

A review on Thermal Properties of Polymer Composite Materials

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Abstract

Across the globe, scientists and engineers are focusing their attention on hybrid polymer composites because of the unique opportunities they provide for solving pressing material challenges. Polymers and hybrid composites are developing as versatile replacements to metals and their alloys in many conventional and innovative technical applications. Hybrid composites need extensive testing due to variations in temperature and mechanical loads. Hybrid composites degrade and alter characteristics when subjected to extremes of temperature, such as those found in the environment. To improve the mechanical and thermal qualities of structures, carbon fibre composites are increasingly being employed in place of reinforcing bars or concrete. The thermal property values of hybrid polymer composites made with various filler materials will change depending on the temperature. After reading this paper's overview on the thermal characteristics of fibre-reinforced hybrid composite materials, I realised that there is still a lot of room for investigation into the study of composite materials' thermal properties, particularly those made using Silicon oxides, aluminium oxides, carbon, and graphite as filler material in conjunction with glass fibre and natural fibres. This literature review demonstrates that hybridization has a positive influence on the thermal characteristics of fiber-reinforced hybrid composite materials.

Keywords: Hybrid Polymer Composites, Carbon Fiber, Silicon Oxides.

Introduction

Composites are structural materials made up of two or more materials that are insoluble in each other

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yet may be mixed at the macroscopic level. One component, the reinforcing phase, is embedded in another, the matrix. Any of fibres, particles, or flakes may be used for the reinforcing phase. The components of the matrix phase are unbroken. The three main types of composites are those with a ceramic matrix, metal matrices, and polymer matrices (PMCs). Polymer matrix composites are so named because polymer resin is utilised as the matrix material. The features of polymer composites include low density, excellent thermal and electrical insulator, and cheap cost. Typically, people will use either PMCs or MMCs. Metal matrix composites feature a metal matrix, whereas polymer matrix composites are made of polymer (epoxy, polyester, etc.) reinforced by fibres. Metals are often strengthened to alter their characteristics. With its high strength, cheap cost, great chemical resistance, and readily accessible fibre form, glass has become the material of choice for most polymer matrix composites.

Natural Fiber

Sustainable materials made from organic materials like jute, coir, sisal, bamboo, etc. The materials made from natural fibres are sustainable, affordable, biodegradable, and kind to the environment. The reinforcement in polymer matrix composites often consists of plant fibres like cotton, jute, sisal, hemp, pineapple, ramie, bamboo, banana, etc., but it may also be wood or flax seeds. Reinforcement for glass, carbon, and other artificial fibres, they are readily available, inexpensive, and have good mechanical qualities. Despite their superior specific strength, the expensive manufacturing cost of glass fibres severely limits their usefulness. As a result of their lower price and greater accessibility, natural fibres like sisal and jute are gradually replacing more expensive and less environmentally friendly synthetic materials like glass and carbon fibres.

Resin

Fiber reinforced composites' resins are also referred to as polymers. One essential feature shared by all polymers is that they are built from chains of basic repeating units. Synthetic resins, or just resins, are another name for man-made polymers. Thermoplastic polymers are those that retain their original shape and characteristics when heated, whereas thermosetting polymers undergo a change in structure when heated. Epoxy Resin, Polyester Resin, and Vinyl Ester Resin are the three main resins utilised in the composite materials industry. In most commercial settings, epoxy resin is used in conjunction with a hardener, a curing cross-linking agent. Polyetheramine epoxy resin.

Hybrid Polymer Matrix Composites

Two varieties of polymer matrix exist:

1. Thermoplastics

Thermoplastics are materials with intermolecular linear polymer architectures. When it comes to elasticity, thermoplastics thrive, but they can't take much of a beating before breaking. After being heated

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to a melting point, thermoplastics' intermolecular polymer structures undergo a reorganisation. When subjected to high temperatures, the chemical linkages that make up the linear structure weaken. Thermoplastics may be manipulated by heat to become malleable or fused, and then cooled to a rigid state. Thermoplastics, in contrast to thermosets, may be altered or recycled several times. As well as being more resistant to cracking, the shelf life of thermoplastics is much greater than that of thermoset resins. In comparison to thermosets, thermoplastic resins have a high viscosity and poor creep resistance. Polyethylene, polystyrene, polyamides, and nylons are all examples of thermoplastics.

2. Thermosets

Thermoset materials have a strongly chemically-bonded polymer matrix that forms a highly crosslinked structure. Stronger than thermoplastics but with poor elastic properties because of their highly crosslinked structure, thermosets are still a kind of solid. The thermosets cannot be recycled back into a liquid condition after they have been transformed into a solid during the solidification process. Thermosets include common synthetic materials including epoxy, polyester, and phenolic polyamide. When compared to other resins, epoxy offers superior adhesive qualities and mechanical properties. Epoxies are more costly and less water-resistant than polyester. Polyester's benefits include inexpensive price, simple maintenance, resistance to chemicals, and decent mechanical qualities. Around 85% of fibre reinforced polymer composites are made from polyester and epoxy.

