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Physical and Mechanical Properties of Micro-Size Ceramic Particulate Filled Epoxy Composites

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Abstract

The present work aims at developing a class of polymer composites consisting of thermoset polymer, i.e., epoxy as a matrix material with a micro-size filler material, i.e., hexagonal boron nitride (hBN) as a reinforcing material. A simple hand lay-up technique has fabricated a set of composite with varying filler loading. The effect of filler content on such fabricated samples' physical and mechanical properties is investigated and presented in this work. The various properties evaluated are density, void content, hardness, tensile strength, and the fabricated samples' compressive strength. The values obtained under controlled laboratory conditions are analyzed to identify their behavior. The experimental results found that the density of the composites increases with an increase in filler content. Also, voids are increased when filler in the epoxy matrix increases.

Further, hexagonal boron nitride inclusion in the epoxy matrix increases the composite's hardness and compressive strength. Against that, an increasing-decreasing trend is obtained when the tensile strength of the fabricated samples was analyzed. Tensile strength increases up to 10 wt. % of filler and a further increase in filler content reduces the tensile strength of the composites.

Keywords — *Polymer matrix composite, epoxy, hexagonal boron nitride, physical properties, mechanical properties*

I. INTRODUCTION

(Size 10 & Normal)This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please con. As the demands of high performance, denser and faster circuits, the heat dissipation in microelectronic products is becoming increasingly important. The ability to adequately conduct heat away from the electric devices is an important issue. Thermally conducting but electrically insulating materials attracted more attention since high thermal conductivity and high electrical resistance are needed for fast signal transmits. The properties of composites can be designed according to specific requirements by changing the fraction of the constituents. Almost all polymers are electrically insulating and thermally insulating; thus, polymers alone cannot be used for high thermal conductivity. On the other hand, polymers have low processing temperatures, allowing them to be fabricated to polymer matrix composites. Using ceramic filler with high thermal conductivity and dispersion in poly-matrix can prepare thermally conducting composites [1].

Materials for microelectronic packaging applications need to simultaneously fulfill diverse requirements such as low dielectric loss, moderate dielectric constant, low thermal dependence of dielectric constant, moisture absorption resistance, high thermal conductivity, low coefficient of thermal expansion, high dimensional stability, and mechanical stiffness [2]. In general, the ceramics have low loss tangent, suitable dielectric constant, low coefficient of thermal expansion, and relatively high thermal conductivity and are brittle. In contrast, polymers have low loss tangent, low εr, low T.C., and high CTE and are flexible. Polymer–ceramic composites with excellent dielectric, thermal, and mechanical properties can be prepared at low temperatures by combining the advantages of both the phases [3–4]. Since the past decade, there has been an increasing trend to tailor the thermal, mechanical, and dielectric properties of polymers by incorporating suitable ceramic fillers [5–10]. The key properties of the composite viz. the dielectric constant, dielectric loss, thermal conductivity, and coefficient of thermal expansion depend on various factors such as the number of components or phases, volume fraction of the filler, size of the filler particles, individual properties of the phases, preparation method and the interaction between the filler and matrix. The polymers' thermal properties can be improved with a sufficiently high (440%) volume percentage of filler. However, higher filler content results in low strength, poor flexibility, increased porosity, and defects in the composite. Hence, a detailed investigation of such properties is required to

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justify the practical implementation of such material as drastic decrease in strength will reduce the developed material's applicability. Against this background, an attempt has been made in this research work to develop hexagonal boron nitride (hBN) based epoxy composites using a simple hand lay-up technique and to study their physical and mechanical behavior under controlled laboratory conditions.

