

Preparation and Thermal Analysis of Al₂O₃ filled Polymer Composites

Rakesh Singh¹, J.K. Tiwari², Gaurav Gupta³M. Tech. Scholar, Department of Mechanical Engineering, SSTC, SSGI, FET, Bhilai (C.G.), India¹Head of Department, Department of Mechanical Engineering, SSTC, SSGI, FET, Bhilai (C.G.), India²Assistant Professor, Department of Mechanical Engineering, SSTC, SSGI, FET, Bhilai (C.G.), India³

ABSTRACT: This paper presents the development and analysis of Al₂O₃ filled polymer matrix composite for passive application. The influence of Al₂O₃ filler loading on the thermal properties of composite are studied. Current research work deals with experimental analysis of thermal conductivity of polyester matrix composites filled with Al₂O₃. The results obtained are compared with effective thermal conductivity (K_{eff}) values obtained from experiment and other established models such as Lewis Nelson model, Rule-of-Mixture (ROM), Geometric Mean Model and Maxwell's model. For experimental analysis Al₂O₃ filled reinforced polyester composites are fabricated using hand lay-up technique and the thermal conductivity values are measured with the UnithermTM model 2022 tester according to the ASTM standard E-1530. The present work reveals that the reinforcement of the Al₂O₃ particles result in increase of thermal conductivity of polyester and upon increment of filler concentration the thermal conductivity increase consistently. In this research found that the reinforcement of 25 wt % of Al₂O₃ particulate, effective thermal conductivity of composite increases substantially. With enhanced heat dissipation capacity, these reinforced polyester composites can find their application where low weight and high thermal conductivity required like electronic industry).

KEYWORDS: Thermal conductivity; Polymer matrix composites, Aluminium oxide (Al₂O₃), Heat dissipation capacity.

I. INTRODUCTION

In many field of engineering application huge amount of heat are generated hence high rate of dissipation of heat required for better performance of system. If the dissipation rate is low it increases the system temperature and it may damage the devices. In olden day's polymer are used in electronic devices but because of their low thermal conductivity its uses are decreases the better properties for such application are high thermal conductivity and low thermal expansion coefficient. Thermal conductivity of aluminium oxide is high as compare to other known oxide in approximately same cost material [1]. To solve the problem of low heat dissipation rate of polyester material it is composite with the aluminium oxide (Al₂O₃). Aluminium oxide is filled in particulate form in polyester. The properties of aluminium oxide are added on polyester to make the better composite material. The properties of aluminium oxide are high mechanical strength, high hardness, moderate thermal conductivity and low density. Usually thermo sets like epoxy or polyester resin and thermoplastics like polypropylene or polyamide systems are used for encapsulating a variety of electronic components because of their high thermal stability, and low cost. These resins have poor moisture resistance thermal properties like low thermal conductivity and high coefficient of thermal expansion low thermal conductivity. The high thermal expansion coefficient of plastic resin can be lowered with the addition of ceramic powder filler, like fused silica or quartz. But silica-filled epoxy resins are undesirable for the encapsulation of silicon integrated circuit chips because of silica's low thermal conductivity [2]. Since recent applications of polymers as heat sinks in electronic packaging require new composites with relatively high thermal conductivity, it is important to

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

enhance the conductivity of the polymers. Improved thermal conductivity in polymers may be achieved either by addition of molecular orientation or by conductive fillers. Thermally conducting polymer-matrix composites are becoming increasingly important for electronic packaging and other high heat dissipated engineering application because the rate of heat dissipation ability limits the reliability, performance and miniaturization of devices. By the addition of particulate filler or molecular orientation to plastics the thermal behaviour of polymers can be increased significantly [3]. Such composites polymers with higher thermal conductivities are becomes important area of research because of the wide range of applications, e.g. in electronic packaging in applications with decreasing geometric dimensions and increased power, like in electronic devices. The main idea behind the increase in thermal properties in composite material are to decrease the thermal resistance of particle by embedded the metal particle or by orientation of metal particle but when the percentage of metal particle increase the weight of the composite material is also increase hence the optimum percentage of metal particle is decide according to weight and required heat dissipation. Aluminium oxides with a high thermal conductivity and low cost therefore emerge as a suitable filler material to be used in polymeric materials. In the present work Al_2O_3 chosen as the particulate filler to be dispersed within polyester resin. The objective of present work is fabrication of a new class of composites using Al_2O_3 as the reinforcing filler with an objective to improve the thermal conductive properties of neat polyester. Measurement of effective thermal conductivity (k_{eff}) of these particulate filled polymer composite (with different weight fraction) experimentally. Estimation of equivalent thermal conductivity of this particulate-polymer composite system using various theoretical models developed in previous investigation. Study the effect of TiO_2 on various physical properties like density and void content together. Study on the effect of TiO_2 content on other thermal characteristics of the composite such as glass transition temperature (T_g) and coefficient of thermal expansion (CTE). The present work has been undertaken to investigate the thermal conductivity of aluminium oxide filled polyester composites. The focus has been on numerical study of a series of such particulate filled composites and on the assessment of their heat conduction capability by determining their thermal conductivities by numerical method. Few well established theoretical model are also been used to evaluate the equivalent thermal conductivity of such composites analytically and when the calculated values obtained from both the methods are compared with the experimental results obtained under control laboratory conditions.