There are benefits to using polymer matrix composites, such as increased stiffness and tensile strength. High toughness-related fracture rate, Abrasion resistance is rather high, Good resistance to corrosion and puncture damage. However, there are drawbacks to polymer matrix composites as well. A lack of resistance to heat and cold, The coefficient of thermal expansion is high, The procedures for creating composites take a long time.

Polymer matrix composites manufacturing methods

There are a number of ways to make polymer composites:

1. Hand Layup Method

It's one of the earliest and easiest ways to make composites out of polymers. Molding boxes are constructed out of polymer matrix and fibres, and the latter are then layered into the box, with the necessary quantity of polymer matrix applied to each successive layer. Before putting the fibres and polymer matrix, the surface of the mould box is coated with a non-stick substance to prevent sticking. Curing requires additional time for solidification, and the precision of measurements and form depends on the expertise of the craftsman.

2. Compression Moulding Method

Compression moulding is used to produce composites of the same sort in large quantities. During the compression moulding process, the fibres and polymer matrix are inserted in the female half of the mould box, and the male half is then positioned on top of the mould box. Then, using a hydraulic press, apply

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the required amount of pressure and let cure at room temperature and pressure. Take the composite out of the mould after it has cured. Applying this strategy to cars is preferable.

Resin Transfer Moulding (TRM) Method

Molds having inlets for pouring in the resin/catalyst combination and vents for releasing excess air are used in this production process. This process involves pumping a mixture of resin and catalysts into a mould after they have been mixed in an injection head. After the mould is closed, dry reinforcement is added. The necessary quantity of resin is injected into the mould, and the process of curing occurs at room temperature and humidity. Right after the composites have been released from the mould. Vacuum is used to draw the resin catalyst mixture within the RTM mould. By using vacuum bags in conjunction with the moulds, we can improve resin flow and cut down on the void percentage. The RTM method produces less volatile waste emissions. Panels for automobiles, swimming pools, sandwiched between two pieces of metal, etc. are all products of this method.

Pultrusion Method

Pultrusion is a continuously operating, highly automated moulding method used to produce identical composites in large quantities. The profile of the die is taken into account while arranging the reinforcement materials. After being dipped in a resin solution, the fibres are transported to the pultrusion die, which is made of heated metal. In order to transport heat to the polymer matrix and fibres, the die must be kept at a certain temperature. Polymerization from resin to matrix is accomplished via heating process. After the solid has cooled, it is removed from the mould and its length is trimmed. The building, transportation, electrical, etc. industries are just a few places where this method may be put to use.

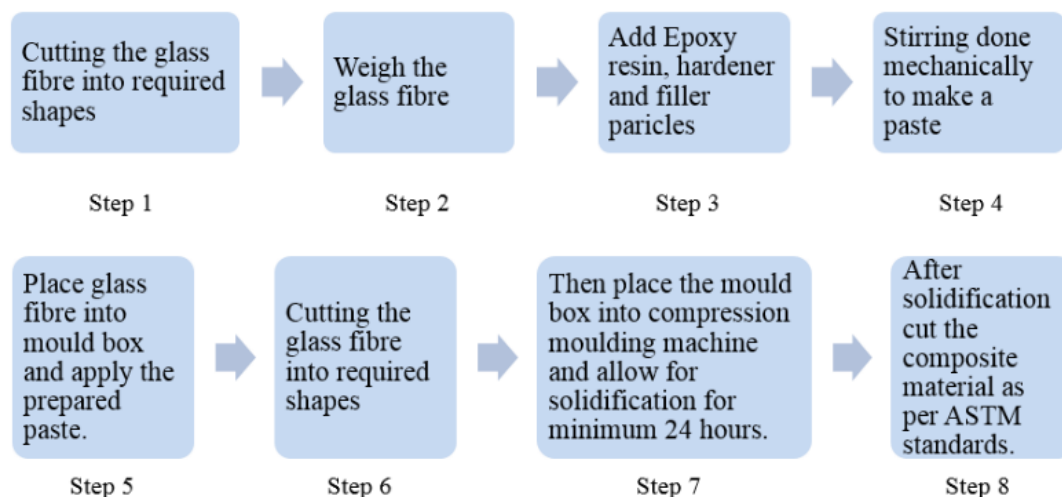


Figure 1. Steps involved in manufacturing hybrid polymer composites.