II. MATERIAL CONSIDERED

Thermoset resin Lapox L12 is a liquid, unmodified epoxy resin of medium viscosity is used as the matrix material in the present investigation. It is used with its corresponding hardener, which is a low viscosity room temperature curing liquid. Hardener K6 is commonly employed with Lapox L12. The matrix material system selected is supplied by ATUL India Ltd., Gujarat, India. The epoxy used in the present investigation possesses a density of 1.16 g/cc, a tensile strength of 40.5 MPa, a compressive strength of 85 MPa, and a hardness of 0.145 GPa. Souvenier Chemicals, Mumbai supply boron nitride in its hexagonal crystal structure of size 5 microns used in the present investigation. It is of ultra-pure grade with a purity level of 99 %. It has a density of 2.3 g/cc.

III. SAMPLE FABRICATION

In the present investigation, hBN filled epoxy composite is fabricated using a simple hand lay-up technique. The fabrication of composite using hand lay-up method involves the following steps:

1. The room temperature curing epoxy resin (L-12) and corresponding hardener (K-6) are mixed in a ratio of 10:1 by weight as recommended.
2. Hexagonal boron nitride will then added to the epoxy-hardener combination and mixed thoroughly by hand stirring.
3. Before pouring the epoxy/filler mixture in the mold, a silicon spray is done over the mold so that it will easy to remove the composite after curing. The uniformly mixed dough is then slowly poured into the mold to get specimens of size as per the ASTM standard.
4. The cast is then cured for 12 hours before it was removed from the mold.

Composites were fabricated with different weight fractions of filler ranging from 0 to 40 wt. %. The list of fabricated composite in the present work is presented in table 1.

IV. EXPERIMENTAL DETAIL

The experimental density (ρ_{ce}) of composites under study is determined using the Archimedes principle using distilled water as a medium (ASTM D 792-91). The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained using the mixture model rule.

TABLE I
List of fabricated composites

Set	Composition
Set A1	Epoxy + 5 wt % of hBN
Set A2	Epoxy + 10 wt % of hBN
Set A3	Epoxy + 15 wt % of hBN
Set A4	Epoxy + 20 wt % of hBN
Set A5	Epoxy + 25 wt % of hBN
Set A6	Epoxy + 30 wt % of hBN
Set A7	Epoxy + 35 wt % of hBN
Set A8	Epoxy + 40 wt % of hBN

A comparison of experimental and theoretical density gives voids generated during the fabrication of composites. The tensile strength of the composites is measured with a computerized Tinius Olsen universal testing machine in accordance with the ASTM D638 procedure by applying uni-axial load through both the ends at a crosshead speed of 2 mm/min. Static uniaxial compression tests on specimens are carried out using the same computerized Tinius Olsen universal testing machine. The method by which the compression test is conducted is in accordance with ASTM D695. The standard requires that the specimen is compressively loaded at a rate of 2 mm/min until fracture. Brinell hardness test was carried out in accordance with ASTM E-10 using Affri LD250 hardness measuring instrument.

V. RESULTS AND DISCUSSION

A. *Density measurement*

Figure 1 shows the epoxy/hBN composites' measured and calculated density with varying content of hBN filler. The figure shows that the density of composite increases with filler content as expected due to the higher density of hBN. The theoretical density is calculated using the rule of mixture model considering epoxy density as 1.16 gm/cm3 and hBN density as 2.3 gm/cm3 for varying content of hBN filler.

The measured and calculated density found that maximum percentage deviation is around 8 % between the two values for hBN/epoxy composites. This deviation is due to voids inside the composites generated during the fabrication of composites by hand lay-up technique. These voids increase with an increase in filler content as we consider that composite consists of three phases i.e. matrix, filler, and voids. The porosity values obtained were shown in figure 2. From the figure, it can be seen that with an increase in filler content, the percentage of void also increases mainly because of the increase in the mixture's viscosity. The maximum porosity value obtained is 8.07 % for a high filler content of 40 wt. % in the present work.

