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Additive Manufacturing and Recent Developments in Polymer Nanocomposites

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ABSTRACT

Additive Manufacturing (AM) is a modern technology that constructs layer-by - layer components. In the field of production, the production of complex geometries has made AM a major competitor. The absence of advanced polymer composites to meet the performance and manufacturing requirements is an important challenge in the AM sector. In the development of functional components by AM, the use of traditional thermoplastic polymers lacks the desirable properties needed for high-performance applications. There have been important developments in the production of materials forAM applications in recent years. Advances in nanotechnology have made way for the production of polymer nanocomposites, which, compared to macro polymer composites, have exceptional mechanical and thermal properties at considerably lower weights. In this review , the authors have attempted to address the significance of various polymer nanocomposites that are compatible with various types of 3D printing techniques. It also addresses perspectives on the preparation of components, performance specifications and applications.

Keywords- Additive Manufacturing, 3D Printing, Polymer nanocomposites, Fused Deposition Modelling Processing Techniques, Selective Laser Sintering

I. INTRODUCTION

Additive Manufacturing (AM) is a community of emerging technologies that produce bottom to up artefacts by adding one cross-sectional section at a time to the content. Researchers and engineers have focused on refining old and producing new methods over the past three decades, as well as developing novel materials. There are some benefits to AM methods over conventional production techniques [4]. First, AM provides engineers with "design freedom"; it is possible to create geometries that can notbe generated by any other means due to its additive approach. Moreover, without the need for assembly, it is possible with AM to build usable parts. The use of AM as a medium to produce end-use components has historically been dampened by thetechnology's restricted choice of available materials, notwithstanding these design advantages [8]. Specialized polymers are the majority of materials used by current AM methods at present. Therefore, application choices are typically limited to models for form / fit testing, practical testing, presentation models, prototypes and non-load bearing items within these genres of materials. Innovations in both process management methods and material selection would be needed to solve these problems [2].

Nanotechnology is a very significant area of research. Nanotechnology deals mostly with nanoscale materials. The size of individual atoms ormolecules is already similar to this scale. Carbon nanotubes are typically made of materials and devices associated with this area of technology [18]. The nanometer (nm) is 1,000,000thof a metre. The unique shape formed by a group of atoms is a nanotube. This particle structure guarantees the special properties of matter. Flexibility, conductivity, exceptional strength and resistance, to name a few, are these special properties. Not all nanotubes are carbon-composed. In the form of nanotubes, boron nitride, gallium nitride, silicone, or titanium can also occur [21]. Technically, the nature of life, the DNA molecule, is also a type of nanotube. These small pipes can have fundamentally different shapes. There are single- walled nanotubes which are multi-walled. Zigzag configurations can shape the lattice of atoms [17]. The length, diameter, and some other physical parameters may be different. And undoubtedly, for nano materials, nanotubes are not the only possible type of structure. Hollow spheres, ellipsoids, nano rods, nano plates and nano ribbons are also present. Such composite technologies, solid plus liquid or solid plus gas, can combine different phases of matter. This way, it is possible to build nanofoams, nanocrystalline, nanoporous, or nano composite materials [19]. The addition of nanomaterials to AM printing media could therefore allow the production of completely new composites with unique properties and lead to the expansion of the fields of application of AM. The analysis was carried out via systematic searches of related journals in Nanotechnology, rapid prototyping and advanced materials through Scopus and Google Scholar search engines [18]. For Additive Manufacturing (AM), polymer materials are of central significance. This analysis will therefore concentrate only on polymeric materials. In recent years , numerous developments have been made in the field of polymer nanocomposites for various applications, including the automotive, packaging, aerospace and agricultural industries. It is because the properties of polymers could be precisely controlled by nanofiller incorporation. Polymer nanocomposites are referred to as multiphase structures in which the polymer matrix disperses the nanoparticles of at least one dimension in the nanoscale regime [17]. Initially, at the end of 1985, Toyota Central Research Laboratory introduced the term 'nanocomposites' when ensuring progress in the manufacture of nylon emontmorillonite (MMT) clay-based nano composites to create a car belt cover. Extensive research activities in the area of polymer nanocomposites have subsequently been tried world wide. This is because, even at small loadings, remarkable changes in the properties of polymer matrices are possible by nanofiller reinforcement. Nanoparticles demonstrate high surface area in the nanoscale regime and can thus interact with the mobility of polymer chains, which then in turn results in property manipulation [21].

II. POLYMER NANOCOMPOSITEATERIALS FOR AMTECHNIQUES

There are currently several AM polymer techniques in the industry for rapid prototyping. The two distinctive AM methods will mainly be the subject of this review: Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS).

