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Analysis of E-Glass Particle Reinforced PLA Matrix Composite for 3D Printing Applications using ANSYS

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ABSTRACT

In this work, the E-glass in the powder form is considered as reinforcement with PolyLacticAcid (PLA) to analyze a composite using the micromechanics approach. The particle reinforced composite properties were estimated through Finite Element software ANSYS. Finite element model was validated with analytical expressions. For evaluating the proposed composite for 3D printing applications, a plate was modeled. This composite plate was analyzed under combined thermal, mechanical loading. Studies were carried out to predict the normal and shear stresses generated in the composite plate. The E glass powder volume fraction was increased from 5% to 30%. The results of normal and shear stresses were compared with pure PLA matrix. It was found that E-glass reinforced composite was superior when compared to pure PLA. The results of the present work suggest addition of E-Glass particles in pure PLA matrix when used as a filament to improve the properties of 3D printed component.

Key words: Glass powder, Micromechanics, Finite Element Method, Elastic Properties, Composite plate, Normal and shear stresses.

1. INTRODUCTION

Glass fiber is the mostly used reinforcement phase for polymer matrix composites. Glass fiber can find applications in aerospace, construction and automotive industries. Similarly particle reinforced composites are replacing many applications of conventional composite materials. In the particle reinforced composites, the reinforcement in the form of particle. Considerable research has been performed on particle and fiber reinforced composites covering synthetic and natural materials. H Ku et al., [1] estimated composite strength and fracture toughness by reinforcing the glass powder with epoxy matrix. The content of the glass powder has been studied on the fracture toughness and Young's modulus and the weight fraction of the glass powder is limited to 35%.

Few authors carried their research on powder and fiber mixed hybrid composites. The research can use different reinforcements in the fiber and particle form or the same reinforcement can be in both forms (fiber and powder). In this line, a review was conducted by Danuta Matykiewicz [2].

In this study, various aspects of the mechanical and thermo mechanical properties of mixture epoxy composites with both powder and fiber fillers were presented. Some studies can also be found on the non-metallic powder effect on the overall composites. Nagaraja et al [3] studied the composites prepared with glass fiber, rubber powder with polymer matrix. Mechanical properties were estimated at 3 different rubber filler contents.

Sudeep Deshpande et al., [4] carried a research work by combining synthetic fiber, such as E glass, natural fiber such as jute and these two fibers are combined with bone and coconut shell powder by selecting epoxy matrix. Mechanical loading supportive properties were obtained from suitable tests. Particle reinforcement such fly debris, aluminium based ceramic powder were selected for E glass fiber and composite specimens were fabricated to study the influence of particle reinforcement type on E glass composite for mechanical properties[5].

The type of particles used for reinforcing also effects the composite materials and depends on the size of the particle i.e nano or micro and macro size. In this context, Megahed et al., [6] evaluated the mechanical properties by selecting aluminum particles to glass fiber reinforced epoxy composites.

Chandrasekhara Rao[7] calculated the impact of fluctuating the filler and fiber substance in fly debris based polymer composites to limit the usage of matrix phase with enhancement in the properties and life usage of the final composite was estimated. The E glass can be available in fiber or fabric or powder form. Mohan Kumar et al.,[8] chosen E-glass in the form of woven as a stiffed material and for matrix, Polyester resin was selected to estimate the mechanical properties using experimental methods.

Sisal powder reinforced composite properties were estimated by the Katia Moreira de Melo with polymer matrix [9]. The influence of nano graphene on the mechanical behavior of Glass fabric reinforced epoxy composites were reported by Mangisetty et al [10]. By combining E-Glass powder and PLA, a filament is made which is used in 3D printing applications [16].

From the above studies, it was found that there is scope to analyze E-Glass powder reinforced PLA composite further to evaluate its use in 3D printing applications. In this paper, it is proposed to estimate the properties of the E glass particle reinforced PLA matrix composite. Composite plate is studied for stresses under thermal and mechanical load.

2. FINITE ELEMENT MODELLING OF PLA MATRIX & E-GLASS PARTICLE

Using the Micromechanics method, the glass particle reinforced in PLA matrix composite properties are estimated. An assumption is made that all the glass powder particles are distributed uniformly in the PLA matrix and perfectly bonded to the matrix.

