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STUDIES ON WEAR BEHAVIOR OF PMMA-B4C-SiC HYBRID COMPOSITE

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Abstract

Due to their high strength and better wear behaviours, composite materials are used in many applications today, primarily in the automotive, marine, and aerospace industries. This paper studies a hybrid composite that uses PMMA as the base material and SiC and B4C as reinforcements. In this instance, hybrid composites are created to analyse the mechanical properties and wear behavior of the A dry sliding wear test performed on the three PMMA+SiC+B4C samples. On a pin-on-disc Tribometer, the tests were carried out in accordance with ASTM A-99 guidelines. As input parameters, we used the applied force (5N), sliding velocity (1m/s), and sliding distance (1200m). Sample 1, with a value of 0.0000403g/s, was found to have the highest wear loss.

Keywords

composite materials, PMMA, SiC, B4C, hybrid composites, mechanical properties,

1. Introduction

A *composite* is a substance composed of two or more constituent elements that generate a material with properties distinct from the sum of their individual properties. Each constituent material has physical or chemical properties quite different from the other materials. Composites differ from mixes and solid solutions because the various constituent pieces are retained distinct and separate inside the completed structure. The innovative material may be chosen over traditional ones for various reasons, such as the fact that it offers benefits over them in terms of strength, weight, or cost. The most widely used artificial composite material

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is concrete, made of loose stones (aggregate) bonded with a cement matrix.

Concrete is an inexpensive substance that can withstand extremely powerful compressive forces without breaking. However, concrete cannot endure tensile pressure; it will swiftly shatter when stretched. As a result, reinforced concrete, which increases concrete's resistance to stretching, is typically created by combining concrete with steel bars that can sustain significant stretching forces.

Fig 1.1 Concrete Composite

"Fiber-reinforced polymers" (FRP) are a category of materials that includes items like carbon-fibre-reinforced polymer (CFRP) and glass-reinforced plastic (GRP). There are thermoplastic composites, short fibre, long fibre, and long fibre-reinforced thermoplastics if they are separated based on the matrix. One of the various thermoset composite varieties that are accessible is composite paper panels. A common component of many modern thermoset polymer matrix systems is the incorporation of aramid and carbon fibre in an epoxy resin matrix.

2. Literature Review

Doped cerium Diwakar Padalia et al. [1] developed and examined barium titanate/PMMA nanocomposites to identify a viable material for integrated thin film capacitors and electric stress control devices. Cerium doping was used for the BaTiO3 system to produce low-loss and refined grains. Nevertheless, the insulating PMMA shell surrounding the BaTiO3 nanoparticles may prevent charge carriers from moving within the nanocomposites, outperforming traditional composites in the reduced dielectric loss. While Cerium-doped BaTiO3 Nano fillers were produced using a solid-state process, various polymer nanocomposites were created through solvent evaporation. All polymer nanocomposites had filling levels of 30% weight-for-weight and were heated with 2.4 GHz microwaves. The findings demonstrate how altering the Ce-doping in the BaTiO3 nanofiller may enhance the thermal and dielectric properties of the resulting nanocomposites. Further investigation was done into how microwave heating affected the thermal stability of polymer nanocomposites. Fibreglass-reinforced polymer composites were investigated by Eduard A. Stefanescu et al. [2] for prospective application as structural dielectrics in multifunctional capacitors that need both remarkable energy storage capacity and great mechanical qualities.

Finding innovative substitutes for battery and capacitor performance, weight, and volume

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improvements has recently received much attention. Commercial ceramic capacitors are frequently used in applications requiring compact diameters, large capacitances, and low insulation resistances. They cannot be employed in precise applications because of their high sensitivity to temperature changes. Nowadays, it is common to see polymer film capacitors being mainly employed in situations where low dielectric absorption and loss factors are required throughout a wide temperature range. The lesser capacitances of polymer film capacitors, as opposed to their ceramic counterparts, result from their lower dielectric constants. For use in multifunctional capacitors with strict stiffness and energy storage requirements, the development of PMMA-fiberglass structural dielectrics with neat or PEDOT: PSS-coated BaTiO3 particles were focused. In order to reduce the total system weight and volume, multifunctional capacitors may be utilized to replace static load-carrying components in conventional designs (such as hybrid automobiles or airplanes).

