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Comparison Of Mechanical Properties Of Al_2O_3 And Low Density Polyethylene (LDPE)

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Abstract
A composite is a is artificially made material system consisting of two or more phases. Excellent strength to weight ratio and stiffness to weight ratio could be achieved using these materials. Composite materials (laminates, ply built up) could be tailored to give mechanical properties in various dimensions. They are manufactured by using variety of manufacturing processes. In this work various composites of Al_2O_3 and Low Density Polyethylene (LDPE) were prepared using powder injection moulding process. Al_2O_3 and LDPE composite is a biocompatible material which could be used in low load bearing implant applications. The flexural strength of the various combinations of Al_2O_3 and LDPE were determined experimentally and the results have been compared with the results obtained using analytical software ANSYS 12. The flexural strength was calculated using three point bend test.

Keywords: *composite material, flexural strength, simulation, ANSYS 12.*

I. Introduction

Many modern technologies require materials with unusual combinations of properties. These may be combination of low density and high stiffness; they may be required to have high abrasion and impact resistance. However strong materials available are relatively dense. If we increase strength and stiffness by heat treatments impact strength decreases.

But it has been possible to get required properties of materials by using composite materials. Their mechanical performance and properties can be designed for the required purpose. The constituents of these materials include metal alloys, low melting metals, polymers and ceramics. Properties of these materials depend on the properties of constituents, particle size, distribution, orientation and proportion of phases. The distribution of phases should be such as to make the composites homogeneous. This improves quality of the composite. The interphase i.e. the bond between matrix and reinforcement also plays an important role. This may affect failure path, stress-strain behaviour [1].

The finite element analysis is an essential tool in virtual product development. It helps in predicting the product performance before actual prototype is made, reduces the no of physical prototypes and the cost. To confirm the behaviour of composites under required operating conditions, composites are subjected to different types of tests amely tensile test, compressive test, interlaminar shear test, mode I fracture test etc.

M S Abu Bakar et al. carried out test to check the tensile and tension-tension fatigue properties of orthopaedic implants. They found that the ductility of the composite decreases as the percentage of hydroxyapatite (HA) increases. The Young's modulus and the tensile strength of the samples were found to decrease. However these samples withstood the fatigue test [2]. Compressive property durability of carbon fibre reinforced Polyetheretherketone (CF-PEEK) composites was tested by Guigen Zhang et al. under two environments: dry and saline. They were also tested at three different temperatures namely 37, 65, and 95^0C to see the effect of elevated temperatures. The strength values were recorded at eight different times for 5000 hours. The test results showed that there was not much effect of salinity, time and temperatures on ultimate tensile strength, Modulli and poission ratio [3].I Ozdemir et al. studied the failure behaviour of composites of extruded aluminium matrix reinforced with 10 and 20 % volume of SiC particles. The samples were subjected to tensile and thermal cyclic tests. The temperature range was 25^0C to 430 ^{0}C. It was found that the elasticity and strain increase at room and lower temperatures, but reduced as temperature increased [4].Kristina Brandt et al. used a novel method for obtaining high ceramic content composite material. The hard particles were coated by a thin polymer layer and were warm pressed to obtain the desired shape. They used customized four point bend test device to determine the flexural strength and flexural elastic modulus of poly (methyl methacrylate) (i.e. PMMA) encapsulated Titanium dioxide (TiO_2) nanoparticle composite. The composites microstructure showed successful polymer encapsulation of TiO_2 up to 66% of TiO_2 with porosity less than 5% [5]. Inter-laminar shear testing (by using Asymmetric Four Point Bend test) was recommended by V. Dayal et al. for conditions

where only small samples were available in development stage. To achieve pure shear stress in the middle of inner loading points, the span distances between the top and bottom pins were equal but displaced with respect to each other [6]. J. M. Gomez de Salazar et al. carried out compression and wear test on ceramic foams (SiC, and $SiO_2.ZrO_2$) combined with an epoxy vinyl-ester resin. They found that 20 ppi SiC/polymer composite gave the best mechanical properties [7]. Mode I delamination resistance test was accepted for quasi static loading of unidirectional carbon or glass fibre reinforced polymer matrix. A.J. Brunner et al. had studied the possibilities of applying the same for reinforcement of polymer matrix by natural fibres, braided or knitted fabrics and multidirectional fibre laminations. They had found that the Double Cantilever Beam (DCB) test could be used for unidirectional fibre laminates with other fibre types as the methodology of test was equivalent to the standard test method. But it cannot be applied to multidirectional layers [8].

Christensen developed a three dimensional stress based failure criterion for isotropic materials whose tensile strength is less than or equal to compressive strength. For brittle materials along with this, none of the principal stress should exceed the tensile strength of the material [9].The results predicted by the Christensen criterion were found to be in good agreement with the results predicted by Von Mises criteria for ductile materials as well as with other criteria for brittle materials [10].

