INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 04, Issue 11, November 2024, pp : 1776-1779
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

EFFECT OF ADDITION OF MICRO-SIZED SILICON NITRIDE ON THE MECHANICAL PROPERTIES OF THE EPOXY COMPOSITES

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ABSTRACT

In the present investigation, the effect of the addition of silicon nitride particulates in the epoxy resin is investigated and presented. The main concentration of the work is on the mechanical properties of the developed material. The properties under investigation are tensile strength, compressive strength and hardness. All the properties are determined as a function of filler loading. The effect of modification of the surface of the silicon nitride using a silane coupling agent on the mentioned properties of the composites is also investigated. Four sets of composite specimens with filler content ranging up to 40 wt. % has been fabricated. From the experimental results, it is found that the inclusion of silicon nitride in the epoxy resin increases the compressive strength and hardness of the composite body as a function of filler loading. While studying the tensile strength, it is observed that the inclusion of filler first increases the tensile strength of the composite up to 20 wt. % of filler loading and later it starts decreasing when the content of filler increases further. It is also observed that the composite prepared with silane-modified silicon nitride shows better mechanical properties as compared to its counterpart for a given filler loading.

Keywords— Epoxy, Silicon nitride, Tensile strength, Compressive Strength, Hardness.

1. INTRODUCTION

Nowadays, composite materials are everywhere as they extend their horizons in almost every branch of engineering and science. Polymer matrix composites (PMCs) are the best-established form of advanced composite materials. Of the two classes of polymers used as matrices, thermosets and thermoplastics, thermosets dominate the market for structural applications. Current research is being conducted on composite materialsfor thermoset as a matrix material. In the present work, epoxy is selected as a matrix material and a ceramic material i.e. silicon nitride is used as a filler material. Silicon nitride has been used for the development of composite material with polymer as a base matrix material in the past.

The usages of silicon nitride as filler material were mainly established in the twentieth century when He et al. [1] used this filler with a polystyrene matrix. They studied the thermal and dielectric properties of the developed material and reported achieving a thermal conductivity of 3.0 W/m-K with 40 vol. % of filler material. An et al. [2] incorporated silicon nitride with linear low-density polyethene and studied the mechanical, thermal and electrical properties of the developed material. On a similar note, Ramdini et al. [3] used the same filler as nano-filler with polybenzoxazine matrix and fabricated the composites by compression moulding technique. They performed the DMA analysis of the samples and noticed improvement in stiffness and glass transition temperature of the developed material. Later in other work, Ramdini et al. [4] performed thermal

conductivity measurement with increased filler content up to 70 % and reported achieving 5.78 W/m-K of conductivity value over 0.18 W/m-K against neat polymer. Kumar and Reddy [5] worked on evaluating the mechanical and tribological properties of silicon nitride-filled Nylon-6 polymer composites. In their analysis, they found that incorporation of filler in small amounts increases the tensile strength but when filler content increases further, tensile strength decreases. Maximum value of tensile strength is obtained with 4 wt. % filler content.

The hardness of the composite also increases with filler content up to 16 wt. %. With a further increase in filler content, hardness shows a decreasing trend. Wang et al. [6] developed high strength polymer composite with silicon nitride as filler for dental application. The developed material possessed excellent flexural strength with improved hardness and elastic modulus. Chen et al. [7] used silicon nitride with a polyamide matrix and studied the dielectric properties of the material.

Zgalat-Lozynskyy et al. [8] explore the utilization of silicon nitride particles as reinforcement in polymer materials for 3D printing. The research provides significant insights into enhancing the properties of 3D-printed polymer materials. Petousis et al. [9] present a comprehensive exploration of nanomaterials, focusing on optimizing the rheological and thermomechanical response of Acrylonitrile Butadiene Styrene (ABS)/Silicon Nitride nanocomposites for Material Extrusion Additive Manufacturing (MEAM).

The study delivers significant findings, showcasing enhanced material properties. Wan et al. [10] explore the enhancement of in-plane thermal conductivity and mechanical strength in flexible films through the alignment and interconnection of Si_3N_4 nanowires. The study presents a noteworthy improvement in thermal conductivity, with the aligned and interconnected Si_3N_4 nanowires resulting in an impressive value of 3.27 W/m-K. Additionally, the mechanical strength of the films is significantly improved, demonstrating a remarkable increase in tensile strength by 43% and Young's modulus by 31%. It is observed from the earlier investigation that the silicon nitride has been used with various matrix materials but its combination with epoxy resin is rare. Further, it is observed that the properties investigated are mainly thermal properties.

