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ANALYSIS OF THE THERMAL CHARACTERISTICS OF GLASS FIBER AND GLASS BEAD REINFORCED WITH POLYAMIDE 6 USING THE FDM PROCESS

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Abstract
The primary goal of this investigation is to contrast two different polyamide composite mixes with creative thermal properties in terms of their morphological and thermal characteristics. The two separate polyamide composite mixes extruded in the form of wire by twin screw extrusion are polyamide-6 (PA6) reinforced with 5, 15 and 25 weight percent glass fibre (GF) and PA6 reinforced with 5, 15 and 25 weight percent glass beads (GB). The experimental study demonstrates how to print the specimens using a three-dimensional (3D) printer that is based on Fusion Deposition Modeling (FDM). The responses of composites, including their morphology, Thermal Conductivity (TC), and Heat Distortion Temperature (HDT), were evaluated. The findings contrast the growing TC and HDT thermal characteristics of the 3D-printed specimen with the increase in bead content over the course of the study. The PA6 matrix's thermal characteristics are enhanced by the GB, a crystalline material, while the PA6 matrix's high modulus is provided by the GF, a dimensionally stable material. In comparison to neat PA6 matrix reinforced with 05, 15, and 25 wt.% GF, it was found that neat PA6 matrix reinforced with 05, 15, and 25 wt.% GB had much higher thermal properties. The thermal characteristics of PA6+25% GB are improved, and this could provide new opportunities for industrial uses such electrical, aerospace, and automotive components.
Keywords: Polyamide 6, Glass beads, Glass fibers, FDM, Thermal properties, Morphological.

Introduction
Advances in additive manufacturing (AM) have made customizable items a standard offering with results conceivable. Another creative development spurred by the shift from straightforward to intricate architecture. Data from 3D object scanners are used in additive manufacturing fabrication and are afterwards changed to (STL) record [1]. These developments are expanding quickly, altering the application's possible outcomes and capacities in terms of timing, quality [2,3,4]. AM makes it

possible to create substantial amounts of models or reasonable sections with complex geometries that are impossible or difficult to create using conventional approaches [5,6]. Rapid prototyping technology (RPT) is a group of techniques and technological advancements used to build models, specifically from three-dimensional computationally assisted configuration, layer by layer. RPT is widely used in a variety of industries, including manufacturing, aircraft, construction, and medicine, as a fast-creating assembly innovation [7,8,9]. RPT holds the added substance generating shapes, making it different from conventional machining techniques. It modifies a material's geometry by switching out the substance until the desired shape is achieved [9]. The main processes of RPT include selective laser sintering (SLS), laminated object manufacture (LOM), stereo lithography equipment (SLA), and fusion deposition modelling (FDM) [10]. By heating a thermoplastic fibre to a semi-fluid state and ejecting it via a small nozzle for each 3D CAD model, FDM, one of the AM inventions, fabricates parts layer by layer, often in STL design [11]. When a fibre is forced through the nozzle, it is melted and softened inside the liquefier at a temperature over its melting point. The still-hard fibre then extrudes the molten material as it flows, and the expelled polymer is then sedimented [12,13,14]. The fibre typically has spherical cross sections that are spaced apart at specific intervals. The most commonly used widths are either 1.75 or 3.0 mm [10]. By reducing the lead time and the need for capacity and transportation, especially in applications where high customization is important, the inventory network can benefit from FDM [15]. Hard, ridged, high tensile, good creep, best abrasion, chemical, and heat resistance, and low friction coefficient are all characteristics of PA6 Nylons. Fibers and fillers are added to materials to improve strength, stiffness, and moisture absorption. Because of its high mechanical strength, PA6 is utilised in structural applications. Because of its superior wear resistance, it is utilised in bearings, and PA6 can be regarded as a long chain polymeric substance that has been produced by humans. It is utilised in materials with simple production and moulding properties [16]. Due to its choices over conventional glass filaments, natural fibres and beads as extra reinforcement in polymer composites have captured the attention of numerous researchers and scientists in recent decades [17]. However, compared to natural fibres and beads, glass fibre and glass beads have improved the properties of the virgin polymer as glass fibre has the property of high Nano scale dispersion and even mixing inside the PA and glass beads has the property of giving high modulus of rigidity to the material. Natural fibres and beads may play an important role in the creation of biodegradable composites to determine the current biological and ecological issues [18]. Short glass fibre was added to the FDM filament as reinforcement, and it was discovered that the ABS composite's quality significantly raised the softening temperature and the heat distortion temperature [19]. Interestingly, very few studies have focused on conducting tests on the thermal characteristics of pure polyamide filament processed using FDM. On the mentioned ones, however, there is no in-depth research. Based on a thorough review of the literature, research gaps were identified, and two polyamide composite blends of glass fibre and bead particles in polyamide-6 (PA6) were compared. These blends were prepared using the FDM process, and their morphological analysis and thermal properties were examined.