II. MATERIAL AND SAMPLE PREPARATION

Polyester is a category of polymer which is the ester functional group in their main chain. Polyester resin is also known as a thermosetting plastic, which implies the plastic sets at high temperatures. Unsaturated isophthalic polyester supplied by Reliance India Ltd. is taken as the matrix materials in the present investigation and particulate filler aluminium oxides of average size $100\ \mu\text{m}$ (procured from NICE Ltd.) used as filler material. Composite samples of different percentage compositions are prepared by hand lay-up technique. Hand lay-up technique is used for the fabrication of composites it is simplest method of preparation of composites. It is the simplest method of composite processing. The process requirement for hand lay-up method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mould surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mould plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mould size and placed at the surface of mould after Perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in required proportion with a hardener (it is act as a curing agent) and poured onto the mould. The Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer presen. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing at room temperature / some specific temperature, mould is opened carefully and the developed composite part is taken out and further processed. The polyester-Aluminium oxides composites are prepared in the following steps (i) uncured polyester and its corresponding hardener is mixed in a ratio of 10:1 by weight as per recommendation. (ii) Micro-sized Aluminium oxides particles are mixed with the polyester in different proportions. (iii) The uniformly mixed dough (polyester filled with Aluminium

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

oxides) is then slowly decanted into the glass molds so as to get both disc type specimens (diameter 50 mm and thickness 3 mm), coated beforehand with wax and a uniform thin film of silicone-releasing agent. (iv) The castings are then left at room temperature for about 24 hours and then the Aluminium oxides molds are broken and the samples are released. Composite samples were of the same resin matrix but were filled with Aluminium oxides particulate by 0, 5, 10, 15, 20 and 25% filler weight fractions.

III. PROPERTY MEASUREMENT

Thermal conductivity of a variety of materials is measure by the Unitherm Model 2022. These materials are polymers, composites, ceramics, glasses, rubbers, some metals and other materials of low to medium thermal conductivity. Glass transition temperature (T_g) and coefficient of thermal expansion (CTE) of the composites are measured with a Perkin Elmer DSC-7 Thermal Mechanical Analyzer.

IV. EXPERIMENTAL RESULT

IVA. Density and Void Fraction: Density is a property of material which is of very important in several weight sensitive applications. Polymers are well known for their low density. The low densities of polymer composites are found to replace the conventional metals and materials in many engineering applications. Density of a composite depends on the relative weight proportion of matrix and the reinforcing components. The theoretical and experimentally measured densities of polyester composites reinforced with Al₂O₃, along with the corresponding volume fraction of voids are presented in Table 1. Table shows the filler content and measured density value of the composites.

S.N o.	Filler Content	Measured density	Theoretical density	Voids contents (%)
1	0	1.35	1.35	-----
2	5	1.479	1.485	0.6
3	10	1.517	1.526	0.9
4	15	1.561	1.575	1.4
5	20	1.632	1.649	1.7
6	25	1.669	1.69	2.1

Table - 1: Density values along with the void fractions of the Al₂O₃ filled polyester composites

IV B. Effective thermal conductivity- The effective thermal conductivities of polyester composites filled with micro-sized aluminium oxide particles with filler weight fraction ranging from 0 % to 25 % are shown in Table 2 The values of effective thermal conductivities for similar combination are obtained using rules of mixture (ROM) model; Maxwell's correlation, Lewis and Nielsen model are also presented in Figure. It presents a comparison among the results obtained using various empirical models with regard to the values of effective conductivity obtained experimentally. It can be seen from graph that with increase in content of aluminium oxide in polyester matrix, the conductivity of the composite body increases. This results in increase in the Heat dissipation capability of the fabricated composite. Thermal conductivity of composites by different rule is shown in graph 1.