The production of PMMA/polyimide/hexagonal boron nitride (hBN) composites by mixing PI and hBN powder into the PMMA matrix was the focus of a study by Garima Mittal et al. (see reference 3). White graphite, also known as hexagonal boron nitride (hBN), is a multilayer ceramic material with a hexagonal lattice structure that is an isoelectric counterpart of graphite. Its strong resemblance to graphite means that it shares many of the latter's advantageous mechanical characteristics, which make use of it in high-temperature equipment more accessible, as well as its extraordinary thermal and chemical durability. The hexagonal form of boron nitrides is the most stable and soft enough to be utilized in lubrication. Because of its exceptional environmental stability, which includes moisture resistance, UV resistance, scratch resistance, and other properties, including moisture resistance, PMMA/PI polymer composites reinforced with silane-functionalized hBN powder have a distinctive position in the industry.

Along with them, PMMA has excellent mechanical qualities, visual clarity, and a low coefficient of friction. Creating a charge-transfer complex inside the molecules, which results in ordered intermolecular stacking, gives rise to the distinctive structure of polyimide (PI), which is why it is regarded as a high-performance thermoplastic material. It has excellent chemical and radiation resistance, excellent thermal and mechanical qualities, and good electronic properties.

Leslie Banks-Sills et al. conducted experimental evaluations of the mechanical properties of PMMA reinforced with functionalized Carbon nanotubes (CNTs) [4]. One of the toughest materials on the market is carbon nanotubes (CNT). This material, like fullerene, graphite, and diamond, is a carbon allotrope. Before the early 1990s, when CNTs were discovered and the research that followed, carbon nanotubes were not created. The first mentions of carbon structures date back to the 1970s. Despite having better mechanical, thermal, and electrical qualities, CNTs are frequently insufficient. This study will examine the mechanical properties of a PMMA matrix augmented with functionalized CNTs. The outcomes will be compared to those of the same material with non functionalized CNTs. Two processes were used to functionalize the CNTs. In order to compare the two functionalization procedures, the mechanical properties are also determined. Tensile tests were used to evaluate the mechanical characteristics of dog-bone test specimens. Using a twin screw extruder, the composite material was produced. The specimens were created using an injection moulding (IM) technique.

An in-depth investigation of the mechanical characterization of PMMA/MWCNT composites under static and dynamic loading conditions was conducted by Prashant Jindal et al. [5]. PMMA is a lightweight, moldable polymer that is often used in a variety of technical applications. However, its poor mechanical strength cannot be used in some applications, especially when subjected to heavy external static and dynamic stresses. Therefore, it is conceivable to develop and describe composite materials that utilize stronger filler components to increase the strength of PMMA. MWCNTs are one such filler material with particular mechanical and structural characteristics. Therefore, without including any additional components or changing the surface of the PMMA, changes in the static and dynamic mechanical parameters (elastic modulus and hardness) for various compositions of synthesized/untreated MWCNTs were examined utilizing nanoindentation methods.

In order to enhance the mechanical properties of adsorbed particle PMMA, Tetsuya Yamamoto et al.'s study [6] found that recycled carbon fibre fillers from CFRP may be disseminated, diffused, and attached to surfaces. The space industry makes considerable use of carbon fibre reinforced polymers (CFRP), one of the most well-known composite materials that are light and strong. Thermoplastic poly(methyl methacrylate) (PMMA) resin and recovered carbon fibres created by grinding carbon fibre reinforced plastics (CFRP) were used to create composite materials. To improve the interfacial adhesion between the carbon fibres and the PMMA resin and the fibres' dispersion, PMMA particles were electrostatically adsorbed onto the surfaces of the carbon fibres. As a result, the composites' mechanical characteristics were improved.

According to Chao Shi et al.'s studies [7], surface-modified a-Si3N4 fiber-reinforced PMMA-based composites. This work also revealed how these composites' mechanical qualities were achieved using free radical polymerization in batches. The links between Si3N4 and PMMA that create g-MPS were demonstrated to be methacrylate and alkoxy groups, which graft to hydroxylated Si3N4 fibres and copolymerize with the PMMA monomer through C55C bonds, respectively. The glass transition temperature and thermal decomposition increased, improving the thermal stability of Si3N4-PMMA. The aerospace industry and disciplines of civil engineering may be candidates for using the composite's extraordinary mechanical and thermal stability capabilities.

