Thermal Properties of Aluminium Nitride Particles Filled Polyester Composites for Microelectronics Applications

Chandan Kumar
Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal-462022

Alok Agrawal
Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal-462022

Tanmay Awasthi
Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal-462022

***Abstract*— In the present work, polyester composites are prepared with micro-sized aluminium nitride as filler material at varying content. The filler loading is varied from 0 wt. % to 40 wt. %. The effect of filler content on the thermal properties like thermal conductivity, glass transition temperature and coefficient of thermal expansion of such fabricated samples is investigated. From the experimental results, it is found that the inclusion of aluminium nitride filled polyester composites improves the thermal properties of the material. The thermal conductivity and glass transition temperature increase with filler content and the coefficient of thermal expansion decrease with filler content.**

***Keywords*—Polymer matrix composites, polyester, aluminium nitride, thermal properties.**

I. INTRODUCTION

In microelectronics applications, the requirement is quite different. Here high thermal conductivity is required for proper heat dissipation but at the same time, electrical resistivity is mandatory for proper signal distribution and to avoid short-circuiting. On that note, Zhou et al. [1] used a combination of SiC with linear low-densitypolyethene (LLDPE) composites and found improvement in thermal conductivity. Another silicon-based ceramic i.e. Si_3N_4 with still higher intrinsic conductivity value than SiC is proved to be an excellent filler, which steadily improves the conductivity of polystyrene [2]. In more recent work,An et al. [3] also agreed on the reinforcing potential of Si_3N_4 when they found an appreciable improvement in thermal conductivity. Ramdini et al. [4] modified the surface of the silicon to obtain much better results. They used a silane coupling agent for the surface treatment of silicon nitride particles and found that the thermal conductivity of the polybenzoxazine matrix improved. This shows that surface modification hasa great impact on the improvement of the thermal conductivity of the material. Anjana et al. [5] reported a sharp increase in conductivity from 0.54 to 3.22 W/m-K as cerium oxide (CeO_2) loading increased to 50 vol % in HDPE. Recently, Ozmihci and Balkose [6] found that the incorporation of ZnO increased the thermal conductivity of LLDPE to 1.56 W/m-K with the addition of 20 vol % of filler. Jia et al. [7] used montmorillonite as filler material in an epoxy matrix and found an appreciable increase in the value of thermal conductivity. They also modified the surface of filler using a silane coupling agent and found appreciable results. They further reported that in addition to increasing the thermal conductivity of the epoxy matrix, the filler plays a major role in reducing the dielectric constant and dielectric loss.

Boron nitride with its hexagonal structure has proved its potential to be used as potential filler material incorporated in polymer matrices for microelectronics applications. Gu et al. [8] reported that the thermal conductivity of epoxy matrix increases with an increase in boron nitride content. Hou et al. [9] used boron nitride in its hexagonal and studied the thermal behaviour of the developed material. In very recent work, Fang et al. [10] used boron nitride in the form of nano-sheets and reported unbelievable enhancement in the value of thermal conductivity. Pan et al. [11] used a surface modification technique over boron nitride particles and introduce them tothe PTFE matrix. With this, they found an enhancement in thermal conductivity of around 2.7 times with 30 vol. % of filler.

Aluminium nitride is a ceramic filler which is thermally conductive but electrically insulative in nature. Zhou et al. [12] worked on the combination of aluminium nitride and Polymethyl methacrylate (PMMA) matrix. They incorporated AlN over a wide range of filler content varied from 10 vol. % to 70 vol. % and performed a detailed investigation on thermal conductivity, relative permittivity and dielectric loss. From their analysis, they concluded that the thermalconductivity with maximum filler content reaches1.87 W/(m-K) andrelative permittivity for similar filler content is restricted to 4.4 (at 1 MHz), respectively. This is considered to be a noticeable improvement in both the properties which was beneficial for a certain application. Later Pan et al. [13] also used AlN as filler in the PTFE matrix and performed a similar study. Against this background, an attempt has been made in this research work to develop aluminium nitride-basedpolyester composites using a simple hand lay-up technique and to study their thermal behavior under controlled laboratory conditions.

