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MECHANICAL BEHAVIOUR OF ALUMINUM PARTICULATE EPOXY COMPOSITE – EXPERIMENTAL STUDY AND NUMERICAL SIMULATION

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ABSTRACT

Epoxy resin composites are frequently applied in moulds manufactured with rapid tooling technologies, because of their low shrinkage and easy mouldability. Various percentages of Aluminum particles added with Epoxy resin by weight are formed to dog-bone shaped specimens according to ASTM standards to determine fatigue strength and cylindrical shaped specimens to determine thermal conductivity. Micro-structural analysis is carried out to investigate the distribution of Aluminum particles in the composite. Mechanical properties are characterized in terms of Rockwell hardness and Fatigue test. Thermal conductivity, a critical parameter is determined for good service performance and durability of mould. Proportion of Aluminum and Epoxy resin for which the hardness, fatigue life, thermal conductivity of the composite holds well is determined for better mouldability. A Finite Element analysis is also performed to study the Fatigue behaviour.

Keywords: Aluminum-Epoxy resin, Fatigue analysis, Thermal conductivity, ASTM-3039.

1. INTRODUCTION

A composite material is a heterogeneous solid consisting of two or more different materials that are mechanically and metallurgically bonded together, which are used in combination to rectify a weakness in one material by strength in other (DeGarmo et al., 2008). This combination of two or more materials that exhibit properties distinctly different from those of the individual materials used to make the composite. Each of the various components retains its identity in the composite and maintains its characteristic structure and property. The composite material however, generally possesses characteristic properties such as stiffness, strength, weight, high temperature performance, corrosion resistance, hardness and conductivity that are not possible with the individual components. The various materials involved can be organics, metals or ceramics. Hence, a wide range of freedom exists, and composite material can be designed to meet a desired set of engineering properties and characteristics.

There are many types of composite materials and several methods of classifying them. One such method is based on geometry which consists of three distinct families: laminar (or) layered composite, particulate composite and fiber-reinforced composite (Broutman and Krock, 1967).

Dispersion strengthened composite material are characterized by a microstructure consisting of an elemental or alloy matrix within which fine particles of 0.01 to 0.1 µm in diameter are uniformly dispersed in a volume concentration of 1 to 15%. Particle reinforced composite differ from the dispersion strengthened composite since the dispersoid size exceeds 1.0 µm and the dispersoid concentration exceeds 25% (Benham et al., 1996). In Fiber reinforcing composite material, the reinforcing phase in fiber composite materials spans the entire range of size, from a fraction of a micron to a several millimeters in diameter, and the entire range of volume concentration from a few percent to greater than 70%. The distinguishing micro structural feature of fiber-reinforced material is that their reinforcement has one long dimension, whereas the reinforcement particles of the other two composites do not. The strength of particle reinforced composite material lies an intermediate when compared to dispersion strengthened matrix and fiber reinforced composites strength at both room temperature and elevated temperature.

Ahmad et al. (2010) investigated the bond integrity of epoxy adhesives for in-situ bonding of FRP connections into timber and found that addition of nano and micro filler additives increases the bond strength by 20%. Patnaik et al. (2010) have investigated experimentally the thermal conductivity of particle-filled polymer composite and made a correlation between thermal conductivity and specific wear resistance. Anilkumar et al. (2011) found that the tensile strength, compressive strength and hardness of the fly ash reinforced aluminium alloy composite decreases with increase in fly ash particle size. Goyanes et al. (2003) analyzed the yield and internal stresses developed in aluminum filled epoxy resin to investigate the influence of filler content using compression test and positron annihilation analysis. Irawan et al. (2011) developed a ramie fiber reinforced epoxy composite (RE) and compared its tensile and flexural strengths with ramie polyester composite and fiberglass polyester composite and found that RE has highest tensile and flexural strengths. Ho et al. (2006) has investigated the mechanical properties, tensile test and Vickers hardness test of epoxy based nano clay composite. Vasconcelos et al. (2006) studied the tribological behavior of epoxy, Aluminum particles and epoxy-aluminum-milled glass by considering thermal conductivity and wear resistance. Post et al. (2008) reviewed the modeling of fiber reinforced polymer composite materials subjected to variable amplitude fatigue.