Against this background, in the present work, a class of composite is fabricated in which the continuous phase is a thermoset epoxy matrix and the discontinuous phase is micro-size silicon nitride particles. A simple hand lay-up method is used for the fabrication of composites with a wide range of filler content. The properties evaluated are tensile strength, compressive strength and hardness. Further, the effect of surface modification of the filler on the mentioned properties of the composites is also investigated and presented.

2. MATERIALS AND METHODS

Thermoset resin Lapox C-51along with thehardener K6 is used as a matrix material in the present investigation. The matrix material system selected is supplied by ATUL India Ltd., Gujarat, India. Silicon nitride of size 50 microns is used in the present investigation supplied by Intelligent Materials Private Limited, Mohali. The surface of the silicon nitride is modified using a silane coupling agent and ethanol to study the effect of surface modification on the different properties under investigation. A simple hand lay-up technique is used in the present investigation for the fabrication of silicon nitride particles in an epoxy matrix. Two different sets of composites are fabricated. In set A, the composites are prepared with the addition of untreated silicon nitride particulates. In set B, the composites are prepared with treated silicon nitride composites. The treatment of the filler material and the fabrication of the composite body are by the previous work conducted by Agrawal and Chandrakar [11].

The tensile strength of the composites is measured with a computerized Tinius Olsen universal testing machine by ASTM D638. Static uniaxial compression testson specimens are carried out using the same computerized Tinius Olsen universal testing machine following standard ASTM D695.The hardness test was performed using a PosiTector SHD Shore hardness Durometer following ASTM D-2240.

3. RESULTS AND DISCUSSION

The dependence of the ultimate tensile strength of epoxy composites filled with untreated and treated micro-size silicon nitride with different content is shown in Figure 1.

The tensile strength of the epoxy composites increases with an increase in silicon nitride content till the filler content is limited up to 20 wt. % irrespective of the type of filler used. The tensile strength of neat epoxy is measured to be 34.5 MPa. The value increases to 38.4 MPa with 10 wt. % untreated silicon nitride content and further increases to 41.8 MPa when the filler content increases to 20 wt. %. The tensile strength value obtained at this filler content ismaximum where the improvement of 21.15 % over neat epoxy is registered. When the content of silicon nitride increases beyond 20 wt. %, tensile strength starts to show a decreasing trend with an increase in filler content.

It is seen that when 30 wt. % filler is added to an epoxy matrix, the tensile strength of the composite is 37.2 MPa and when the content of filler increases to 40 wt. %, the tensile strength reduces to 34.9 MPa. It is also observed from the figure that the composite prepared with surface-treated filler delivers superior tensile strength as compared to the composite prepared with untreated filler material for a given filler loading. The maximum tensile strength obtained for this category of composite is 44.2 MPa for a filler loading of 20 wt. % of silane-modified silicon nitride.

The dependence on the compressive strength of epoxy composites filled with silicon nitride with different filler content is shown in Figure 2.

It can be seen from the figure that with an increase in the content of silicon nitride, the compressive strength of the composites increases and this increasing trend continues till the maximum content of filler is added in epoxy resin. The compressive strength of neat epoxy is 68.5 MPa which increases to 85.3 MPa at a loading of 40 wt. % of micro-size silicon nitride. In this case, a 24.52 % enhancement in the value of compressive strength is reported for the maximum content of filler. It is also observed from the figure that when the composite is prepared surface modified silicon nitride, the rate of enhancement in the value of compressive strength is increased appreciably. For a surface-modified silicon nitride of 40 wt. %, the maximum compressive strength obtained is 89.6 MPa which is 41.7 % higher than the value of the neat epoxy resin.

The increment in the value of compressive strength with surface-modified silicon nitride is because of the increased compatibility between the two phases and the reduction in the value of void content within the composite body.