Materials and Methods

Nylon 6 is a semi-crystalline polyamide known as PA6. High elasticity, unbelievable scraped area, synthetic and thermal resistance, and a low coefficient of friction make PA6 highly intense, allow for widespread use, The expansion of the strands and fillers improves the quality, solidity, and moisture retention of the material. Due to its excellent mechanical quality and rigidity, PA6 is used in many auxiliary applications.

Figure-1 Filament Extruder

Comparing glass fibre to other fibres, it generally has equivalent mechanical properties. Glass beads have a density of 1.68 g/cm3 and a sharp softening range of 1200 °C, while it has a density of 2.58 g/cm3 and no actual melting point but softens up to 1000 °C, where it begins to disintegrate. Because of their excellent thermal properties, blends of PA6 and GF (in 5,15,25 wt.%) and PA6 and GB (in 5,15,25 wt.%) in the form of pellets were chosen as the material for the current investigation.

Extrusion of the Material

Drying the material at 90°C for at least 6 hours is a necessary step before ejection. The "Heraeus Instruments" are then set to the desired weight level of crushes under heated conditions to complete the process. The 3Devo-NEXT Filament Extruder is used to extrude the heated material, as shown in Figure 1, at an extrusion temperature of 175°C and a nozzle diameter of 1.75mm. the various arrangements for the extrusion of PA6 filament blended with 5%, 15%, and 25% glass fibre and 5%, 15%, and 25% glass beads. Finally, a wire of 10 metres in length is coiled from the mixed cum extruded filament.

Specimen Prepared by using 3D Printer/FDM

The fusion deposition modelling device is fed the extruded wire. The CAD model used in this example is created using Pro/ENGINEER Wildfire 5.0 as a fundamental requirement. It is then delivered as a Standard Template Library (STL) document to the Maker Bot programming, where the format is modified to X3G [tool path files], which is the necessary arrangement. When the 3D printer starts printing through the hot nozzle, the thin filament of PA6 is extruded. The bottom platform of the printer is where it settles and solidifies.

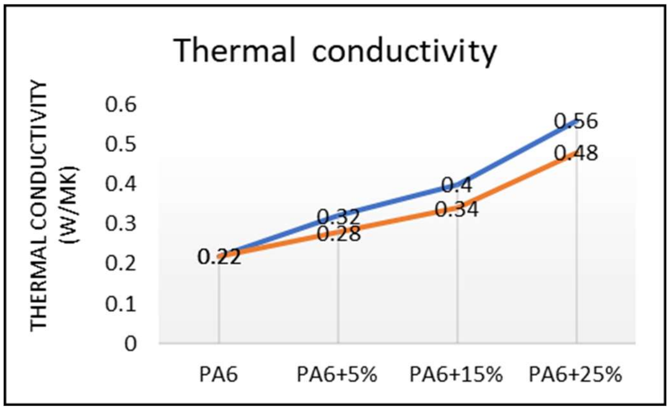
Figure-2 FDM Printer

As the thing is constructed film by film from the bottom up, the subsequent layer fuses with the layer below. Nozzle diameter [0.5mm], filament diameter [1.75mm], layer height [0.3mm], fill pattern [rectilinear], print speed [30 mm/s], extruder temperature [215°C], bed temperature [60°C], and nozzle angle [45°] were chosen as 3D printing process parameters based on prior research [21,22,23,24] and pilot experiment bases, and final printed samples were processed by various influenced process parameters.

Figure-3 FDM printed specimen

The sample of pure PA6 is printed as a result. Wire filament was fed into the 3D printer as we changed the composition's weight percentage of glass fibre and glass beads. The samples of PA6 +5,15,25%GF and PA6 +5,15,25%GB were created using the same 3D printing process at the intended dimensions of 40x20x5 mm, as illustrated in Figs. 3 and 4.