Zhao et al. (2008) developed a model system of nanoscale alumina filled bisphenol-A based epoxy, which leads to improvements in ductility and modulus. Suhermana et al. (2010) investigated the filler loading concentration, curing temperature and moulding pressure on electrical conductivity of CNTs/Graphite/Epoxy nanocomposite and found that it is 200% higher than graphite/epoxy composite. Chung et al. (2005) evaluated the mechanical properties in micro-scale structures and investigated the effect of particle size in epoxy-aluminum particle composite. Zunjarrao et al. (2006) studied the effects of nanometer and micrometer sized Aluminum particles with epoxy, on the fracture toughness of the composite. Vasconcelos et al. (2005) employed charpy impact tests to determine toughness of epoxy, aluminum and milled fibre composite. Yidris et al. (2010) determined the peak load and energy absorption during quasi-static crush analysis and predicted the damage of C-glass/epoxy composite used for unmanned aerial vehicle fuselage section through experimental and FEM analysis. Zamri et al. (2011) studied the wear behaviour of palm oil clinker/aluminium composite and found that wear resistance increases with the presence of palm oil clinker particle and is better below 11N load.

In general, the composite elastic modulus of particulate-reinforced composites fall under “rule of mixtures” law,

$$E_c = V_m E_m + V_p E_p \tag{1}$$

where, V_m, V_p - Volume concentration of matrix and particle, and E_c, E_m, E_p - Elastic modulus of composite, matrix and particle. Since the elastic moduli of dispersed particulate composite should follow iso-stress modulus,

$$E_c = \frac{E_m E_p}{V_m E_p + V_p E_m} \tag{2}$$

and any positive deviation signifies matrix constraint.

2. MATERIAL SELECTION

Table 1 Properties of epoxy resin matrix.

Property	Value
Mixed Viscosity, ASTM-D-2393, 25°C (MPa)	3.9-4.4
Gel Time, ASTM D-2471 at 25°C (min)	410-460
Gel time, ASTM D-2471, at 120°C (min)	6-10
Glass Transition Temperature (T_g) (°C)	45-53
Flexural Strength at 25°C (N/mm^2)	145
Flexural Modulus, at 25°C (N/mm^2)	3724

The material selected for fatigue analysis is Aluminum filled Epoxy resin particulate reinforced composite material (Goyanes et al., 2003) in which aluminum particles of grade D (which is of size > 150µm of about 5%, < 45µm of about 50 to 70% and remaining portion between 45µm and 150µm) were spreaded in a matrix of Epoxy resin (Araldite LY 556). Triethylene tetra amine is used as the aliphatic amine hardener for epoxy resin curing. The properties of Epoxy resin, which is used as a matrix, are shown in Table 1.

2.1 Specimen preparation

Casting is the simplest of the shape forming processes because no inserts are used and no pressure is required, as the liquid polymer (or any resin that will polymerize at low temperature and atmospheric pressure) is simply poured into a container having the shape of the desired part. To convert the liquid polymer resin into solid product, 10 phr of hardener is added. The resin is poured into the mold and is cured, either at the room temperature or by heating for long times at elevated temperature inside a furnace. After curing, the product is removed. This process is relatively inexpensive because of costly dies, equipment and control. While dimensional precision can be quite high, quality problems can occur because of inadequate mixing, air entrapment, gas evolution and shrinkage. These problems can be rectified by mixing it thoroughly for a fixed time period and providing proper cope and drag in mould die.

Aluminum filled epoxy resin composite materials have very high oxygen index, good thermal conductivity, low mould shrinkage and density when compared with other modified epoxy resin. However, at the same time the presence of aluminum fillers can inhibit cure. It does not resist to acids and also it has very low tensile strength, flexural modulus and notched impact strength and highest linear expansion when compared with other modified casting epoxy resin.

3. EXPERIMENTAL SET-UP/ METHODOLOGY

3.1 Fatigue analysis

The aluminum filled epoxy resin composite material whose fracture strength is to be determined by Fatigue test (Avner, 1997) is cast to a dog-bone shaped specimen according to ASTM-3039 standard, as shown in Figure 1.

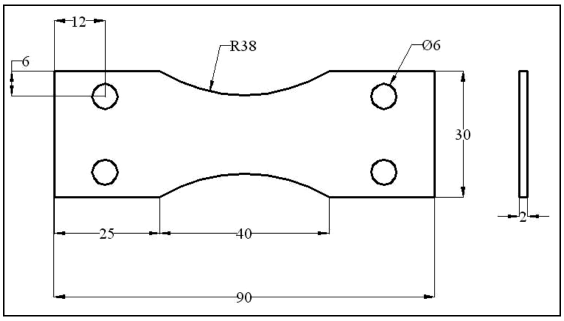


Figure 1 ASTM-3039 fatigue test specimen.