After studying the tensile characteristics, He Runqin et al. [8] concluded that the ideal fiber loading for a CNT/PMMA composite was at 20 vol%. Increasing TiO2 content improves the CNT/PMMA composite's flexural strength. The findings demonstrate that the TiO2 addition enhances the adherence of the fibers to the matrix, increasing flexural characteristics. The 20-vol% CNT/PMMA composite, the proper amount of TiO2, provides good impact strength. It has been noticed that adding CNT and TiO2 seems to help boost mechanical strength by increasing the interface dispersed phase.

H. Varela-Rizo et al. [9] investigated and compared the characteristics of CNF/PMMA nanocomposites made using three distinct widely used methods for processing thermoplastic polymers, taking into account the functionalization of CNF. The potential matrix interactions and dispersion were considered when evaluating the mechanical properties. The covalent bonds in the in situ polymerized composites were discovered by FTIR analysis and confirmed by further techniques. The elastic modulus increased due to functionalization and dispersion. While in situ polymerization and solvent processing did, they became better with treatment, melt compounding did not. By increasing elongation during solvent processing or melt compounding, CNFs improved toughness. In the presence of a strong interfacial contact, such as that present during in situ polymerization, elongation was decreased, and the material stiffened. Because the CNFs accelerated the polymer transition to the solid-like behavior, the in situ polymerized samples showed more dramatic changes in rheological behavior.

A successful method for covalently grafting PMMA onto GP sheets has been demonstrated by Jialiang Wang et al. [10]. In NMP, graphite was directly exfoliated to produce GP, which was then polymerised in the solution of well-dispersed GP. The PMMA functionalised GP was characterised using a variety of techniques. In contrast to previous functionalised GO or RGO, the GPMMA produced had a flawless structure with minimal flaws, allowing for effective reinforcement of composites. The well-dispersed nature of GPMMA in organic solvents facilitates the fabrication of various composites. The resultant PMMA/GPMMA composite film displays considerably higher mechanical properties than pure PMMA film, with improvements in Young's modulus and tensile strength of 151% and 115%, respectively, with the addition of just 0.5 weight percent of GPMMA. Strong interfacial adhesion and high dispersion in the PMMA matrix further increase thermal stability.

Jun-long According to Wang et al.'s [11] research, CTC-IPN technology can modify the CE. Modified CE has improved mechanical qualities over pure CE. Maximum values of the mechanical properties occurred when the weight ratio of CE/PMMA was 80/20. There was a 2.37-fold improvement in impact strength compared to pure CE and a 1.31-fold increase in flexural strength. SiO2 can improve the polymer's ability to load. IPN's impact and flexural strength were enhanced by 20.05% and 29.96%, respectively, when nanoscale SiO2 was added to the material compared to its mechanical qualities without it.

Research by A. Akinci et al. [12] found that the coefficient of friction of the pure PMMA and ZrO2-filled PMMA composites rose with higher applied loads, sliding speeds, and ZrO2 filler content. Increasing ZrO2 content up to 30%wt and raising applied loads and sliding speeds decrease ZrO2-filled PMMA composite wear rates. The wear rate of the PMMA + ZrO2 composite decreased with higher ZrO2 concentration. PMMA composites with ZrO2 filling demonstrated that the worn surface morphologies of the 10% and 30% ZrO2 PMMA composites were smooth with a few minor abrasion grooves. The surface gets smoother as the ZrO2 content rises.

Poomalai et al. [13] found that increasing the TPU content in the blends resulted in a significant increase in % elongation at the break while slightly decreasing the tensile strength and tensile modulus. The 80/20 PMMA/TPU blend has the most significant wear volume, while the lowest wear volume loss is found in pure PMMA. Plain PMMA and a 95/5 PMMA/TPU blend show a more vital link between specific mechanical parameters and wear volume. TPU possesses the best wear resistance of any material, yet adding this polymer to PMMA does not boost the material's abrasion resistance. SEM micrographs of TPU-filled PMMA mixtures showed indications of the abrasion process in the form of deep furrows, broader fissures, and more debris.