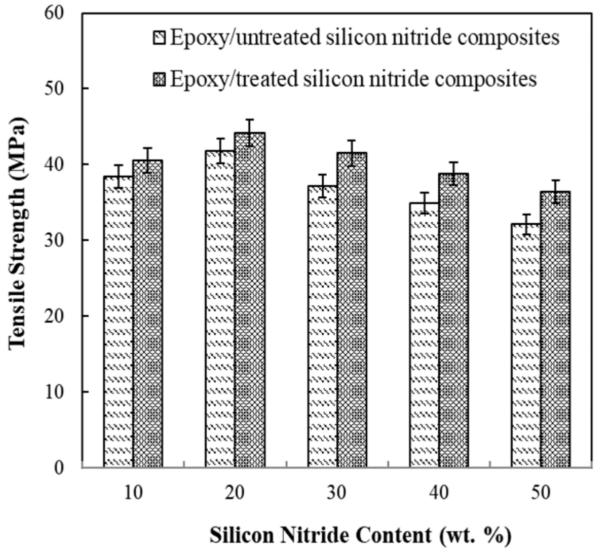

Fig. 1 Tensile strength of epoxy filled with silicon nitride

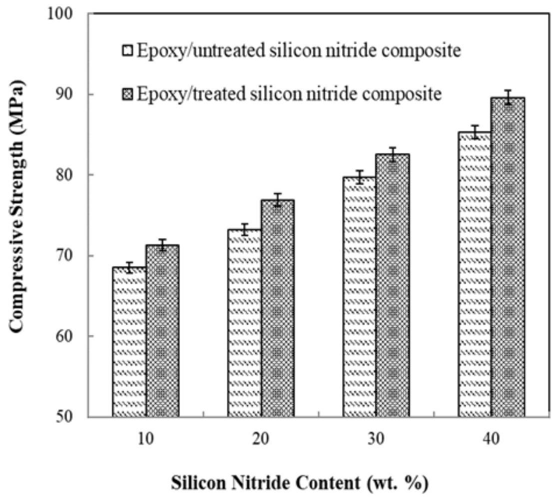

Fig. 2 Compressive strength of epoxy filled with silicon nitride

Figure 3 shows the variation in the value of hardness of the composite material for different content of silicon nitride in an epoxy matrix. The hardness of the neat epoxy is 74.4 Shore-D number. With the addition of 40 wt. % of silicon nitride, the hardness of the composite body increases to 78.8 Shore-D number. This is a remarkable enhancement in the value of hardness which is around which comes out to be of 5.91 % over neat epoxy. It is also observed that the composite prepared with silane-treated silicon nitride shows a higher shore D number for a given filler loading as compared to its counterpart

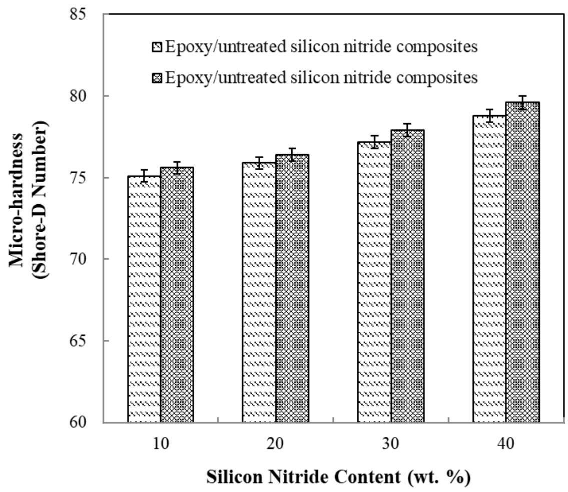

Fig. 3 Micro-hardness of epoxy filled with silicon nitride

4. CONCLUSIONS

This experimental investigation has led to the following specific conclusions:

1. Epoxy matrix composites reinforced with micro-size silicon nitride are possible by simple hand-lay-up technique.
2. The tensile strength of the epoxy composites increases with an increase in silicon nitride content up to 20 wt. %. When the content of silicon nitride increases beyond 20 wt. %, tensile strength starts to show a decreasing trend with an increase in filler content.
3. The compressive strength of the composites increases with an increase in silicon nitride content. The compressive strength of neat epoxy is 63.2 MPa which increases to 85.3 MPa at a loading of 40 wt. % of micro-size untreated silicon nitride and 89.6 MPa at a loading of 40 wt. % of micro-size treated silicon nitride.
4. With the addition of silicon nitride fillers, the micro-hardness of the composites improved and this improvement is mainly a function of the filler content. With the addition of 40 wt. % of silicon nitride, the hardness of the composite body increases from 74.4 Shore-D number for neat epoxy to 78.8 Shore-D number for 40 wt. % untreated filler and 79.6 Shore-D number with treated fillers.

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