The various proportions of aluminum particles and epoxy resin matrix, based on which dog-bone shaped aluminum filled epoxy resin composite material specimens are cast for fatigue analysis are given in Table 2.

Table 2 Specimen cast for various % of Aluminum and epoxy resin.

Sl. No	Proportions in weight%	
	Aluminum	Epoxy resin
1	40	60
2	45	55
3	50	50
4	55	45
5	60	40

3.2 Thermal conductivity

Thermal conductivity is the transfer of thermal energy through free electron diffusion without a flow of the material medium (Domkundwar et al., 2000). To quantify the ease with which a particular medium conducts, engineers employ the thermal conductivity, also known as the conductivity constant or conduction coefficient '*k*'. The thermal conductivity defines *k* as the quantity of heat '*Q*', transmitted in time '*t*' through a thickness '*L*', in a direction normal to a surface of area '*A*', due to a temperature difference 'ΔT'. Steady-state conduction exist when the temperature at all locations in a substance is constant with time, as in the case of heat flow through a uniform wall.

The thermal conductivity of a material is calculated by,

$$\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x} \tag{3}$$

where, *A* is the cross-sectional surface area, ΔT is the temperature difference between the ends and Δx is the distance between the ends.

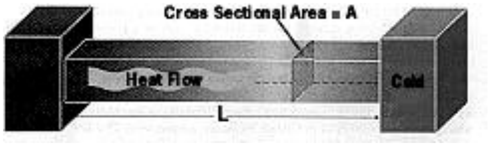


Figure 2 Schematic representation of heat conduction.

Figure 2 shows the schematic representation of heat conduction through a solid specimen, whose ends are kept at two different temperatures.

3.3 Fatigue analysis using FEM

Finite Element Analysis is a numerical tool where a physical problem is modeled into a mathematical model and that model is solved by Numerical technique. The physical domain under consideration is discretized into sub-domains of finite dimensions known as finite elements that are made up of nodes. The elements are interconnected at a discrete number of nodal points on the boundaries. The appropriate boundary conditions and the loads are applied at the nodes. The element mathematical equation of each element are assembled and solved to get the total global solution.

Characterizing the capability of a material to survive the many cycles a component may experience during its lifetime is the aim of fatigue analysis. In this ANSYS Fatigue Module is used to simulate the fatigue behaviour of composite for dynamic behaviour.

4. RESULTS AND DISSCUSSION

4.1 Micro-structural analysis

Using Optical Metallurgical microscope, the distribution of aluminum particles inside the epoxy resin matrix for different proportions by weight is investigated. It is identified that the distribution of aluminum particles inside the matrix of epoxy resin is uniform over the matrix, which is maintained by stirring it for a period of 10 min and the uniformity is verified in the microstructure. The aluminum particles appear bright against a black background. The microstructures of the composites for various proportions are shown in Figure 3. It is observed that, as the proportion of aluminum particles increases in the epoxy resin matrix, the distribution of aluminum particles are more even. The average size of the aluminum particles visualized is 100 µm.

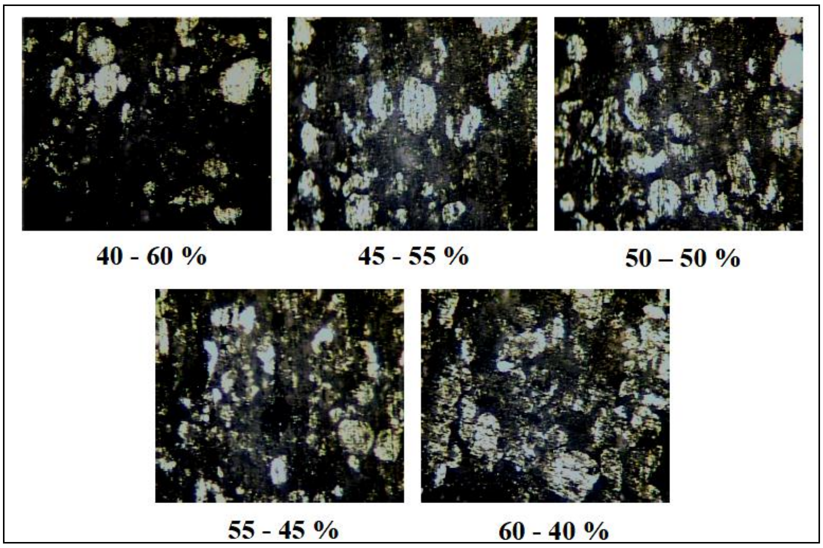


Figure 3 Microstructure of various proportions of composite.