3. MATERIALS USED -POLY(METHYL METHACRYLATE)

Poly (methyl methacrylate), or acrylic or acrylic glass, is a transparent thermoplastic commonly used in sheet form as a lightweight or shatter-resistant substitute for glass. It is also known by the trade names Crylux, Plexiglas, Acrylite, Lucite, and Perspex, among many others (see below). Despite not being a common silica-based glass, the substance, like many thermoplastics, is frequently technically categorized as a type of glass (in that it is a non-crystalline vitreous substance), which is why it occasionally has been referred to historically as acrylic glass. Chemically, it is a methyl methacrylate synthetic polymer. In 1928, a group of chemists led by Willard C. Smith discovered the first acrylic polymer. When tensile strength, flexural strength, transparency, polishability, and UV tolerance are more crucial than impact strength, chemical resistance, and heat resistance, PMMA is a cost-effective substitute for polycarbonate (PC). PMMA also does not contain the potentially dangerous bisphenol-A subunits that polycarbonate does. It is typically chosen because of its valuable qualities, simplicity in handling and processing, and affordable cost. Without treatment, PMMA is more prone to scratches than traditional inorganic glass and exhibits brittle behavior under load, especially when struck with an impact force. However, modified PMMA can occasionally attain exceptional scratch and impact resistance.

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4. EXPERIMENTAL PROCEDURE:

In the aqueous solution method, silane was treated on PMMA and SiC particles, as described by Arun Prakash (2016). High-toughness epoxy composites were created through the hand layup method, utilizing silane-treated PMMA, SiC, and E-glass fiber. The composites underwent post-curing at 110°C for a complete cure. Abrasive water jet machines were used to cut post-cured composites for potential test specimen preparation. In accordance with ASTM standards D 638, 3039, and 790, tensile and flexural characteristics were evaluated using an all-purpose testing apparatus (INSTRON 4855, UK). A tiny impact tester was used to determine impact hardness in accordance with ASTM D 256. According to ASTM D2240, microhardness was measured using a Shore-D durometer.

Using a Pin-on-disc tribometer from Ducom Instruments, Pvt. Ltd., India, with set process parameters—track diameter of 100mm, disc speed of 800 rpm, and an applied load of 5 kg—epoxy composite wear behavior was evaluated. Thermal characteristics, including DSC and TGA, were investigated using a DSC-TGA-linked thermo scanner (NETZSCH, STA Jupitar 409 PL Luxx, N2 Atm, 0-600°C, Germany). According to ASTM D 4762, the low-velocity impact test was carried out utilizing an INSTRON-9000 drop load impact or with a 2 Kg mass and 1.3 ms-1 indenter velocity. Fracture toughness, fatigue, and DMA were evaluated following ASTM standards D 3479, 4065, and 5045, respectively.

The fatigue behavior of a tension-tension machine (MTS Landmark 370 load frame, USA) was investigated. The viscoelastic (DMA) properties were evaluated between 30°C and 240°C at a constant frequency of 1 Hz. Dual-form cantilever fixtures with a 50°C/min heating rate were the process parameters. The toughness of fractures was investigated using the mode I fracture model with recommended values. With samples coated in gold to lessen the effects of charging, various components were fractographic ally scanned using a scanning electron microscope (HITACHI, S1500, JAPAN). Table 1 displays the composite compositions.

Table 1: Composites and Compositions Material Designation

Material Designation	Epoxy (Vol%)	Fibre (Vol%)	PMMA (Vol%)	SiC (Vol%)
E	100	0	0	-
EF	70	30	-	-
EP1	65	30	5	-
EP2	60	30	10	-
EPS1	59.5	30	10	0.5
PS2	59	30	10	1

Epoxy; F- fibre; P-PMMA and S-SiC

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COMPRESSION MOLDING

The heated, open mould cavity is filled with the warmed moulding material in the compression molding process. Pressure guarantees that the material contacts every mould region when the mould is sealed with a top force or plug portion. The moulding mixture is kept under pressure and heated until it becomes rigid. The thermosetting resins used in this method are partly cured and are available as granules, masses that resemble putty, or preforms.