Fused Deposition Modeling(FDM)

FDM, also known as extrusion of materials, is currently the market's most common AM technology. It helps the manufacture of robust components such as ULTEM, polycarbonate, polyphenylsulfone, polylactic acid, and acrylonitrile butadiene styrene (ABS) made from high-strength thermoplastics [6]. In applications, FDM systems are widely flexible, ranging from easy and inexpensive fast prototyping to tough and rigid parts suitable for end-use. In order tominimise weight and processing time for component repairs, the aerospace industry has historically replaced metal parts with sufficiently strong FDM-produced parts. FDM technology is suitable for prototype applications that do not need high resolution and surface finish, since it is inexpensive and does not need chemical post processing.

Polymer nanocomposite materials forFDM

Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are among the most widely used thermoplastics for FDM. Because of porosity and weak interlayer bonding, it is commonly accepted that FDM printed parts frequently have lower mechanical performance compared to injection moulded parts [16]. It is intended to provide a summary of the advances made in recent developments in novel printable FDM materials for mechanical, thermal, electrical and flammable applications. Recent developments in high- performance polymer nanocomposites for AM are the subject of the following discussion [5].

Claynanocomposites

Since the last century, clay materials have been widely studied as fillers in polymer matrices from many nanofillers (nanocellulose, carbon nanotubes, graphene and nanosilica) being tested for their reinforcing ability, to achieve considerable improvement in their properties. In fact, the substance 'clay' consists of layered silicate/clay minerals comprising metal oxides, such as alkali metals, alkali earth metals, magnesium, etc., as well as organic matter, present in particular in trace quantities [5]. A problem caused by the presence of covalent bonds occurring between the interlayer of clay sheets is the dispersion of clay in the polymer matrices. Until dispersion in the polymer matrices, clay particles are subjected to alteration to overcome this challenge [16]. Basically, the spacing between the interlayers of clay particles is improved by intercalation of surfactants or grafting of hydrophobic functional moieties during the modification process. It is possible to introduce hydrophobic properties into clay particles through these modifications in such a way that they can be finely distributed in the polymer matrices[13].

Carbon nanotube and carbon nanofiber nanocomposites

Specific interest has been attracted by carbon nanotubes because they are expected to have superior mechanical and also other physical properties. The intersection of standard carbon fibres with the fullerene family is mostly seen as carbon nanotubes with usual diameters in the range of ~ 1-50 nm and lengths of several microns [19]. They can comprise of one or more graphitic concentric cylinders. The shape of the graph primarily differentiates carbon nanofibres from nanotubes. Whereas the graphic layers in nanotubes are parallel to the axis, nanofibres can display a broad variety of graphic layer orientations with respect to the fibre axis. Since they have graphitic edge terminations on their surface, they could be visualised like stacked graphitic discs or truncated cones and are intrinsically less fine [21]. Although 50-100 nm is more common, these nanostructures may be in the shape of hollow tubes with an external diameter as small as ~5 nm. Slightly bigger (100-200 nm) fibres, even though the graphic orientation is roughly parallel to the axis, are often also referred to as carbon nanofibres[17].

Grapheme nanocomposites

In the development of polymer nanocomposites, Graphene is being used as an effective carbon- based nanofiller and has shown improved mechanical, thermal and electrical properties. Recent developments have shown that flexible displays and touch screens can replace brittle and chemically unstable indium tin oxide. It is well known that its single-layer is related to the superior properties of grapheme [16]. However, at ambient temperatures, the processing of single-layer graphene is difficult. If the sheets are not very well separated from one another, graphene sheets with a large surface area appear to create irreversible agglomerates and restacks by stacking and Vander Waals interactions to shape graphite [21]. By adding other molecules or polymers to graphene sheets, aggregation can be decreased. The existence of hydrophilic or hydrophobic groups prohibits strong polar-polar interactions or their bulky size from aggregating graphene sheets. In hydrophilicor hydrophobic media, and also in organic polymers, the binding of functional groups to graphene also helps in dispersion[5].