4.2 Hardness test

The term hardness of a material is defined as, resistance to permanent deformation such as indentation, abrasion, scratching and machining. For determining the Hardness value in Rockwell Hardness machine suitable load, scale, ball size has to be selected. For aluminum filled epoxy resin composite, L scale is selected, Ball Size is ¼”, load is 60 kgf and red dial is selected. The Rockwell Hardness values determined for various proportions of aluminum and epoxy resin composites are given in Table 3.

Table 3 Hardness values for various proportions.

Sl. No	Proportions in % (Al – Ep)	R_{HL}
1	40-60	69
2	45-55	72
3	50-50	78
4	55-45	86
5	60-40	89

From Figure 4, it is observed that as the proportion of Aluminum in the Epoxy resin matrix increases the R_{HL} value of the composite decreases and it is higher for 60% Aluminum and 40% Epoxy resin proportion.

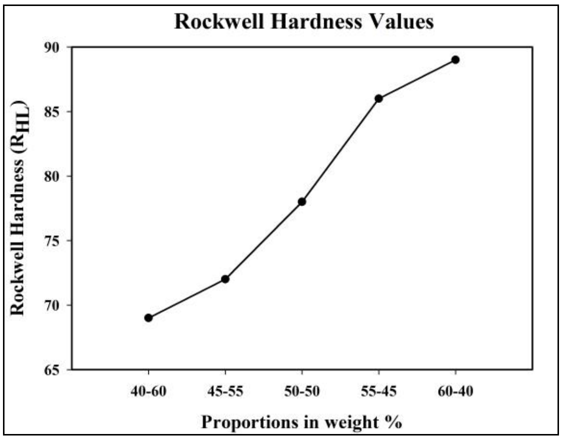


Figure 4 Rockwell hardness value of composite.

The hardness curve shows an upward trend, having a positive slope. The slope of the hardness curve is 0.5 when the Aluminum percentage increases from 40 to 45%. When the percentage of Aluminum is further increased by 5%, the slope is further increased by 1. By increasing the percentage of Aluminum from 50 to 55%, the slope of the curve attains a maximum value of 1.352. The slope of the hardness curve is 0.504, when the percentage of Aluminum is increased from 55 to 60%.

4.3 Thermal conductivity (*k*)

For determining the thermal conductivity of the composite, aluminum is taken as the reference material, whose thermal conductivity is known. The aluminum filled epoxy resin composite whose conductivity is to be determined are cast to a cylindrical shaped specimen for a diameter of 14 mm. An aluminum rod of diameter 14 mm is taken as reference.

The experimental set up consists of a heating plate, which is heated to about 180 °C and maintained at the same temperature throughout the experiment. The aluminum filled epoxy resin composite specimens of different proportions and the reference aluminum rod is placed on the hot plate and the temperature at the other end is noted down after a time period of 6 min. The thermal conductivity of various proportions of aluminum filled epoxy resin composite are determined, which are given in Table 4.

Table 4 Thermal conductivity of various proportions of composite.

Sl. No	Proportions in weight %	Thermal Conductivity (*W/m-K*)
1	40 – 60	3.97
2	45 – 55	4.06
3	50 – 50	4.64
4	55 – 45	4.97
5	60 - 40	5.39

From Figure 5, it is evident that, as the proportion of aluminum particles in the epoxy resin matrix increases the thermal conductivity value of the composite increases and it is maximum for 60% aluminum and 40% epoxy resin proportion. This shows that the proportion of more aluminum particles favours more thermal conductivity.

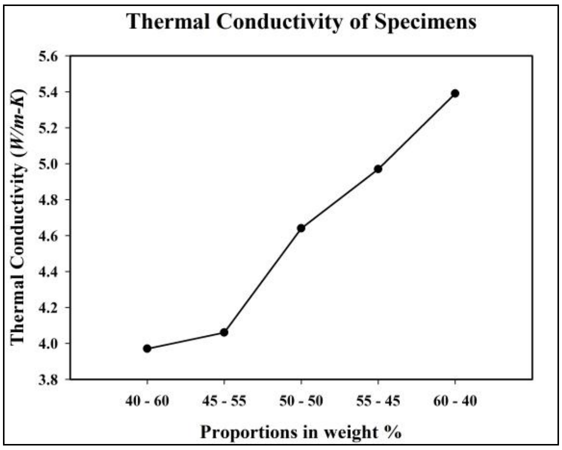


Figure 5 Thermal conductivity of composite specimens.