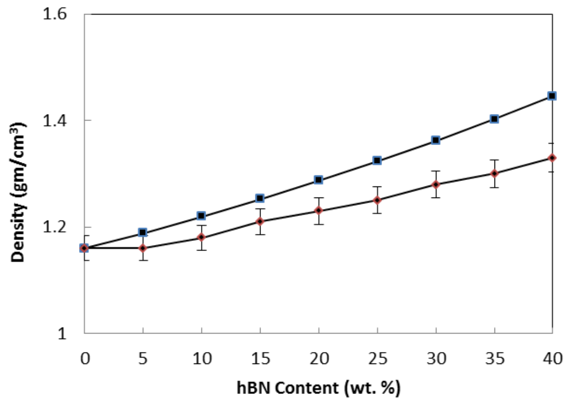

Fig 1: Theoretical and measured density of epoxy/hBN composites

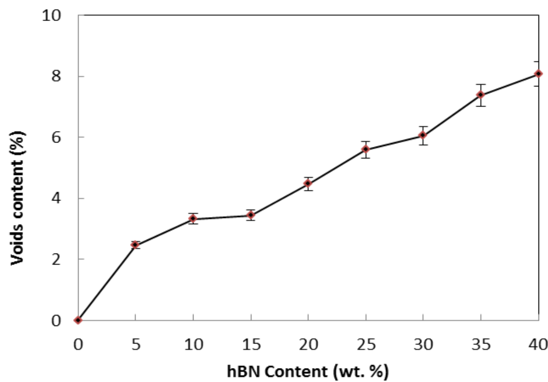

Fig 2: Void content generated in epoxy/hBN composites

B. Tensile strength

The dependence of the tensile strength of epoxy composites filled hBN with different content is shown in figure 3. The tensile strength of epoxy/hBN composites increased with hBN content when hBN content is up to 10 wt. %. The tensile strength of neat epoxy is 40.5 MPa, which increases to 44.6 MPa at a loading of 10 wt% of micro-size hBN. However, when hBN content increases beyond 10 wt.%, the composite's tensile strength decreases with increased hBN content for maximum filler loading of 40 wt. %, the tensile strength of composites decreased to 18.2 MPa. A limited quantity of filler can successfully remedy the defects from epoxy self-curing.

Meanwhile, B.N. can transfer stress and avoid the expansion of cracks, thus enhancing tensile strength. The drastic decline in tensile strength due to the high loading of hBN may be clarified because excessive fillers served as local stress-concentration points in the resin matrix. With increasing hBN content to a certain level, the combination's viscosity began to intensify quickly due to the nonappearance of inertia solvent such as acetone. Consequently, some voids or interfacial defects, pitiable interfacial wettability between the hBN and the matrix might appear in the composites, causing the weakening in tensile strength.

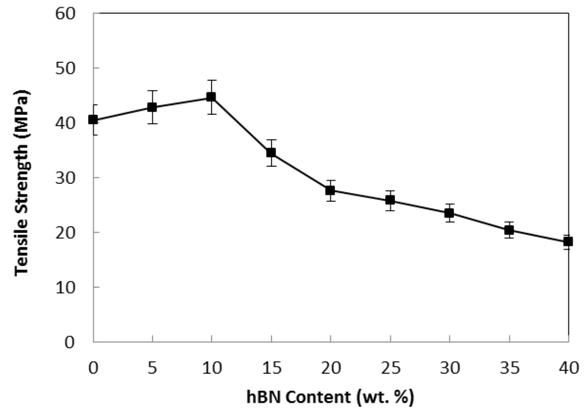

Fig 3: Tensile strength of epoxy/hBN composites

C. Compressive strength

The dependence of compressive strength of epoxy composites filled with hBN (raw and surface modified) with different filler content is shown in figure 4. It can be seen that with increase in hBN content, the composites' compressive strength increases. The compressive strength of neat epoxy is 85 MPa, which increases to 100.9 MPa at a loading of 40 wt% of micro-size hBN. This is an appreciable increment of 18.7 %.