The maximum value of effective thermal conductivity among the various sets of fabricated composites is obtained when 25 wt% of aluminium oxide is incorporated in polyester matrix i.e. 1.64 W/mK. This increase is more than 6.3 times when compared to the neat polyester. With further increase of filler the conductivity value can increase further

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

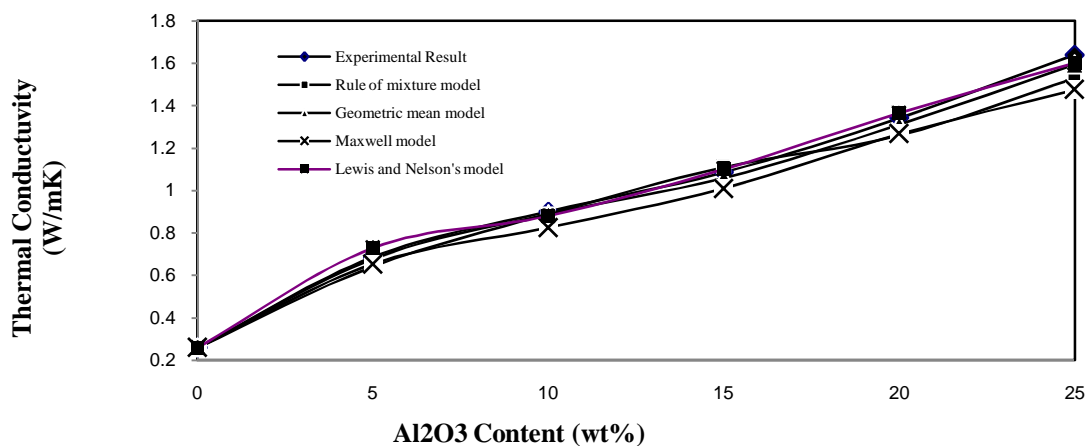
Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

but in present case it is not possible to increase the filler content more than 25 wt% because of percolation. Also hand lay-up technique restricts increase in filler content, though with other techniques like compression moulding or injection moulding it can be increased maximum by 5-10 wt % more. Table 2 shows the deviation in the value of different empirical model with the experimental determined values. On comparison, it is found that while the errors associated Maxwell model is highest i.e. 9.97 % which is deviating maximum from the experimental value, the associated error for geometric mean model is lowest i.e. 1.31 % which is the minimum deviation with the experimental value.

Sample	Aluminium oxides content (wt %)	Percentage error with respected to measured value			
		Rule of mixture model	Geometric mean	Maxwell's Model	Lewis and Nielsen model
1	5	6.56	1.50	6.5	6.23
2	10	1.34	1.31	8.42	2.34
3	15	2.12	2.55	7.13	1.40
4	20	6.05	2.35	8.20	1.68
5	25	6.71	2.71	9.97	2.35

Table 2 Percentage errors of $k_{\text{effective}}$ obtain from different method with respect to the measured value



Graph 1: Effective thermal conductivity of Composite as a function of Al₂O₃ percentage.

IV.C Glass Transition Temperature (T_g) - The glass transition temperature (T_g) of the fabricated aluminium oxide filled polymer composite samples are measured with a Perkin Elmer DSC-7 thermal mechanical analyzer (TMA). Graph 2 presents the variation of T_g with aluminium oxides content. It is observed that the T_g of neat polyester is about 90°C and it gradually increases to 102.6°C with an increase in filler content. A maximum increase of 12.6°C in T_g is obtained as the aluminium oxides content increases from 0 wt% to 25 wt%. A maximum increase of about 12.6 % in T_g is obtained. Usually, addition of such filler increases the T_g of the composites, which results from the interaction

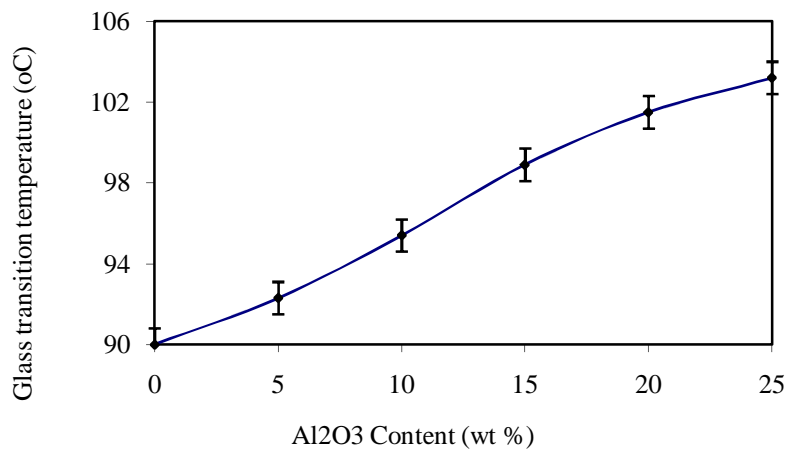
International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