The spherical particles can be idealized for the glass powder and these particles can be distributed in the matrix as shown in Figure.1.

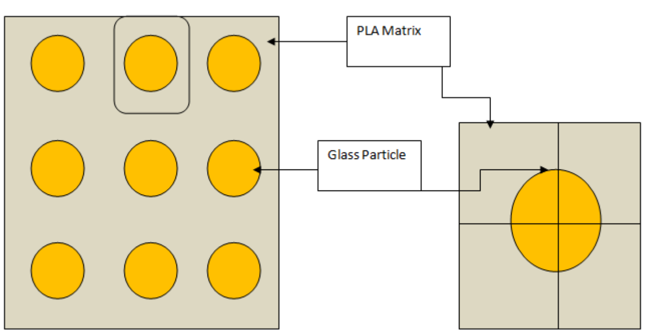

Figure.1. Idealization of glass particle in PLA matrix and one unit cell

The boundary conditions are applied in such a way that the FE model behavior in close to the real composite nature under considered assumptions.

Solid 20 node 186 element was selected for both particle and matrix materials discretization as shown in Figure 2. The dimensions of the Finite element model are calculated based on the volume fraction of the glass powder. The glass Particle Size Mean Diameter 11 and 18 microns are taken and for the present study, 18 microns size is considered [1]. The Young's modulus of the Glass powder is 58.63GPa, Poisson's ratio is 0.165 [13] The PLA Young's modulus is 3100MPa and Poisson's ratio is 0.3[14]. Using, roller supports, multipoint constrains, and with the support of Hook's law, the young's modulus, Poisson's ratio was determined [11-12].

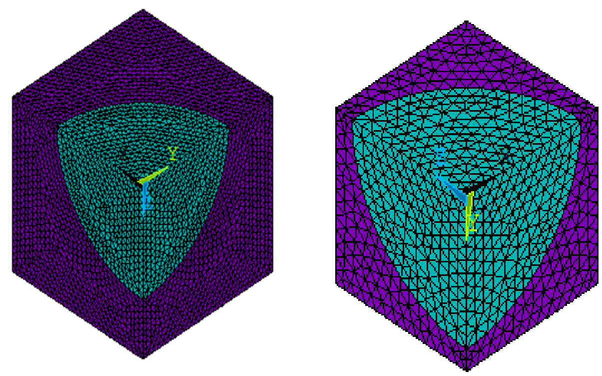

Figure.2 Finite Elemental plot of unit cell with 20% & 35% volume fraction of E-Glass.

3. VALIDATION STUDIES

Figure.3. shows the elemental plot of unit cell with load applied.

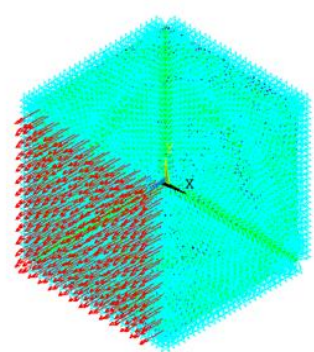

Figure.3 Loading and Boundary condition on the unit cell

The Finite element procedure in ANSYS is used for the evaluation of the properties. Validation of Finite element models is done with Guth model as presented below. Table 1 represents the comparison of FE model results with the analytical predictions.

$E_c=E_p(1+K_E V_f+14.1V_f^2)$

Where E_c is the modulus of composite
E_p is the particle modulus
K_E= Einstein coefficient
V_f= volume fraction of the particle

Table 1: Comparison of FE models results with analytical results

Volume Fraction of E glass powder	Young's modulus from FE models [MPa]	Young's modulus from the Guth model[15] [MPa]	Percentage of error (%)
5	3428.11	3312	3.50
10	4150.34	3978	4.33
15	4352.00	4175	4.23
20	4940.44	4712	4.84
25	5688.56	5422	4.91
30	5928.85	5674	4.49
35	7657.99	7269	5.35