The thermal conductivity curve shows an uptrend line, which has a positive slope. Uptrend line shows that, as the percentage of Aluminum increases, the thermal conductivity increases. When the percentage of Aluminum increases from 40 to 45%, 0.218 increases the slope of the curve. When the Aluminum percentage increases by 5%, the slope is increased by 1.331. The slope increases by 0.78 when the Aluminum percentage increases from 50 to 55%. The slope of the curve is 0.976 when the Aluminum percentage is further increased by 5%.

4.4 Fatigue test (ASTM D3479-76)

Methods for conducting Fatigue test as per ASTM D3479 - 76 is,

Method 'A': A system in which the load is controlled so that the test specimen is subjected to constant amplitude of load in each cycle.

Method 'B': A system in which the strain or deformation is controlled so that the test specimen is subjected to constant amplitude of strain in each cycle.

For conducting Fatigue Test on Aluminum filled Epoxy resin composite material, Method 'A' is selected in which test specimen is subjected to constant amplitude of load in each cycle. The required bending moment is set in the flywheel of the motor so that a uniform cyclic load of 375 MPa is applied on to the tested specimen.

$$\begin{aligned} &Number\ of\ cycles\ required\ for\ fracture\ (N) \\ &= Time\ of\ fracture\ (\mathrm{min})\ x\ motor\ rpm \end{aligned} \tag{4}$$

The numbers of cycles that are required for attaining fatigue fracture for different proportions of aluminum powder in the matrix of epoxy resin are presented in Table 5.

Table 5 Fatigue life of Aluminum epoxy resin composite.

Sl. No	Proportions in weight %	No. of Cycles required for fracture
1	40 – 60	15786
2	45 – 55	10011
3	50 – 50	5384
4	55 – 45	2970
5	60 - 40	734

Figure 6 shows the comparison graph of fatigue life of composite for various proportions. It is observed that, as the proportion of aluminum in the epoxy resin matrix increases, the number of cycles required for fracture decreases and it is lower for 60 % Aluminum and 40 % Epoxy resin proportion.

The fatigue curve shows a downtrend line, having a negative slope. It is observed that the slope of the curve decreases as the percentage of Aluminum increases in the composition. This is due to the brittleness property of the composite material. The slope of the curve is 1.25, when the percentage of Aluminum increases from 40 to 45%. When the Aluminum percentage is further increased by 5%, the slope decreases by 0.96. When the Aluminum percentage increases from 50 to 55%, the slope decreases by of 0.52. The slope is 0.472, when the Aluminum percentage increases from 55 to 60%.

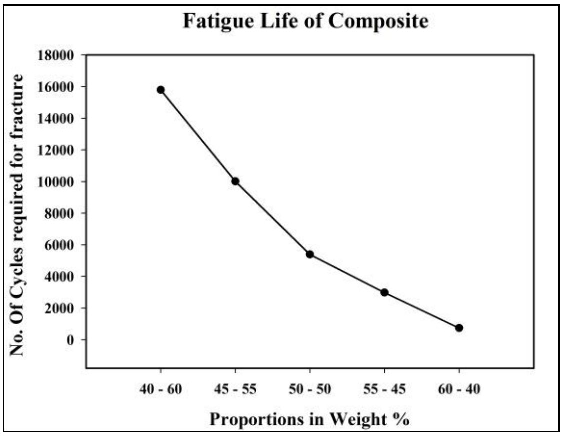


Figure 6 Fatigue life of composite.

4.5 Fatigue Analysis using FEM

For analyzing the specimen using ANSYS, one end of the specimen is made as a fixed support and the bending moment of 5 N-m is applied on the other end of the specimen and the analysis is carried out. The element type is solid with quadrilateral Mesh, number of elements is fixed as 546 and the number of nodes is chosen as 3606. The various input parameters that are given to the fatigue test specimen are presented in Table 6.

Figure 7 shows the meshed fatigue test specimen used in the finite element analysis. The specimen is modelled as per ASTM-3039 standard specifications.