Table-1 TC & HDT of PA6+GB



------ GB ------ GF

Figure-4 Thermal Conductivity

Testing of the Printed Sample

Heat distortion temperature (HDT) was determined using an HDT 3 VICAT in accordance with ASTM D 648 standards. Thermal conductivity of the composites was investigated using TC 3010 equipment, and the thermal conductivity test was performed in accordance with ASTM Standards. Tables 1 and 2 include the testing findings for PA with GF and PA6 with GB.

Results and Discussion

Thermal Conductivity

Figure 3 shows the thermal conductivity of PA 6 reinforced with various glass fibre and glass bead compositions. It is obvious that adding more beads increases the thermal conductivity of virgin PA 6. In comparison to clean PA6, PA6+5%wtGB has a 50% greater thermal conductivity. When compared to clean PA6, the result of PA6 + 15%wt GB composite is increased by 96%. Thermal conductivity is improved by 120% in PA 6 + 25%wt GB compared to PA 6 clean. It is obvious that adding more beads increases the thermal conductivity of virgin PA 6.

Sample	PA6	PA6+5% GB	PA6+15% GB	PA6+25% GB
TC (W/mk)	0.22	0.32	0.4	0.56
HDT (C)	57.06	98.52	124.6	168.7

PA6+5%wt GF has a 26% greater thermal conductivity than hot PA6. Compared to PA6 alone, PA6 + 15%wt GF composite exhibits an improvement of 80% in performance. PA6 +25%wt GF exhibits a 96% higher thermal conductivity than PA6 alone. Virgin polymer's thermal properties quickly improve when GB is added to a blend of virgin polymers. Due to the great nanoscale dispersion feature of glass beads, PA6 reinforced with glass beads has a better thermal conductivity than glass fibre.

Sample	PA6	PA6+5% GF	PA6+15% GF	PA6+25% GF
TC (W/mk)	0.22	0.28	0.34	0.48
HDT (C)	57.06	89.52	107.6	138.2

Table-2 TC & HDT of PA6+GF

Heat Distortion Temperature

In Figure 4 shows the heat distortion temperature of several glass beads and glass fibre reinforced PA 6 composite compositions. It is obvious that when the amount of beads increases, the virgin PA 6's heat distortion temperature rises. PA6+5% wt. GB has a heat distortion temperature that is 112% greater than virgin PA6. In comparison to pure PA6, the outcome for PA6+15%wt GB composite is raised by 165%. HDT is raised by 213% when PA6+25% wt. GB is compared to pure PA6. PA6+5% wt. GF has a heat distortion temperature that is 85% higher than that of virgin PA6. Comparing PA6+15%wt GF composite to pure PA6, the result is improved by 105%. HDT is raised by 165% when PA6+25% wt. GF is compared to pure PA6. Virgin polymer's thermal characteristics quickly improve with the addition of GB to the blend. The thermal properties of the clean polymer blend gradually improve as more GB is added because it has excellent nanoscale dispersion capabilities. Due to the high crystalline content of glass beads, PA6 reinforced with them has a greater heat distortion temperature than glass fibres.

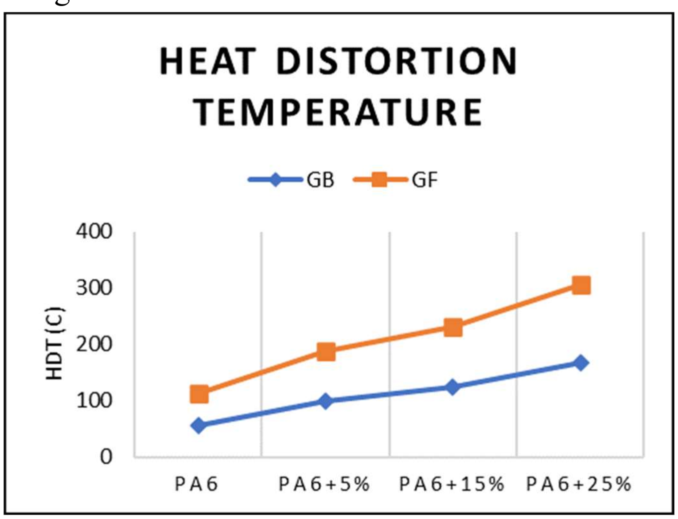


Figure-5 Heat Distortion Temperature

SEM Analysis

The micrography of the example PA6+30wt%GB & PA6+30wt%GF was captured using a SEM analyzer of the Philips XL 30ESEM type, and the results are shown in Figs. 6 & 7. It is derived from micrography (SEM), Glass beads were available and frequently strewn, it was obvious. Over one of the two's polymer composites creations. Figure 6 demonstrates the extensive and typical dispersion of glass beads found in the polymer composite as a result of their 25% individual support, while Figure 7 displays the relatively insignificant dispersion of glass fibre.