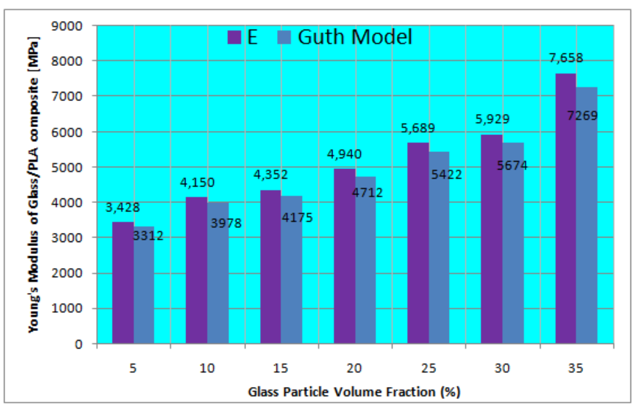

Figure.4 Young's modulus of E-glass powder particle reinforced composite

Figure.4. shows the variation of Young's modulus of E-glass powder reinforced PLA reinforced composite by varying the volume fraction from 5 to 35%. For validation of FE models, the Young's modulus of FE results is compared with analytical results obtained from the Guth model [15]. The comparison is presented in Figure. 4. The Young's modulus is rises with raising the volume fraction of glass powder. The study is limited to 35% because; exceeding the 35% may give the agglomeration in the experimental studies [1]. Based on the experimental studies, the particle volume fraction is limited to 35%.

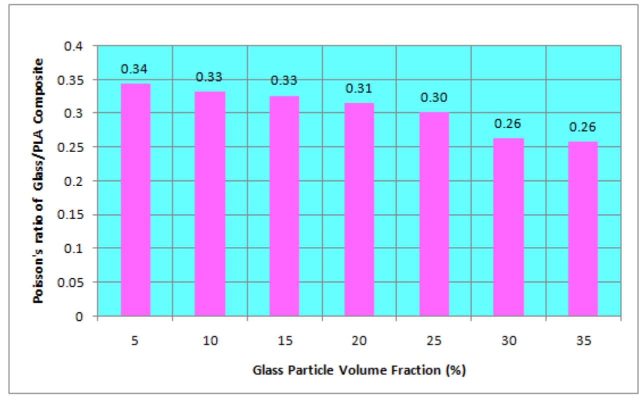

Figure.5 Variation of Poisson's ratio with respect to E-glass powder

Figure.5. shows the magnitude of Poisson's ratio and this property reduces the intensity by the addition of E- Glass powder in PLA.

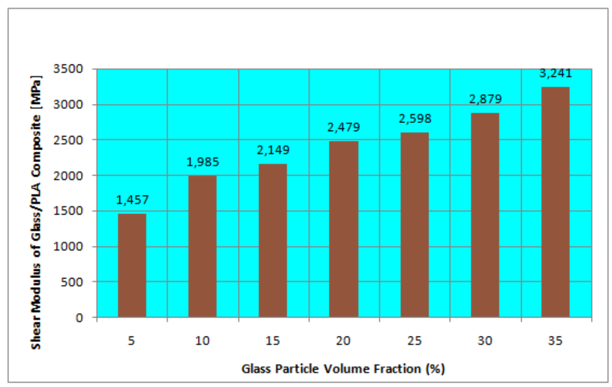

Figure.6 Variation of Shear Modulus (G) with respect to E glass particle volume fraction

Figure.6 presents the magnitude of shear modulus and it response with the inclusion of E-Glass powder particles. Similar to Young's modulus shear modulus also increases with E glass reinforcement.

4. ANALYSIS OF PLATE MODELED WITH E GLASS POWDER REINFORCED COMPOSITE UNDER COMBINED MECHANICAL AND THERMAL LOADING

The mechanical properties of E-Glass & PLA is the main moto of the present work as these materials will be used for 3D printing applications. Under this process, the material will subjected to mechanical and thermal load. The effect of these combined loads on the stresses of the composite plate will be estimated.

As a part of the study, a composite plate has been models and it is subjected to combined pressure load of 10MPa and temperature of 50^0c (obtained from the technical data sheet of the PLA). The Normal and shear stress generated in the composite plate is estimated and compared to the Pure PLA plate. The homogenized composite properties are taken from the results presented in earlier sections i.e Figure. 4-6.

The stress in X, Y and Z directions and Shear stresses XY, YZ and ZX plane were taken by considering the Homogenized properties of glass powder reinforced PLA matrix. Figure.8-10 show the variation of stresses generated on composite plate under combined thermal and mechanical loading. Among all the stresses the σ_z stresses have more magnitude due to applied load in the XY plane. Corresponding plane got more shear stresses.