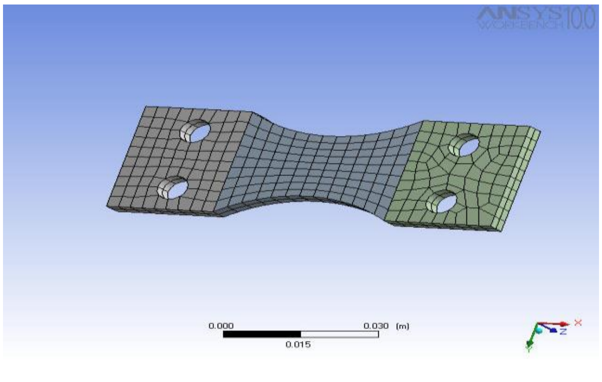
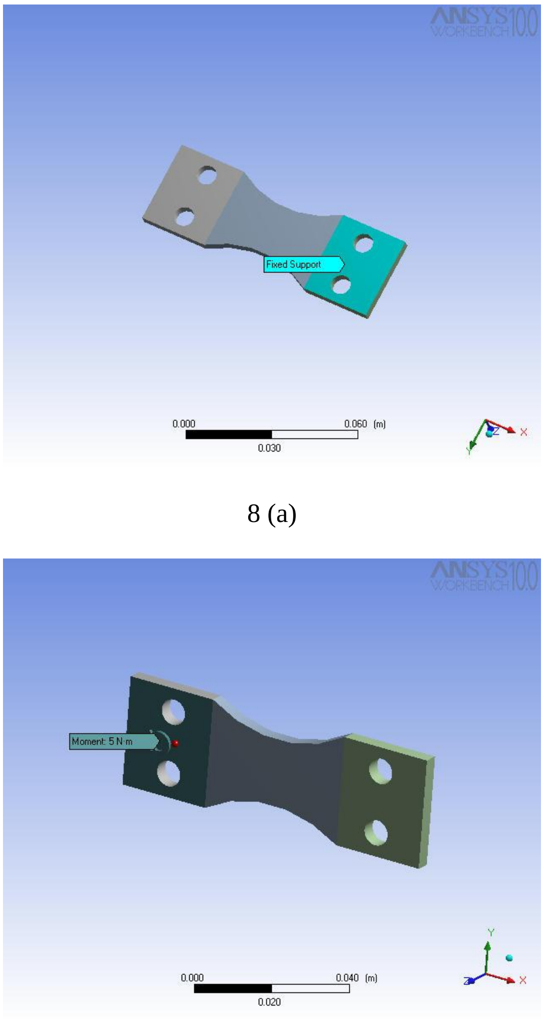


Figure 7 Meshed test specimens used in FEM.

Table 6: FEM input details for analysis.

Sl. No	Proportions in weight %	No. of cycles required for fracture	Young's modulus (*GPa*)	Poisson ratio	Density (*kg/m*^{3})
1	40 – 60	15786	69	0.3	1330
2	45 – 55	10011	69	0.3	1414
3	50 – 50	5384	70	0.3	1509
4	55 – 45	2970	75	0.3	1541
5	60 – 40	734	73	0.3	1578

Figure 8 shows the end conditions of the modelled dog-bone shaped specimen. One end of the specimen is fixed and at the other end bending moment is applied for analyzing the specimen using ANSYS.



8 (a)

8 (b)

Figure 8 End conditions of modelled specimen.

From the Finite Element Analysis, it is observed that for all proportions of Aluminum and Epoxy resin, shear stress is maximum at the narrow cross-sectional area and minimum at the clamped portion of the specimen. For different proportions, there is no change in maximum shear stress values. Figure 9 shows the maximum shear stress value obtained during finite element analysis for 40-60 % composition of composite.

While studying the total deformation for all the proportions of Aluminum and Epoxy resin, the total deformation is maximum for 40 – 60 proportion and minimum for 60 – 40 proportion. As the aluminum, percentage decreases in the epoxy matrix, the total deformation increases gradually, and as the proportion of aluminum increases inside the epoxy resin matrix, the fatigue life of the specimen increases gradually. Figure 10 shows the total deformation for 40 - 60% composition of composite.

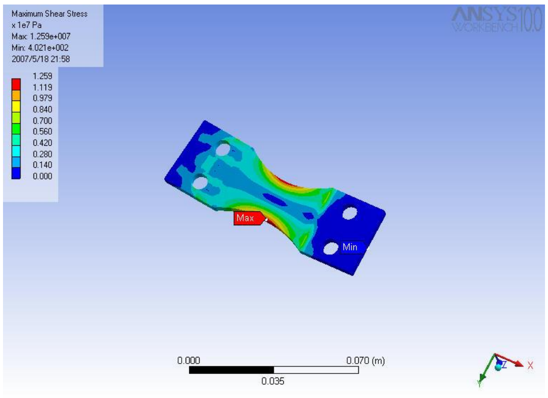


Figure 9 Maximum shear stress for 40-60 % composition.