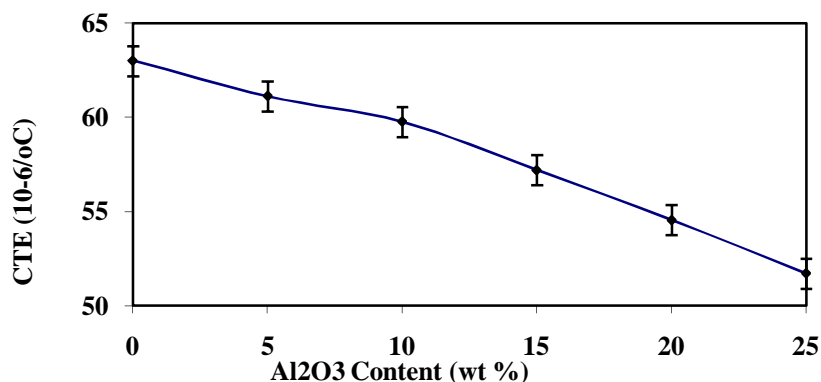
Vol. 6, Issue 5, May 2017

between a filler and a polymer by forming a network structure between them. Because of this network structure, the movement of molecular Aluminium oxides is increase in it and hence the glass transition temperature decrease.



Graph 2 Glass transition temperatures of polyester/aluminium oxides composite

IV.D Coefficient of Thermal Expansion (CTE)- The intrinsic Coefficient of Thermal Expansion values of aluminium oxides are higher compared to that of neat polyester. Hence, on Heating, the polymer matrix will expand less as compared to these filler. However, if the inter-phases are capable of transmitting stress, the expansion of the matrix will reduce giving rise to a reduced value of Coefficient of Thermal Expansion for the composite as a whole. Graph 3 shows that the Coefficient of Thermal Expansion of all the fabricated composites in present investigation. It is clear from the graph that CTE of the composite decreases with filler content and reaches from $62.5 \times 10^{-6}/^{\circ}\text{C}$ to $51.6 \times 10^{-6}/^{\circ}\text{C}$ for maximum filler content of 25 wt%. A maximum decrease of about 17.44 % in CTE is obtained is shown also in table . The constraint of mobility of the aluminium oxides filled polyester chain due to the interaction of and polyester are responsible for the reduction of CTE. Hence, the thermal stability of polymer improves with addition of filler.



Graph 3: Coefficient of thermal expansion of polyester aluminium oxides composite.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

V. CONCLUSION

This present investigation on particulate filled aluminium oxides polyester composites has led to the following conclusions:

- 1) Aluminium oxides possess reinforcing potential to be used as a filler material in polyester matrix composites.
- 2) Successful fabrication of polyester matrix composites reinforced with Aluminium's oxides particles is possible by simple hand-lay-up technique.
- 3) The density of the fabricated composites increases with increase in weight fraction and it also possesses low void content; even when it is prepared by hand lay-up technique.
- 4) Composite of Aluminium oxides is found to have resulted in increase in the value of thermal conductivity of polyester resin and thereby improves its heat dissipation capability.
- 5) A significant increment in the glass transition temperature is noticed with the incorporation of Aluminium oxides in polyester matrix.
- 6) However it is also observed that the coefficient of thermal expansion of polyester is slightly decrease by the addition of Aluminium oxides. It is observed that a drop of 17.44 % in CTE of polyester is obtained with 25 wt% inclusion of aluminium oxides. These changes improve the thermal stability and expand the application domain of the composites.
- 7) With increase in thermal conductivity(6.34 times) of these new class Aluminium oxides filled polyester composites can be used for applications of high heat dissipated material in electronic industry because of its low weight and high thermal conductivity.

REFERENCES

- [1]. Nayak, R, Satapathy, A, and Tarkes, DP, A computational and experimental investigation on thermal conductivity of particle reinforced epoxy composites, Computational Material Science, 48: 576–581, 2010 .
- [2]. Rao, Y., Yue, J., and Wong, C. P., "High K polymer nano-composite development, Characterization, and modelling for embedded capacitor RF application," in Proc. 51st Electron. Compon. Technol. Conf., pp.1408–1412, 2001.
- [3]. Antunes, PV, Ramalho, A, Carrilho, EVP, Mechanical and wear behaviors of nano and micro filled polymeric composite: Effect of filler fraction and size. Materials and Design, 61: 50–56, 2014.
- [4]. Agrawal ,BD and Broutman, LJ. . Analysis and performance of fiber composites. Second edition,John Wiley & Sons:2-16, 1990.
- [5]. Xu, Y, Chung, DDL and Mroz, C, Thermally conductive aluminium nitride polymer matrix composites. Composites: Part A, 32: 1749-57, 2001.
- [6]. Anjum, N, Prasad, SLA, Suresha, B, Role of silicon dioxide filler on mechanical and dry sliding wear behaviour of glass-epoxy composites. Advances in Tribology, 2013: Article ID 324952, 2013.
- [7]. Anjana, PS, Deepu, V, Uma, S, Mohanan, P, Philip J, and Sebastan, MT, Dielectric, thermal and mechanical properties of CeO₂-filled HDPE composites for microwave substrate applications. Journal of Polymer Science, 48: 998-1008, 2010.