II. Experimental work

1. **Methodology:**

The properties of composite materials are calculated by using formula for rule of mixture:

$$\sigma_c = [\eta * \sigma_f * V_f] + [\sigma_m * V_m] \quad 1$$

$$E_c = [\eta * E_f * V_f] + [E_m * V_m] \quad 2$$

$$\upsilon_c = [\eta * \upsilon\upsilon_f * V_f] + [\upsilon\upsilon_m * V_m] \quad 3$$

Where,

σ_c = Composite material property
σ_f = property of reinforced material
σ_m =property of matrix material
V_f = volume fraction of reinforced material.
V_m = volume fraction of matrix material
E_c = modulus of elasticity of composite material
E_f = modulus of elasticity ofreinforced material
E_m = modulus of elasticity ofmatrix material
υ_c= poissons ratio of composite material
υ_f= poissons ratio of reinforced material
υ_m= poissons ratio of matrix material
η=1/6
[1]

Christensen failure criterion:
For all materials $\sigma_t \leq \sigma_c$
In terms of principle stresses,

$$\left[\frac{1}{\sigma_t} - \frac{1}{\sigma_c}\right][\sigma_1 + \sigma_2 + \sigma_3]\sigma_c + \frac{1}{\sigma_t \sigma_c}\left\{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]\right\} \leq^1 \quad 4$$

For brittle materials following criteria should be checked:

$$\sigma_t \leq \left(\frac{1}{2}\right)\sigma_c \quad 5$$

[9]

3. The flexural strength is calculated by

$$\sigma = \frac{3PL}{2BD^2} \quad 6$$

P = load at rupture in N
L = distance between two supports in m
B = width in m
D = height in m
σ = Flexural strength in N/m^2

2. Experiment

Injection moulding process was used to prepare ceramic-polymer composites of varying compositions. The injection moulded composites were tested for flexural strength using test standard ASTM-D790 for three point bend test on UTM with a cross head speed of 2 mm/min.

III. Results:

Table 1: Test results

MATERIAL	DIMENSIONS L x B x D (mm)	RUPTURE LOAD	FLEXURAL STRENGTH
50%Al_2O_3 50% LDPE [NON POROUS]	50 x 10 x 5.9	66.3 N	14.05 MPa
50% Al_2O_3, 50% LDPE [POROUS]	50 x 9.9 x 6	98.1 N	20.68 MPa
60% Al_2O_3, 40% LDPE [Al2O3 as Matrix]	50 x 10.38 x 6	50.40 N	10.39 MPa
40% Al_2O_3, 60% LDPE [NON POROUS]	25 x 10.1 x 6	82 N	8.29 MPa
40% Al2O3, 60% LDPE [POROUS]	25 x 9.92 x 6.14	52.5 N	5.18 MPa

Simulation:

The flexural strength of composite was simulated using analysis software ANSYS 12 and it is compared with results obtained experimentally. Three point bend test is used to determine flexural strength of composite.

For comparison of results, the load value corresponding to Christensen failure criteria was compared with the load value at rupture which is obtained experimentally. The stress values (principle stresses) computed from ANSYS12 were used as an input values in Christensen failure criteria.

First analysis was carried out for Al_2O_3 sample. The results compared well with those given in the literature. This has been shown in table 2.

Table 2: Rupture load and flexural strength values for Al_2O_3

	RUPTURE LOAD	FLEXURAL STRENGTH
ANALYSIS VALUE	3608 N	372.11 MPa
LITERATURE VALUE	980 - 3920 N (CALCULATED USING FLEXURE FORMULA)	150 MPa - 600 MPa [11]

Then the same analysis was carried out on ANSYS 12 for samples of different compositions of Al_2O_3 and LDPE. The results were compared with test results. The same are tabulated in table 3.

Table 3: The results of analysis

MATERIAL	RUPTURE LOAD	FLEXURAL STRENGTH
Al_2O_3	3608 N	372.11 MPa
50% Al_2O_3, 50% LDPE [NON POROUS]	730 N	152.08 MPa
50% Al_2O_3, 50% LDPE [POROUS]	510 N	71.54 MPa
60% Al_2O_3, 40% LDPE [LDPE AS MATRIX]	1000 N	200.71 MPa
60% Al_2O_3, 40% LDPE [Al2O3 AS MATRIX]	5040 N	674.37 MPa
40% Al_2O_3, 60% LDPE [NON POROUS]	738 N	76.11 MPa
40% Al_2O_3, 60% LDPE [POROUS]	738 N	74 MPa

IV. Discussion

It is observed that there is a difference between the analytical values and experimental values of flexural strength of samples of different compositions.

The possible reasons could be, faults in materials due to faulty manufacture like the temperature not properly adjusted considering the melting point, plasticity point and viscosity of the material for injection moulding process.This may be due faulty screw rig or electrical heater used. The adhesion between the reinforced particles and the matrix depends upon the grain size and the grain shape, as the area of adhesion increases when the grains are of odd shape and is comparatively less in case of circular particles. It also depends upon the grain size, the surface tension of the matrix when heated. All these have to be closely controlled. The samples may contain defects such as blow holes, surface cracks etc; that reduces the strength of the material. The samples therefore

must be tested for such faults before actual testing is carried out.

Another reasons may be non uniform mixing of materials while sample preparation which makes the sample non homogeneous while for analysis materials were assumed to be perfectly homogeneous. This may also be due to improper bonding between two constituent materials.

The properties of the sample material like Young's modules, Poisson's ratio etc.assumed for the analysis may be different from the properties of the actual sample. Difficulty in modelling actual load condition was found during analysis in ANSYS 12. The load was modelled as point load while in actual testing it was a distributed load along the roller surface.

Therefore the implant must be tested for any such faults before it is actually used.

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