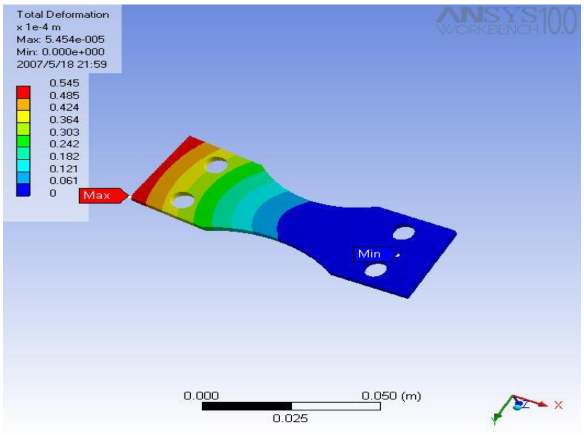


Figure 10 Total deformation of 40-60 % composition.

When the percentage of Aluminum is increased from 40 to 45%, there is no deformation in the composite material. There is a deformation of 1.36%, when the percentage of Aluminum is increased to 50%. By further increasing the percentage of Aluminum by 5%, a maximum deformation of 6.68% is observed. For 60% of Aluminum, the deformation of the dog-bone shaped specimen is 3.85%.

For 40-60 proportions by weight of aluminum particle and epoxy resin, the hardness is about 69 RH_L, fatigue life of 15786 cycles and thermal conductivity of 3.97 *W/m-K* is achieved. Although the fatigue strength of this proportion is high, the hardness value is very low. Hence this proportion is not recommended.

For 50-50 proportions, the hardness is about 78 RH_L, fatigue life of 5384 cycles and thermal conductivity of 4.64 *W/m-K*. For 10% increase in aluminum, the fatigue life decreases by 65.89%. But hardness increases by 13.04%. The hardness value for this proportion is more than 45-55 proportions, but the fatigue life is low. Hence it is not recommended.

For 55-45 proportions, the hardness is about 86 R_L, and has a fatigue life of 2970 cycles and has a thermal conductivity of 4.97 *W/m-K*. For 15% increase in Aluminum, the fatigue life decreases by 81.19%. But hardness increases by 24.64%. Even for very good hardness, the fatigue life is low. Hence this proportion is not recommended.

For 60-40 proportions, hardness is about 89 RH_L, fatigue life of 734 cycles and thermal conductivity of 5.39 *W/m-K*. For 20% increase in aluminum, the fatigue life decreases by 95.35%. But hardness increases by 28.98%. The Hardness of the composite is good, but the fatigue life is very low when compared to other proportions. Hence this proportion is not recommended.

For 45-55 proportions, hardness is about 72 RH_L, fatigue life of 10011 cycles and thermal conductivity of 4.06 *W/m-K*. For 5% increase in aluminum, the fatigue life decreases by 36.58% and hardness increases by 4.34%. Since both the hardness value and fatigue life is nominal for this proportion, than any other proportions. So for better mould durability and performance, this proportion is recommended.

Moreover as the percentage of aluminum particles increases inside the epoxy resin matrix, the thermal conductivity of the composite gets increased, and the composite becomes brittle.

5. CONCLUSION

Various proportions of aluminum particles are mixed with epoxy resin and then mould to a dog-bone specimens and cylindrical specimens. The mechanical strength of the composite is characterized by Rockwell Hardness test, fatigue strength by Fatigue test. Thermal conductivity is determined experimentally and optical metallurgical microscope is employed to investigate distribution of aluminum particles inside the composite.

1. Investigation by optical microscope reveals that the distribution of aluminum particles in the matrix of epoxy resin is uniform and even.

2. It is found that as the proportions of aluminum increases the hardness value increases proportionately and for 60 % wt. of aluminum with 40 % wt. of epoxy resin the hardness value is higher amongst all the proportions.

3. Thermal conductivity of the composite increases with increase in aluminum particles, which is maximum for 60-40 proportion and minimum for 40-60 proportion. However, as the aluminum percentage increases inside the Epoxy resin matrix, the composite becomes brittle.

4. As the proportion of aluminum increases inside the epoxy resin matrix the fatigue strength of the composite decreases which is higher for 40-60 proportion and lower for 60-40 proportion.

5. FEM fatigue analysis shows that, when the epoxy resin matrix composition is higher, the deformation is higher when compared to other proportions.