II. MATERIALS AND METHODS

A. *Material considered*

The presently used matrix is a thermoset polymer polyester along with its accelerator and catalyst.The polyester resin is procured from Carbon Black composites, Mumbai, India.Aluminium nitride is an aluminium-based ceramic material used as one of the filler materials in the present work. The used aluminium Nitride has been procured from Souvinier Chemical, Mumbai, India. The particle size analysis of the material provides the information that the average sizes of particles are about 60-70 microns.

Published By:
International Journal of Engineering Research in Current Trends

B. Composite Fabrication

A simple hand lay-up technique is used in the present investigation for the fabrication of aluminium nitride particles in a polyester matrix. This method is considered the simplest technique for composite fabrication. The fabrication of composite using the hand lay-up method involves the following steps:

1. First the room temperature curing polyester resin is added with the given percentage of AlN micro-particulates and mixed well through hand-stirring.
2. Later 1 wt. % of the cobalt accelerator is added into the mixture and mixed well through hand stirring.
3. This is followed by the addition of 1 wt. % MEKP catalyst and the combination is mixed properly through hand stirring over a period of around one minute.
4. A coating of silicon spray is mandatory over the mould before pouring the mixture into it, a silicon spray is done over the mould so that it will be easy to remove the composite after curing. The uniformly mixed dough is then slowly poured into the mould.
5. The cast is then cured for 2 hours before it was taken from the mould.

Composites were fabricated with different weight fractions of filler ranging from 0 wt. filler i.e. neat polyester to 40 wt. % AlN filler. The composite fabricated under the investigation is given in table 1.

TABLE I: POLYESTER COMPOSITES FILLED WITH ALUMINIUM NITRIDE

S.No.	Composition
1	Neat Polyester
2	Polyester + 10 wt % Aluminium Nitride
3	Polyester + 20 wt % Aluminium Nitride
4	Polyester + 30 wt % Aluminium Nitride
5	Polyester + 40 wt % Aluminium Nitride

A. Thermal Characterization

The thermal conductivity of the fabricated composites is measured by Unitherm Model 2022. The tests are in accordance with ASTM E-1530 Standard. Glass transition temperature and Coefficient of thermal expansion of the composites are measured with a Perkin Elmer DSC-7 Thermal Mechanical Analyzer. During the measurement, the specimen is heated from 30 to 150°C at a heating rate of 5°C/min.

III. RESULTS AND DISCUSSION

B. Thermal conductivity

The thermal conductivity of neat polyester is 0.147 W/m-K. To improve this quantity, aluminium nitride in the form of micro particulates was added. With the addition of AlN, the thermal conductivity of the combination increases. The same can be seen in figure 1. The rate of increase is purely a function of the content of aluminium nitride i.e., with an increase in the content of the aluminium nitride, thermal conductivity increases.For low filler content of 20 wt. %, the rate of increase of thermal conductivity is low, i.e., the conductivity of polyester composites reaches 0.193 W/m-K with this filler content. The thermal conductivity value achieved is 0.387 W/m-K which is an improvement of 163.2 %. This huge improvement is attributed to the fact that when the content of filler increased continuously, the filler could come in contact and form the thermally conductive path within the matrix body, leading to higher thermal conductivity.