Thermal property of hybrid polymer composite materials

1. Thermal Conductivity

Hybrid composites' thermal behaviour under different situations must be studied in order to create and develop them for varied purposes. Hybrid composites are notoriously difficult to detect and forecast the temperature behaviour of due to their unknown thermal conductivity and the nonlinearity of their thermal property fluctuations. Due to the intricacy of temperature fluctuations, measuring the thermal conductivity of hybrid composite materials is a difficult job. The thermal conductivity of clean epoxy polymer composites with silicon carbide filler particles varies between 0.41 W/m K for a volume fraction of 20% SiC filler particles and 0.51 W/m K for a volume fraction of 30% SiC filler particles. In contrast to the strong thermal conductivity of pure silicon carbide, the poor thermal conductivity seen in silicon carbide epoxy resin composites may be attributed to the smaller filler particles used in this material. They are not, however, helpful in creating electrical connections. Therefore, electrical gadgets will fail due to poor cooling. A device's reliability and performance can only last up to the maximum allowed by its operating temperature range. Optimal thermal management is crucial to the excellent performance of semiconductors.

2. Coefficient Thermal Expansion

Adding 5% by weight of multi-walled nanotubes to polyurethane composites increases the thermal degradation temperature from 409 degrees Celsius to 421 degrees Celsius, and increases the coefficient of thermal expansion. Epoxy resin, fly ash, stone powder, glass fibre and silicon carbide are mixed to make hybrid composites, which are then filled with 5% and 20% by weight. The results of the thermal experiments show that the glass fibre epoxy resin (GFER), GFER + silicon carbide 5%, and GFER + silicon carbide 20% composites have higher thermal conductivities than the other composites, while the composites GFER + fly ash 5%, GFER + silicon carbide 20%, and GFER + stone powder 20% have lower CTE. The coefficient of thermal expansion of polymer composites may be reduced by the use of hybrid fillers (Aluminum nitride, Silicon carbide, and Boron nitride).

3. Thermogravimetric Analysis

After subjecting composites comprised of polyester resin, glass fibre, and jute fibre to thermogravimetric analysis, researchers discovered that composites with a higher proportion of glass fibre, such as PO56-JU21-VI23 (polyester 56% + jute 23% + glass fibre 23%), had less mass loss as a function of temperature than those with a lower percentage of glass fibre, such as PO77-JU23-V10 (polyester 77% + jute 23% + Through thermogravimetric analysis (TGA), we observed that hybrid polymer composites had greater thermal stability than glass fibre composites or carbon fibre composites. Greater mass loss was seen in TGA analysis of PMMA toughened glass-epoxy composite, but SiC addition maintained temperature stability. Both the epoxy matrix and the surface of the glass fibres were modified using a variety of graphene-based nanomaterials. These included graphene oxide (GO), reduced graphene oxide (rGO), graphene nanoplatelets (GNPs), and multi-walled carbon nanotubes (MWCNTs). According to the findings, thermal conductivity is improved by the incorporation

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of GNPs, GO, rGO, and MWCNTs. For 1.2 wt.% of GNPs in GFER composites, the thermal conductivity of two-phase epoxy/nanoparticle composites was improved by up to 6.0%.

4. Effect of filler materials on glass transition temperature of polymers

The increased glass transition temperature (GTT) of hybrid polymer matrix composites is attributable to the use of micro and nano filler particles in epoxy resin glass fibre (ERGF) composites. The glass transition temperature (GTT) of polymers is between 90 and 120 degrees Celsius, while thermogravimetric analysis tests are conducted at temperatures of 200 to 300 degrees Celsius or more, which is much higher than the GTT of epoxy resin. Since the thermal conductivity values of filler particles are greater than those of glass fibre and epoxy resin, the GTT of polymer hybrid composites is higher.

The thermal conductivity and thermal stability of epoxy resin fibre reinforced composites are improved when fillers with a higher thermal conductivity value are added to the epoxy resin glass fibre (ERGF). This is because the fillers are distributed more uniformly in the polymer matrix after the covalent connections between the matrix and the fillers are delinked. Fillers are often added in the range of 5-30% by volume or weight. Fillers may come in a variety of shapes, including balls, flakes, tubes, and "whiskers." Advanced composites research and testing have shown that Nanoparticle fillers are superior in hybrid polymer composites, which need a minimum filler size in the micron range. How fibres and fillings affect thermal characteristics is context-dependent. The thermal conductivity, thermal expansion coefficient, and thermal stability with regard to high temperature will all be affected by the fibre orientation, additives, filler size, and resin type. The structural integrity of certain composites is also evaluated at low temperatures.

Literature Review

(Santhosh et al., 2017) The materials made from natural fibres are sustainable, affordable, biodegradable, and kind to the environment. Hybrid composites are presented in this work as the following types of fibres: sisal/Sic/Glass Fiber; jute/sansevieria Fiber; sisal/jute Fiber; jute/bamboo Fiber. In this article, we'll go over the mechanical and thermal characteristics of hybrid composites, wherein Epoxy resin serves as the binder, and wherein the incorporation of Filler into Natural Fibers materials serves to further enhance the performance of these composites.