Selective Laser Sintering(SLS)

For modern material processing, Selective Laser Sintering (SLS) is a promising additive manufacturing method. More and more focus is being drawn from research societies and industries. While recent technological advances have made it switch from rapid prototyping to manufacturing, due to the limited quality of the resulting parts compared to those from traditional processes, SLS is not yet a reliable process for thermoplastics [7]. More efforts are still required to understand the physical phenomena involved in the process, model them easily, incorporate the corresponding models in a computational method to simulate the different stages of the process, validate the method and conduct relevant studies in order to improve the quality of the final parts in order for the SLS to become reliable for thermoplastic materials [9]. Therefore, new knowledge and academic innovations are required to conduct SLS process studies and establish a connexion between process, material structure, and final properties of parts. The process of Selective Laser Sintering starts with the conversion of 3D CAD data produced by customers into a sliced STL file using proprietary software [7]. After the STL file is formed, it will then besent to the Selective Laser Sintering Machine for printing. Until the feed bed rises (usually by < 0.1 mm), the system warms up (with content heated to just below melting point) and the levelling roller moves fresh powder around the building platform or part bed. The first layer is then traced by a CO_2 laser that, on contact, melts and fuses the material [11]. The building platform / part bed drops by a pre-set sum once the first layer is completed. A newlayer of powder is swept over the building platform and the feeder bed grows. The next layer is then traced out and once the model has "completely evolved," the phase repeats layer by layer [14]. Upon completion, before being removed and any loose material swept away, the model is left to cool as the Selective Laser Sintering process requires no supportstructures.

Polymer nanocomposite materials forSLS

The most popular materials used in SLS include thermoplastic polymers such as polyurethane, polycaprolactone and polyamide. Glass, aluminium, or fibrous materials may be filled with these thermoplastics to lead to certain applications. Ceramics and metals are also used by industry grade SLS printers [15]. Owing to the high cost involved with using a high-power laser, SLS devices are more costly than other 3D printing machines.

Nanosilica/Polyamide 12Composites.

As a nanofiller, nano silica was used for polyamide 12 in SLS by [1].Using the dissolution precipitation method, 3 percent nano silica was dispersed in polyamide 12. After the precipitation phase of dissolution, a composite powder was formed. Compared to unfilled polyamide 12, an improvement in tensile strength, tensile modulus, and impact strength of SLS printed specimens was observed by 20.9, 39.4 and 9.54 percent respectively [10].

Nanosilica/Polyamide 11Composites

A functionally graded nylon 11 and silica nanocomposites have been prepared by SLS. Powder mixtures of

Nylon 11 and silica nanoparticles (0-10 percent by vol.) were prepared using a rotary tumbler. In terms of the filler volume fraction, the mechanical properties of Nylon 11 and silica nanocomposites show nonlinear variations [22].

Nanoclay/Polyamide 6composites.

Polyamide 6 with clay reinforced composites was prepared by [15] for SLS printing. At liquid nitrogen temperature, samples have been reduced into powder. Increased values of fusion melt and crystallisation heat were observed due to clay and polymer chain interactions. Increasing composition of clay contributes to a composite of viscous polymers. Due to the limitation of the mobility of polymer molecules, the crystallisation temperature of nanocomposites was decreased by3^{o}C.

Functionalized GraphiteNanoplatelets

/Polyamide 12 Composites

In an attempt to achieve superior mechanical properties in SLS printing, a nanocomposite powder of PA12 and functionalized graphite nanoplatelets have been prepared. With polyamide 12 matrices, the functionalization of graphite nanoplatelets enhances its interfacial bonding force. Without sacrificing the thermal and rheological activity of the nanocomposites, a few nanofillers increased the mechanical properties of SLS printed components[10].

Carbon Nanotube/Polyamide 12 Composites

The effect of carbon nanotubes (CNT) on the rheological and dynamic mechanical properties of SLS printing polyamide 12 was investigated by [17]. CNT presence in polyamide 12 increased the modulus of storage, the modulus of loss and the viscosity of nanocomposites. Nanofillers and polymer matrix interactions matrix has interfered with the polymer molecules chain mobility. Compared to PA12, the laser-sintered component of PA12 CNT nanocomposites had an improvement in elastic modulus[1].

CONCLUSION

This study aims to provide a detailed overview of nanocomposites of polymers. Polymer nanocomposites for AM provide a way of improving the portfolio of material performance, allowing more design flexibility for the development of multifunctional components. By integrating nanoparticles, major improvements in mechanical properties such as tensile strength , impact strength, flexural strength, compression strength and hardness have been seen. Nanocomposites also allow low electrical resistance and biodegradable flame retardant properties of 3D printed components. In the context of AM, polymer nanocomposites and their production, structure and performance relationship will encourage the discovery of lightweight, stronger and multifunctional materials that further extend AM 's potential. In major industries such as manufacturing and medical research, the applicationof AM involves the manufacture of parts with improved properties to fulfil the intended purpose. The use of polymer nanocomposites in this situation can play a vital role in influencing society. The combination of continuous fibre reinforcement polymer nanocomposites could yield strong AM parts with enhanced interlaminar strength.

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