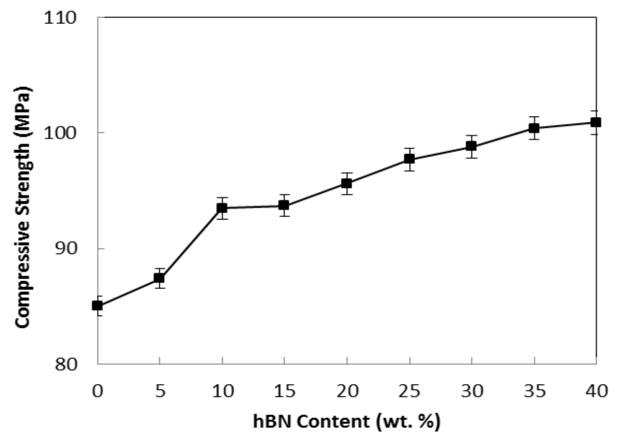

Fig 4: Compressive strength of epoxy/hBN composites

The improvement in compressive strength with filler addition is mainly because of the high compressive strength of filler material. Also, the increase in compressive strength with increased filler content is due to the favorable deformation processes facilitated by fillers' presence in the matrix. Under a compressive loading situation, the fillers aid the load-bearing capability of a composite rather than acting as a stress raiser, as is the case in tensile loading. Further, the fact that in a compression test, any crack or flaw introduced by dispersion of the filler will, if at all, get healed (closed) and made ineffective,

contrary to the crack opening mechanism occurring in a tensile loading situation.

D. Hardness

The dependence of micro-hardness of epoxy composites filled with hBN with different filler content is shown in figure 5. It is evident from the figure that with the addition of fillers, the composites' micro-hardness improved, and this improvement is mainly a function of the filler content. Incorporation of hBN in epoxy results in an increase in its micro-hardness value and is obvious because of the high hardness value of hBN compared to epoxy. Increased filler content increased the composite modulus, leading to a corresponding increase in the composite's hardness for 40 wt. % hBN content hardness increases from 0.145 GPa to 1.161 GPa, which is around eight times that of neat epoxy.

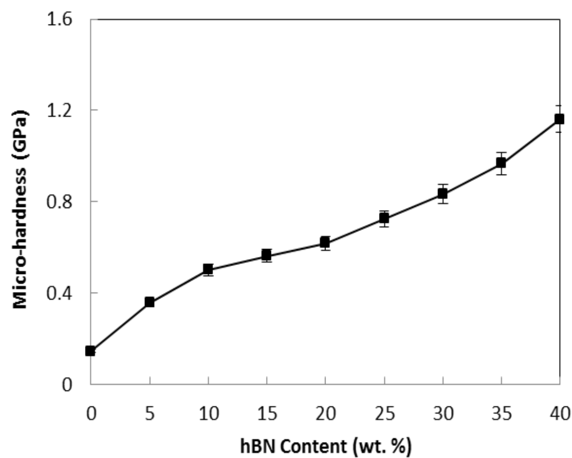

Fig 5: Micro-hardness of epoxy/hBN composites

VI. CONCLUSIONS

This experimental investigation on hexagonal boron nitride filled epoxy composites has led to the following specific conclusions:

1) Successful fabrication of epoxy matrix composites reinforced with micro-size hBN is possible by a simple hand-lay-up technique.
2) The tensile strength of epoxy/hBN composites increased with hBN content when hBN content is up to 10 wt. %. The tensile strength of neat epoxy is 40.5 MPa, which increases to 44.6 MPa at a loading of 10 wt% of micro-size hBN. However, when hBN content increases beyond 10 wt.%, the composite's tensile strength decreases with increased hBN content for maximum filler loading of 40 wt. %, the tensile strength of composites decreased to 18.2 MPa.
3) The compressive strength of the composites increases with an increase in hBN content. The compressive strength of neat epoxy is 85 MPa, which increases to 100.9 MPa at a loading of 40 wt% of micro-size hBN.
4) With hBN fillers' addition, the composites' micro-hardness improved, and this improvement is mainly a function of the filler content, for 40 wt. % hBN content hardness increases from 0.145 GPa to 1.161 GPa.

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