Compression For the purpose of moulding complicated, high-strength fiberglass reinforcements, moulding is a high-volume, high-pressure process. Additionally, woven fabrics, randomly oriented fibre mats, chopped strands, and unidirectional tapes can be used to compression mould advanced composite thermoplastics. Compression moulding has the benefit of being able to form big, relatively complicated items. Additionally, it wastes less material, which is beneficial when working with expensive materials. It is one of the least expensive moulding techniques, along with injection moulding and transfer moulding.

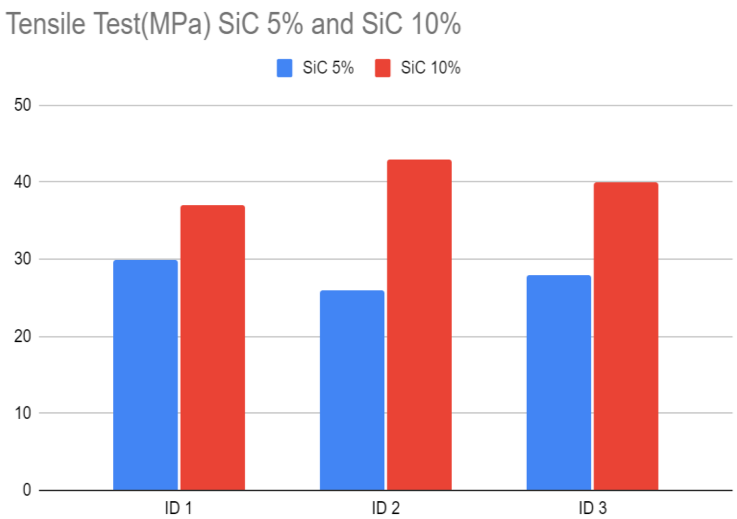
5. RESULTS AND DISCUSSION

Mechanical Behavior

Tensile Strength

Tensile Test:

The most basic mechanical test you can do on a material is a tensile test, often known as a tension test. Simple, reasonably priced, and completely standardized are tensile testing. You may find out quickly how something will respond to tension forces by pulling on it. The material's strength and amount of elongation may be determined as it is tugged.



Pure epoxy resin has a 65 MPa tensile strength and a 2790 MPa modulus, respectively. When 30% of E-glass fibre is added to epoxy resin, the tensile strength and modulus increase to 131 MPa and 5628 MPa, respectively. This improvement is brought about by the effective load transfer from the delicate matrix, which causes the stress intensity factor to drop. As a result, the composite can support heavier weights. Adding PMMA micro beads to epoxy resin has been found to increase toughness, albeit this enhancement has a minimal effect on tensile qualities. Because the inclusion of PMMA created an IPN structure, tensile performance losses of 8% and 18% were reported for EP1 and EP2 composite designations, respectively. The

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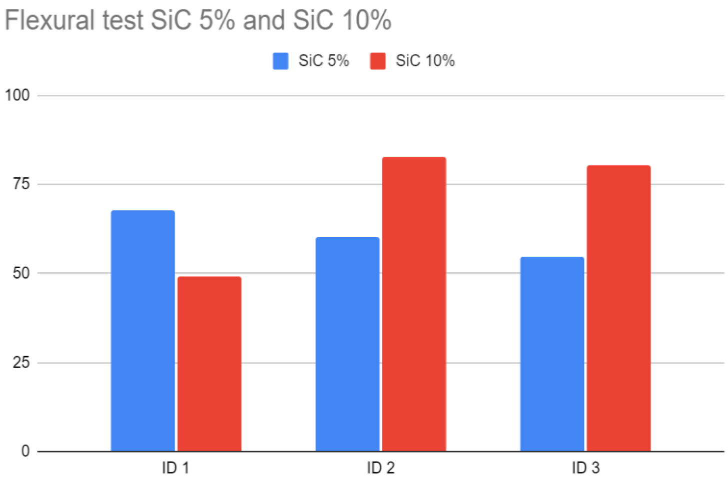
tensile strength and modulus of the PMMA-epoxy resin composite are further enhanced by employing 0.5 and 1.0 vol.% SiC particles. Tensile strength improvements of 49% and 54% and 50% and 54% tensile modulus improvements were recorded for the composite designations EPS1 and EPS2. As crack inhibitors, the SiC particles reduce the emergence and spread of cracks while enhancing the tensile properties. Additionally, they effectively transfer and absorb shocks.