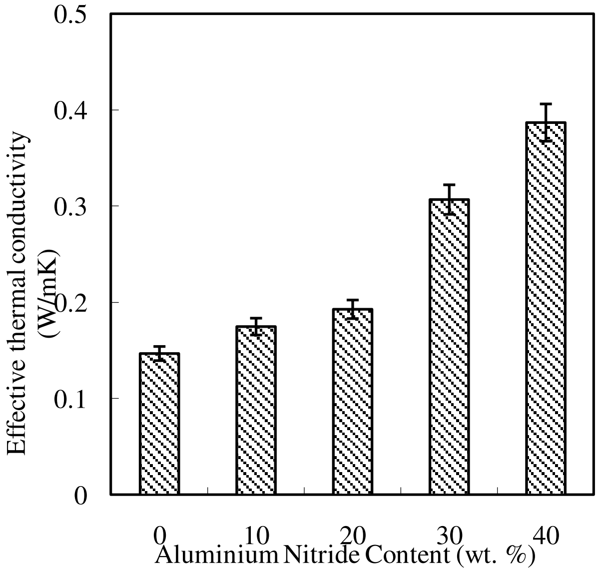

Fig. 1: Thermal conductivity of polyester/ aluminium nitridecomposites

C. Glass transition temperature

The glass transition temperature of polyester/AlN composite as a function of AlN content is shown in figure 2. From the figure it is clear that the glass transition temperature of polyester composites was higher as compared to that of neat polyester and it increases with an increase in AlN content. Glass transition temperature increases from 80 oC for neat polyester to 94.1 ^{o}C for 40 wt. % AlN filled polyester. The increment is measured to be 17.62 % which is an appreciable improvement.

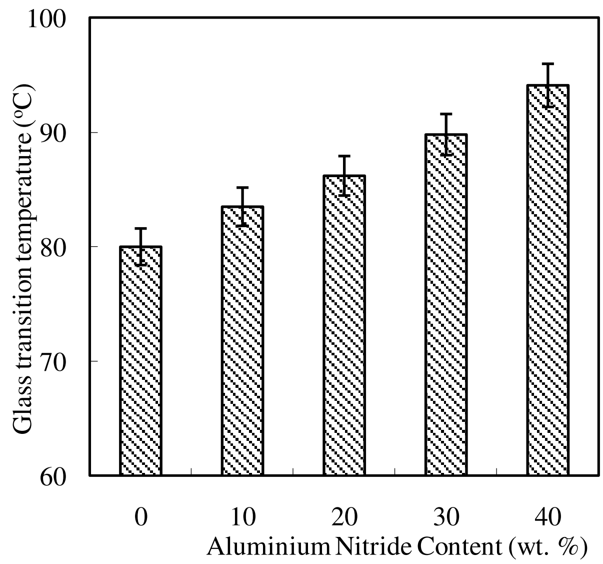

Fig. 2 Glass transition temperature of polyester/aluminium nitridecomposites

D. Coefficient of thermal expansion

The inclusion of AlN provided is beneficial as with an increase in the content of AlN, the CTE of the polyester matrix decreases. The same can be seen in figure 3.It is expected because the intrinsic CTE of AlN is much lower than that of the polyester matrix. Also, the addition of AlN particles into polyester results in a reduction in the value of CTE of the composites due to the restricted mobility of the polymer molecules arising out of adsorption of AlN surfaces.

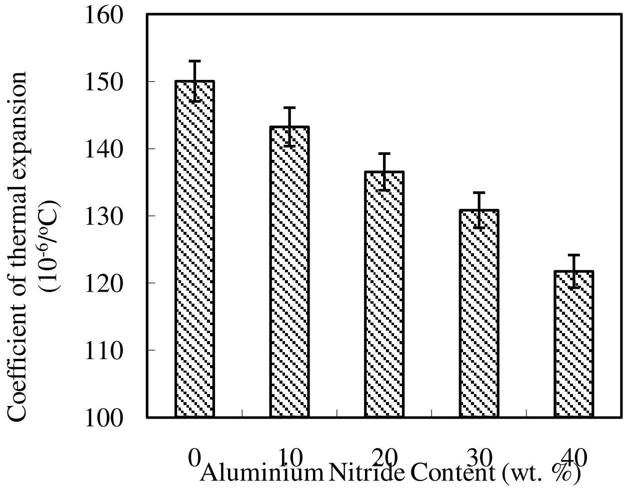

Fig. 3 Coefficient of thermal expansion of polyester/aluminium nitridecomposites

The CTE of the composite reduces from 150 × 10^{-6}/°C to 121.7 × 10^{-6}/°C for 40 wt. % of AlN. The decrement observed in this analysis is 23.25 %.