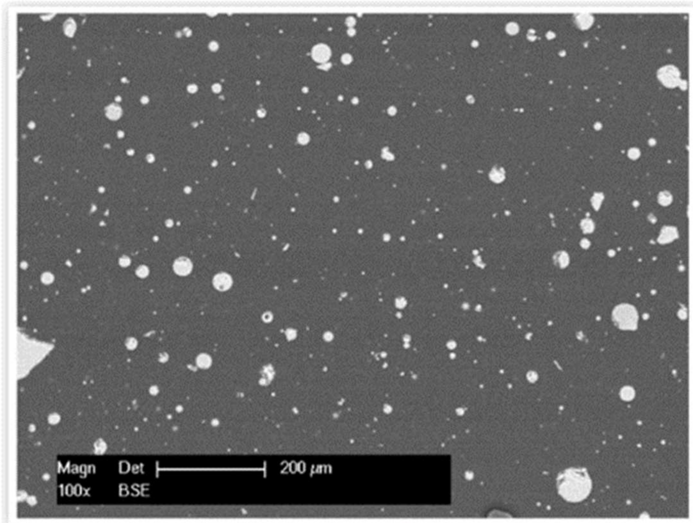


Figure-6 SEM for PA6+25wt%GB

Due to the glass beads 25 weight percent support, Fig. 6 shows the high thickness and homogenous dispersion of glass beads within the polymer lattice. When compared to PA6 reinforced with 25% glass fibre, the micrography of a polymer reinforced with 25% glass beads reveals that a greater amount of particles were distributed over the polymer composite, changing its thermal properties. According to the experimental findings, PA6 reinforced with glass beads has better thermal qualities than PA6 reinforced with glass fibres. The heat distortion temperature and thermal conductivity of glass beads reinforced PA6 are higher than PA6 reinforced with glass fibres because glass beads are highly crystalline materials and they impart better Nano scale dispersion property to the composition. Even mixing glass beads with PA6 improves the thermal properties.

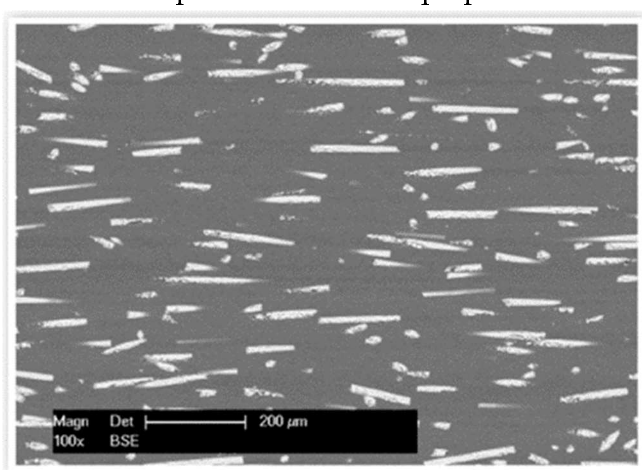


Figure-7 SEM for PA6+25wt%GF

Conclusion

The comparison of printed instances of glass fibre and glass beads reinforced polyamide matrix in the FDM process has been found to contribute as follows, according to the current research.

1. In the polymer matrix of the combinations of glass beads with a 25 weight percent concentration, uniform distribution of the glass beads and good nanoscale dispersion were found.

2. The polymer matrix's thermal conductivity and heat distortion temperature increased by 213% and 120%, respectively, following the addition of glass beads at a 25wt% concentration.
3. The heat distribution temperature and thermal conductivity of the virgin polymer have risen by 120% and 80%, respectively, with the inclusion of 25wt% of glass fibre.
4. When 25% glass beads are combined with PA6, the thermal attributes including thermal conductivity and heat distortion temperature are significantly higher than when 25% glass fibre reinforcement is combined with PA 6.
5. Based on the aforementioned findings, PA6 + 25% GB can be employed in high temperature and high-performance domains like engine blocks and aviation.

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