Flexural Test:

The flexure test method looks at how materials respond to a straightforward beam loading. For some materials, it is also known as a transverse beam test. The maximum fibre stress and strain are calculated for each load increase. On a stress-strain diagram, the results are displayed. Flexural strength is defined as the highest tension in the outermost fibre. This is calculated at the specimen's convex or tension side surface.



Epoxy resin has a flexural strength and modulus of 77 MPa and 2944 MPa, respectively. It has been shown that adding 30 vol.% E-glass fibres to epoxy resin increased the material's flexural strength and modulus, which are now 154 MPa and 6120 MPa, respectively. The efficient load transmission of glass fibre is responsible for this improvement. It has been shown that adding PMMA at 5 and 10 vol.% increases toughness, enhancing flexural characteristics. Flexural strength and modulus of PMMA toughened epoxy resin composite for the ten composites named EP1 and EP2 yield 7 and 10%, respectively.

Similarly, adding SiC particles of 0.5 and 1.0 vol.% improved the flexural strength and modulus. Flexural Strength and modulus improvements of 59%, 64%, 57%, and 59% were noted for the composite designations EPS1 and EPS2. Including very tough SiC particles in the PMMA-toughened epoxy resin composite is responsible for this enhancement.

Impact Test

A destructive mechanical test is when a pendulum hammer breaks a piece of material with a standard-size notch in it with a single blow. Measuring the energy absorbed during the break predicts how the material will react to abruptly delivered shock (stress). In the Charpy test, a short beam with measurements of 55 mm (2.17 inches) in length and 10 mm (0.39 inches) in square cross-section is subjected to three-point flexural impact stresses brought on by a swinging pendulum. To simulate failure there, the test specimen has a 2 mm/0.079 inches deep, 45° included-angle notch on the tensile side. The test findings are given in foot-pounds or kilojoules.

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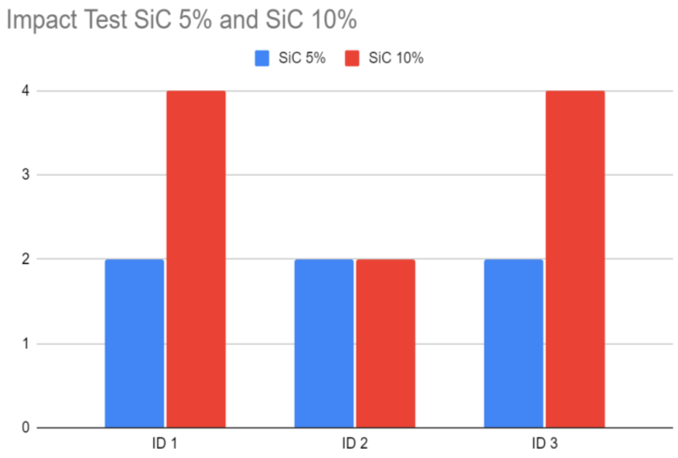

The impact energy absorption of pure epoxy resin was assessed at 0.35 J. However, including 30 vol.% glass fiber improved energy absorption, with a composite designated as EF exhibiting energy absorption of 4.5 J. The continuous glass fiber was found to absorb more energy, leading to an improvement in energy absorption. The addition of 5 and 10 vol.% PMMA into the epoxy resin further increased the energy absorption to 5.3 and 5.8 J, respectively, due to the enhanced stretchability of the epoxy molecules and the formation of additional IPN structures. Similarly, adding 0.5 and 1.0 vol.% SiC particles also contributed to improved energy absorption rates, with the highest energy absorption of 7.2 J recorded for the composite designated as EPS2. The shore-D hardness of pure epoxy resin was measured at 86, and the addition of glass fiber did not improve. The addition of 5 and 10 vol.% PMMA further decreased the hardness, with decreases of 9.4% and 13.5% recorded for the composite designations EP1 and EP2, respectively. This was attributed to the formation of flexible IPN structures due to the incorporation of PMMA beads. However, adding 0.5 and 1.0 vol.% SiC particles improved hardness, as the SiC particles filled the voids within the polymer matrix and reduced the free volume.

6. CONCLUSION:

In the Charpy test, three-point flexural impact loads caused by a swinging pendulum are applied to a short beam with dimensions of 55 mm (2.17 inches) in length and 10 mm (0.39 inches) in square cross-section. To mimic failure, the test specimen contains a 2 mm/0.079 inches deep, 45° included-angle notch on the tensile side. In foot pounds or kilojoules, the test results are reported.