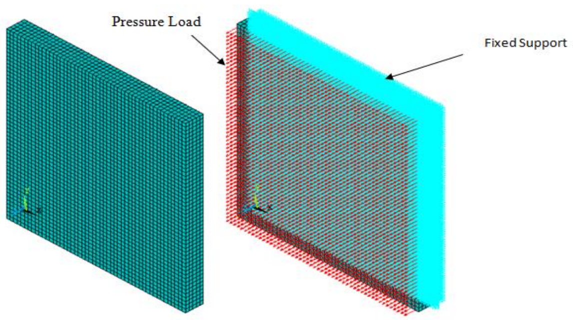

Figure.7 FE model of Composite plate with pressure load

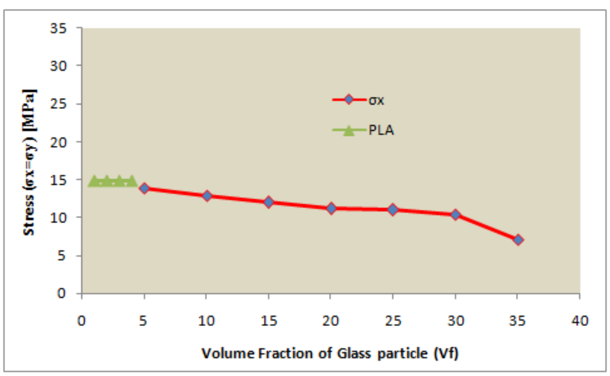

Figure.8 Variation of σX and σY of E-Glass powder reinforced composite plate

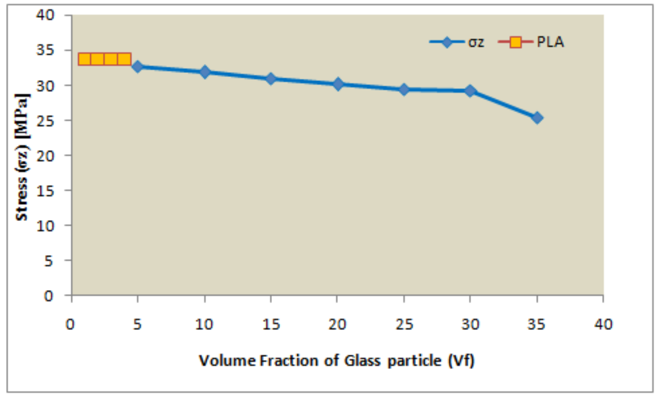

Figure.9 Variation of σz of E-Glass powder reinforced composite plate

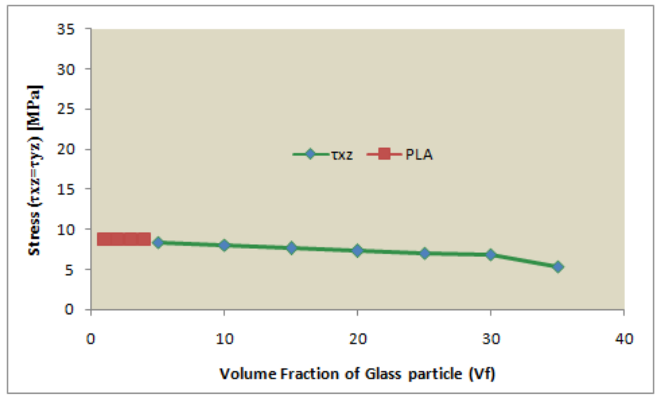

Figure.10 Variation of $\tau_{XZ} = \tau_{YZ}$ of E-Glass powder reinforced composite plate

5. CONCLUSIONS

E glass powder reinforced PLA composite properties were estimated from Finite element based software ANSYS with the support of Micromechanics approach. The conclusions were listed below.

1. The modulus of elasticity along with shear modulus increases by the improvement of E-Glass particle volume fraction in the PLA matrix.
2. The Poisson's ratio magnitude declines with the contribution of E-Glass powder in PLA matrix.
3. The stresses in PLA composite plate modeled by homogenized properties are decreasing with ascend in the volume fraction of E-Glass powder when subjected to combined Mechanical & Thermal loading.

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