(Abas & Abass, 2018) Hardness, impact strength, bending distortion, and heat conductivity were all measured on ASTM-compliant specimens. Once the thermal conductivity property has been established, the hardness, impact strength, and bending distortion of both the unfilled and particulate-filled composites are measured as filler content varies to observe the composite material's response to loading.

(Offer, n.d.) Composites of carbon and metal have remarkable heat resistance. When compared to other carbon-based reinforcements, graphite flakes stand out due to their superior thermal properties, low cost, and ease of machining. Metals, however, have a very difficult time penetrating their densely packed preforms.

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(Kiran, 2016) Random Sequential Adsorption (RSA) was used to construct 2D and 3D Representative Volume Elements (RVEs) for the study, with the use of MATLAB and Python programmes. Thermal conductivity was measured for both two-dimensional and three-dimensional RVEs, with varying results depending on the percentages of the RVEs' areas and weights. To conduct a 3D (2D) analysis, spherical and ellipsoidal alumina nanoparticles were considered. It was discovered that incorporating nanofillers into a material improved its heat conductivity. At equivalent area or weight fractions, thermal conductivity was increased in about the same amounts for both kinds of inclusions in 2D or 3D analyses.

(Kim et al., 2016) Using three-dimensional (3D) non-destructive micro X-ray CT analysis, we demonstrate the connection between the heat conductivity of polymer composites and the realistic size of GNP fillers inside the polymer composites, all while limiting the influence of the physical characteristics other than size. When the GNPs were thicker and more widely spaced, the matrix-bonded interface shrank and the composites' thermal conductivity and heat dissipation improved noticeably..

(Huang et al., n.d.) Improving polymers' thermal conductivity is a hot area of study because of their widespread use in various fields. The goals of this review article are twofold: 1) to provide a comprehensive summary of the current state of knowledge regarding the molecular level understanding of the thermal transport mechanisms in polymers in terms of polymer morphology, chain structure, and inter-chain coupling; and 2) to highlight the rationales behind recent efforts to improve the thermal conductivity of nanostructured polymers and polymer nanocomposites.

(Irshad & Sagar, 2022) Natural fibres have several benefits, including being cheap, renewable, biodegradable, and eco-friendly. Jute, coir, kenaf, areca, sisal, bamboo, and so on are all examples of natural fibres. A novel polymer composite material was developed using these fibres, which were employed by several researchers. To improve the composites' rich mechanical and thermal characteristics, scientists have recently been looking into the creation of certain cutting-edge materials. Hybrid composites are created by combining two or more fibres of varying types and orientations within the same matrix to create a new material with desirable properties. When compared to its constituent parts, this hybrid composite's mechanical and thermal qualities are superior.

(Behrens, 2016) Integrals over the space-dependent thermal conductivities may be used to directly describe the average thermal conductivities of a lamellar composite. Only in the Wigner-Seitz approximation and with a stepwise modification of the thermal conductivities inside the elementary cell can such clear expressions be derived for a filamentary composite. The average thermal conductivity of a cubic symmetric composite, such as one with isotropic spherical inclusions in a cubic lattice, is determined in the same way.

(Vaggar, 2021) Glass fibre reinforced epoxy resin composites have high strength and stiffness but weak in thermal stability and readily degrades at high temperatures, much like polymers, which have been discovered to have low thermal characteristics and low strength under high temperature settings.

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As a result, the thermal stability and thermal resistivity of glass fibre reinforced epoxy resin composites may be improved by adding high thermal conductivity filler particles to these materials.

(Lattimer et al., n.d.) Some of these qualities need in-depth data analysis, and this process requires a study of the experimental methods that have been utilised to produce them. Methods of verifying the accuracy of the derived attributes are also explored. The morphology of a material may be seen in real time during an experiment using an ESEM, which can help with the creation of constitutive models and the creation of materials with decreased flammability.

Conclusion

In order to learn how well polymer hybrid composites hold up at low or high temperatures, it is necessary to characterise their thermal properties. The decomposition temperature, the rise or reduction in thermal conductivity value, and the fluctuations in CTE are all factors that may be taken into account when studying the thermal characteristics and thermal characterisation of hybrid polymer composites with different volume fractions of fillers. To manufacture hybrid composites, fillers are added to a composite material to increase or enhance its thermal qualities without compromising the material's fundamental strength. There are a number of factors that contribute to the increased difficulty of analysing the failure of advanced composites. These include the fact that failure can occur either along or across the fiber, that micro-level cracks can form in either the fibre or the matrix, and that fibre debonding from the matrix as a result of exposure to a wide temperature range.

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