The PMMA-toughened glass-epoxy composite performed better, according to the tensile, flexural, and impact testing findings. The glass-epoxy composite's load-bearing capabilities were improved even more by adding surface-modified SiC particles. The composite that included 1.0 vol.% of SiC particles had the most significant tensile strength, flexural strength, and Izod impact toughness (142 MPa, 211 MPa, and 7.2 J, respectively).

The creation of an IPN structure was blamed for the lower hardness values of the PMMA-toughened glass-epoxy composite. However, the hardness was increased to 91 Shore-D by adding 0.5 and 1.0 Vol% of SiC particles.

Any property losses brought on by the toughening operation were made up by including SiC particles in the PMMA-toughened glass-epoxy composite. To produce the best possible composite, high-hardness SiC particles must be added to create highly toughened epoxy composites.

7. References

1. Diwakar Padalia, Garima Bishta, U.C. Johri, K. Asokan (2013). Fabrication and characterization of cerium doped barium titanate/PMMA nanocomposites. Solid State Sciences, 19, 122-129.
2. Eduard A. Stefanescu, Xiaoli Tan, Zhiqun Lin, Nicola Bowler, Michael R. Kessler (2011). Multifunctional fibreglass-reinforced PMMA-BaTiO3 structural/dielectric composites. Polymer, 52, 2016-2024.
3. Garima Mittal, Kyong Yop Rhee, Soo Jin Park (2017). Processing and characterization of PMMA/PI composites reinforced with surface functionalized hexagonal boron nitride. Applied Surface Science, 415, 49-54.
4. Leslie Banks-Sills, David Guy Shiber, Victor Fourman, Rami Eliasi, Amit Shlayer (2016). Experimental determination of mechanical properties of PMMA reinforced with functionalized CNTs. Composites Part B, 95, 335-345.
5. Prashant Jindal, Mohit Sain, Navin Kumar (2015). Mechanical characterization of PMMA/MWCNT composites under static and dynamic loading conditions. Materials Today: Proceedings, 2, 1364-1372.
6. Tetsuya Yamamoto, Yuta Makino, Katsumasa Uematsu (2017). Improved properties of PMMA composites: Dispersion, diffusion and surface adhesion of recycled carbon fiber fillers from CFRP with adsorbed particulate PMMA. Advanced Powder Technology, 28, 2774-2778.
7. Shi, Chao, Zhu, Yingchun, Qian, Huofei, Lu, Liqiang (2014). Fabrication of silicon nitride fiber-PMMA composite through free radical polymerization in batch. Materials Research Bulletin, 51, 161-166.
8. He, Runqin, Niu, Fenglian, & Chang, Qiuxiang (2017). Mechanical properties of TiO2-filled CNT/PMMA composites. Journal of Experimental Nanoscience, 12(1), 308-318.
9. Varela-Rizo, H., Bittolo Bon, Silvia, Rodriguez-Pastor, I., Valentini, L., Martin-Gullon, Ignacio (2012). Processing and functionalization effect in CNF/PMMA nanocomposites. Composites Part A: Applied Science and Manufacturing, 43, 711-721.
10. Jialiang Wang, Zixing Shi, Yu Ge, Yan Wang, Jinchen Fan, Jie Yin (2012). Solvent exfoliated graphene for reinforcement of PMMA composites prepared by in situ polymerization. Materials Chemistry and Physics, 136, 43-50.
11. Jun-long Wang, Chuang Wang, Geng-sheng Jiao, Qiu-ya Wang (2012). Study of SiO2/PMMA/CE tri-component interpenetrating polymer network composites. Materials Science and Engineering: A, 527, 2045-2059.
12. A. Akinci, S. Sen, U. Sen (2014). Friction and wear behavior of zirconium oxide reinforced PMMA composites. Composites Part B: Engineering, 56, 42-47.
13. Poomalai, P., & Siddaramaiah (2006). Studies on Poly(Methyl Methacrylate) (PMMA) and Thermoplastic Polyurethane (TPU) Blends. Journal of Macromolecular Science, Part A, 42(10), 1399-1407.