IV. CONCLUSIONS

This experimental investigation has led to the following specific conclusions:

1) The thermal conductivity of polyester resin increases with an increase in AlN content. By the addition of 40 wt. % AlN, the thermal conductivity of polyester matrix increases from 0.147 W/m-K to 0.387 W/m-K.
2) Glass transition temperatures of polyester resin increase when AlN filler is added into it. Glass transition temperature increases from 80 °C for neat polyester to 94.1 °C for 40 wt. % AlN filled polyester.
3) Coefficient of thermal expansion of polyester matrix decreases with an increase in AlN fillers. The CTE of the composite reduces from 150 × 10^{-6}/°C to 121.7 × 10^{-6}/°C for polyester-based composite incorporated with 40 wt. % of AlN.

REFERENCE

[1] Zhou W, Yu D, Min C, Fu Y, Guo X, "Thermal, dielectric, and mechanical properties of SiC particles filled linear low-density polyethylene composites" by, *Journal of Applied Polymer Science*, 112: 1695-1703. 2009.

[2] He H, Fu R, Shen Y, Han Y, Song X, "Preparation and properties of Si_3N_4/PS composites used for electronic packaging" by, *Composites Science and Technology*, 67: 2493–2499. 2007.

[3] Preparation and characterization of thermally-conductive silane-treated silicon nitride-filled polybenzoxazine nanocomposites.

[4] An Q, Qi S, Zhou W,"Thermal, electrical, and mechanical properties of Si_3N_4 filled LLDPE composite" by, *Polymer Composites*, 30: 866-871. 2009.

[5] Anjana PS, et al., "Dielectric, thermal, and mechanical properties of CeO_2-filled HDPE composites for microwave substrate applications" by, *Journal of Polymer Science: Part B: Polymer Physics*, 48: 998–1008. 2010.

[6] Ozmihci FO, Balkose D, "Effects of particle size and electrical resistivity of filler on mechanical, electrical, and thermal properties of linear low density polyethylene–zinc oxide composites" by, *Journal of Applied Polymer Science*, 130: 2734-2743. 2013.

[7] Jia Z. R, et al., "Effects of filler loading and surface modification on electrical and thermal properties of epoxy/montmorillonite composite" by, *Chinese Physics B*, *27*(11), 117806. 2018.

[8] Chung, S. L., & Lin, J. S. (2016). Thermal conductivity of epoxy resin composites filled with combustion synthesized h-BN particles. *Molecules*, *21*(5), 670.

[9] Hou J,et al., "Preparation and characterization of surface modified boron nitride epoxy composites with enhanced thermal conductivity" by, *Rsc Advances*, *4*(83), 44282-44290. 2014.

[10] Fang H, et al., "Thermal, mechanical and dielectric properties of flexible BN foam and BN nanosheets reinforced polymer composites for electronic packaging application" by, *Composites Part A: Applied Science and Manufacturing*, *100*, 71-80. 2017.

[11] Pan C, et al., "Improved thermal conductivity and dielectric properties of hBN/PTFE composites via surface treatment by silane coupling agent" by, *Composites Part B: Engineering*, *111*, 83-90. 2017.

[12] Zhou Y, et al.,"Fabrication and characterization of aluminum nitride polymer matrix composites with high thermal conductivity and low dielectric constant for electronic packaging" by, *Materials Science and Engineering: B*, *177*(11), 892-896. 2012.

[13] Pan C, et al.,"Fabrication and characterization of AlN/PTFE composites with low dielectric constant and high thermal stability for electronic packaging" by, *Journal of Materials Science: Materials in Electronics*, *27*(1), 286-292. 2016.