stress in All Inclusions in X Direction

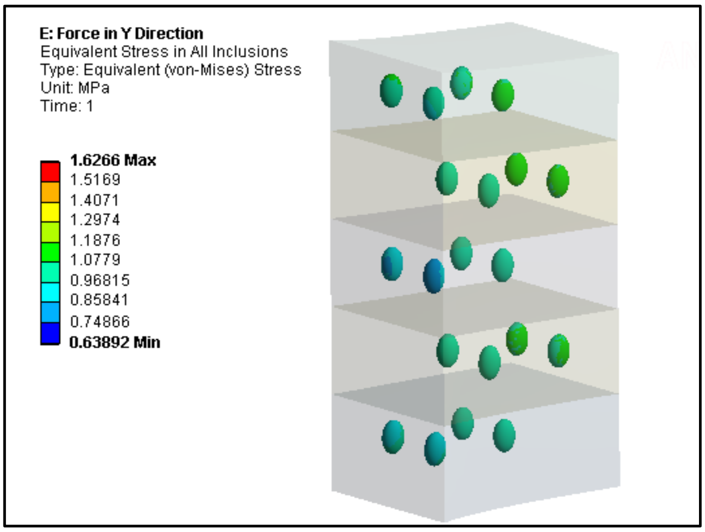

Fig.6 Equivalent Von-Mises Stress in All Inclusions in Y Direction

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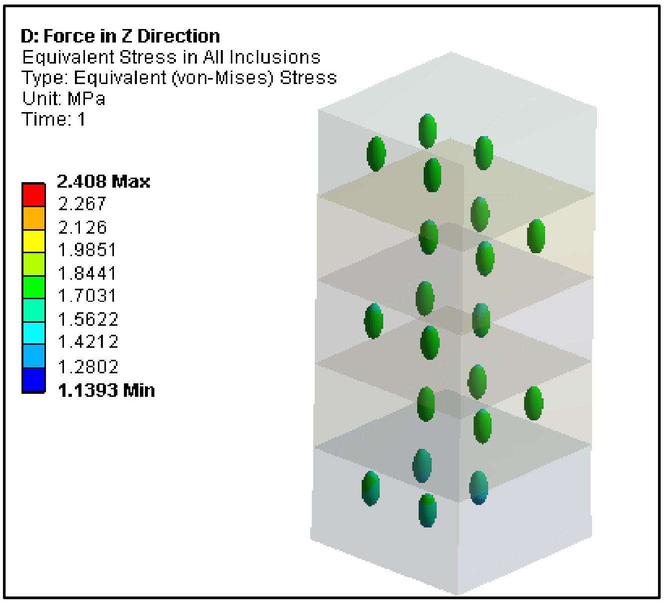

Fig.7 Equivalent Von-Mises Stress in All Inclusions in Z Direction

Table II Stresses in Layer I

Layer 1					
Inclusion / Inclusion Spacing	**108**	**114**	**120**	**126**	**132**
P1	2.2906	2.2728	1.9882	2.1353	2.2389
P2	1.8576	1.7546	2.6864	1.8839	1.7584
P3	1.7469	1.7447	1.7495	1.7449	1.9536
P4	1.7322	1.7695	1.9274	1.7327	1.7437

Table III Normal Value Corresponding to First Inclusion

Normal Value	
P1	1.9882
P2	1.7546
P3	1.7447
P4	1.7322

Table IV Normalized Values for all Inclusions

Inclusion / Inclusion Spacing	108	114	120	126	132
P1	1.152097	1.143145	1	1.073987	1.126094
P2	1.058703	1	1.531061	1.073692	1.002166
P3	1.001261	1	1.002751	1.000115	1.119734
P4	1	1.021533	1.112689	1.000289	1.006639
Total	4.212061	4.164678	4.646501	4.148082	4.254633
Optimum Inclusion Spacing			126		

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Table V Optimum Inclusion Spacing for Each Layers

Layers	X Direction	Y Direction	Z Direction	Optimum Spacing
Layer 1	114	114	126	114
Layer 2	114	108	114	114
Layer 3	114	114	126	114
Layer 4	108	108	132	108
Layer 5	126	120	126	126

Table VI Validation Statistics

Sr. No.	Experimental Deformation mm	Analysis Deformation mm	Percentage Error
1	8.6 mm	8.01 mm	6.86%

- The performance characteristics for the composite have been obtained in all three directions for given inclusion spacing's. It has been observed that stress results firstly increases, then reduced to minimumand again increases with change in inclusion spacing, increasing in ascending order
- The strength of inclusions varies in all three directions, so there is need to find out optimum inclusion spacing in all three principle direction. Optimization technique is used to find out optimum inclusion spacing, which gives superior strength than other inclusion spacing's. The optimum inclusion spacing was found out in all three directions for each layer for inclusion spacing's 108, 114, 120, 126, 132 mm.
- For X Direction the optimized values of inclusion spacing for each layer are 114(Layer 1), 114(Layer 2), 114(Layer 3), 108(Layer 4), and 126 mm (Layer 5). For Y direction the optimized values of inclusion spacing for each layer are 114(Layer 1), 108(Layer 2),114(Layer 3), 108(Layer 4), and 120 (Layer 5). For Z direction the optimized values of inclusion spacing for each layer are 126(Layer 1), 114(Layer 2), 126(Layer 3), 132(Layer 4), and 126 mm (Layer 5).
- So for optimum inclusion spacing in all three directions for respective layers are 114(Layer 1), 114(Layer 2), 114(Layer 3), 108(Layer 4), and 126 mm(Layer 5), from which we conclude as the optimum value of inclusion spacing being 114 mm for each layers in all directions. The worst case inclusion spacing was observed 132 mm.

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