REFERENCES

Ahmad, Z., Ansell, M.P. and Smedley, D. 2010. Epoxy adhesives modified with nano- and micro-particles for in-situ timber bonding: effect of microstructure on bond integrity, International Journal of Mechanical and Materials Engineering 5 (1): 59-67.

Anilkumar, H.C., Hebbar, H.S. and Ravishankar, K.S. 2011. Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites, International Journal of Mechanical and Materials Engineering 6 (1): 41-45.

Avner, S.H. 1997. Introduction to Physical Metallurgy, Tata McGraw Hill Edition, New Delhi.

Benham, P.P., Crawford, R.J. and Armstrong, C.G. 1996. Mechanics of Engineering Materials, second ed. Addison Wesley Longman Limited, England.

Broutman, L.J. and Krock, R.H. 1967. Modern Composite Materials. ASTM Hand Book on Testing of Composite materials, Addison– Wesley Publishing Company, England.

Chung, S., Im, Y., Kim, H., Park, S. and Jeong, H. 2005. Evaluation for micro scale structures fabricated using epoxy-aluminum particle composite and its application, Journal of Materials Processing Technology 160: 168-173.

DeGarmo, E.P., Black, J.T. and Kohser, R.A. 2008. Materials and Processes in Manufacturing, tenth ed. John Wiley & Sons, Inc, USA.

Domkundwar, S., Kothandaraman, C.P. and Domkundwar, A.V. 2000. A Course in Thermal Engineering, Dhanpat Rai & Co, Delhi.

Goyanes, S., Rubiolo, G., Marzocca, A., Salgueiro, W., Somoza, A., Consolati, G. and Mondragon, I. 2003. Yield and internal stresses in Aluminum filled epoxy resin. A compression test and positron annihilation analysis, Polymer 44: 3193-3199.

Ho, M.W., Lam, C.K., Lau, K.T., Ng, D.H.L. and Hui, D. 2006. Mechanical properties of epoxy-based composites using nanoclays, Composite Structures 75: 415-421.

Irawan, A.P., Soemardi, T.P., Widjajalaksmi, K. and Reksoprodjo, A.H.S. 2011. Tensile and flexural strength of ramie fiber reinforced epoxy composites for socket prosthesis application, International Journal of Mechanical and Materials Engineering 6 (1): 46-50.

Patnaik, A., Abdulla, M., Satapathy, A., Biswas, S. and Satapathy, B.K. 2010. A study on a possible correlation between thermal conductivity and wear resistance of particulate filled polymer composites, Materials and Design 31: 837-849.

Post, N.L., Case, S.W. and Lesko, J.J. 2008. Modeling the variable amplitude fatigue of composite materials: A review and evaluation of the state of the art for spectrum loading, International Journal of Fatigue 30: 2064-2086.

Suhermana, H., Sulonga, A.B. and Saharia, J. 2010. Effect of filler loading concentration, curing temperature and molding pressure on the electrical conductivity of CNTS/ graphite/ epoxy nano-composites at high loading of conductive fillers, International Journal of Mechanical and Materials Engineering 5 (1): 74-79.

Suraj, C., Zunjarrao. and Singh, R.P. 2006. Characterization of the fracture behavior of epoxy reinforced with nanometer and micrometer sized aluminum particles, Composites Science and Technology 66: 2296-2305.

Vasconcelos, P.V., Lino, F.J., Baptista, A.M. and Neto, R.J.L. 2006. Tribological behavior of epoxy based composites for rapid tooling, Wear 260: 30-39.

Vasconcelos, P.V., Lino, F.J., Magalhaes, A. and Neto, R.J.L. 2005. Impact fracture study of epoxy-based composites with aluminium particles and milled fibres, Journal of Materials Processing Technology 170: 277–283.

Yidris, N., Zahari, R., Majid, D.L., Mustapha, F., Sultan, M.T.H. and Rafie, A.S.M. 2010. Crush simulation of woven c-glass/epoxy unmanned ariel vehicle fuselage section, International Journal of Mechanical and Materials Engineering 5 (2): 260-267.

Zamri, Y.B., Shamsul, J.B. and Amin, M.M. 2011. Potential of palm oil clinker as reinforcement in aluminium matrix composites for tribological applications, International Journal of Mechanical and Materials Engineering 6 (1): 10-17.

Zhao, S., Schadler, L.S., Duncan, R., Hillborg, H. and Auletta, T. 2008. Mechanisms leading to improved mechanical performance in nanoscale alumina filled epoxy, Composites Science and Technology 68: 2965-2975.