Development of Composite Materials for Additive Manufacturing

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Abstract: Over the past three decades additive manufacturing has emerged as one of the widely used manufacturing technology for complex and intricate components. Moreover, the advancement in composite materials has also impacted the additive manufacturing technology. The present paper focuses on the advancements in the composite and nanocomposite materials development for extrusion-based additive manufacturing. Some micro-seized composites are discussed along with the nano-sized composites. Also, the prospects of developing clay-based nanocomposite is also discussed.

INTRODUCTION

Additive manufacturing also known as 3D printing has emerged as one of widely adopted manufacturing technology world-wide. The application of AM is not limited to production of mechanical parts, but it has also spread its domain in the area of surgical planning and biomedical implants. AM technology can be broadly classified based on their working principle as- Laser sintering, Adhesion, Lithography and Extrusion. However extrusion based AM technology like Fused Deposition Modelling (FDM) have an edge over others in terms of less material wastage, minimal post processing, safe and simple fabrication process [1-8].

Extrusion-based additive manufacturing is one of the widely used technology, which can fabricate functional parts; it is based on the principle of extrusion. It builds objects directly from a three dimensional computer aided design (CAD) models. The thermoplastic material is fed to the head, where it is heated to a semiliquid state; the head then deposits the material on the build platform, one layer at a time [9-14]. Each layer is bonded with the previous layer, as the temperature of the air surrounding the extrusion head is maintained below the melting point of the material [15, 16]. Figure 1 shows the schematic diagram of FDM process.

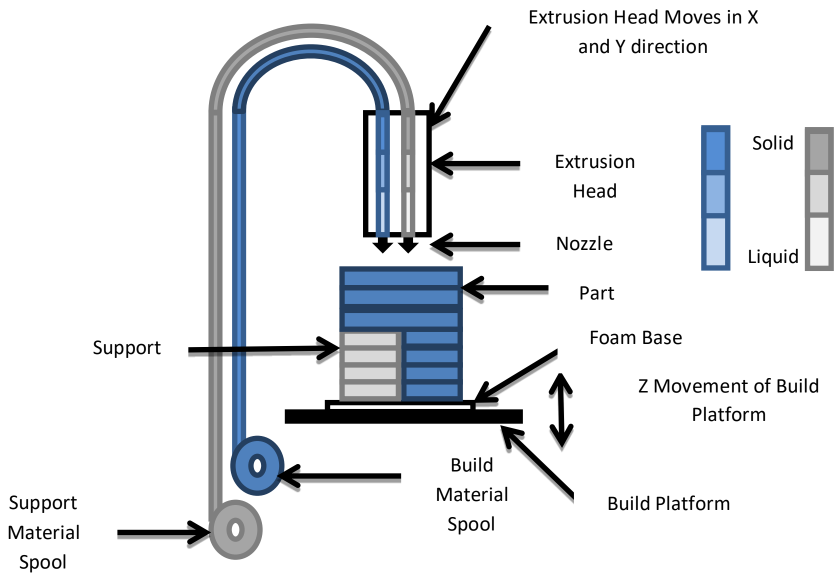

Figure 1 Schematic Diagram of FDM Process

In 1992, Stratasys manufactured its first FDM machine, the primarily material used was Acrylonitrile Butadiene Styrene (ABS). Over the years a variety of materials has been developed such as, polycarbonate (PC), polyphenylene sulfone (PPSF), high impact ABS (ABSi), elastomer (E20) and polyester which are widely used in the industries. The application of FDM processed parts ranges from simple prototyping and pattern making for tooling to fabrication of functional parts.

The performance of the extrusion-based AM parts are inferior compared to the other manufacturing techniques. Some attempts have been made to develop metals and ceramic based composites, which were used in direct rapid tooling. Recently the developments in nanotechnology have influenced the AM process. The effect of introducing nano fillers to the polymer matrix have resulted in enhancement of the desired mechanical properties [16-19].

Filaments Materials Commercially Available

The table 1 shows the commercially available polymer filaments. A comparison between the filaments with respect to their mechanical properties are shown in the table 1.

Table 1 Polymer filaments available for FDM

Property	**ABS P400**	**ABSi P500**	**Elastomer E20**	**Poly carbonate**	**Polyphenyl sulfone**	**Polyester (P1500)**
Tensile strength	34.5	37.2	6.4	63	69	19

(MPa)						
Elongation % at yield	>10%	>10%	>10%	NA	7.2%	<10%
Impact strength (Izod), (J/m)	107	176	347	754	782	32

Micro-sized composite

Iron particles were mixed in nylon matrix to develop the filament for additive manufacturing. Composites having large filler particles and higher volume fraction exhibit lower tensile stress and elongation [3]. Constraint was that the filler particles should be of uniform size (figure 2).

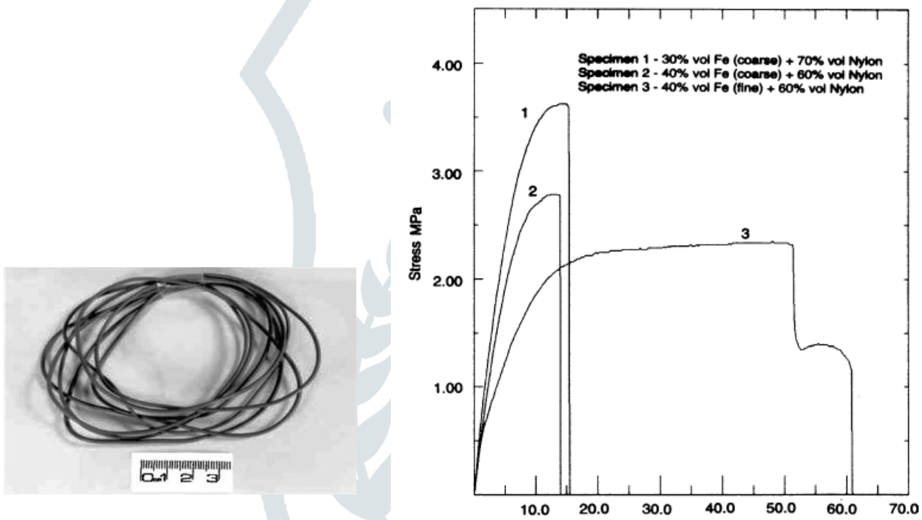

Figure 2 Composite filament and Comparison of different iron content on composite materials

New metal – polymer was developed by filling ABS (polymer) with copper/iron (metal). Metallic filler were introduced up to 40% by volume. Test specimen of ABS/iron and ABS/copper were studied. Due to highly filled metal filler in the matrix, the parts produced exhibits higher stiffness compared to pure polymeric material and can withstand higher injection moulding pressure.

Iron particles tends to decrease the elongation of the part, as the composite behaves as hard and brittle material. Tensile strength is significantly lowered due to the presence of iron particles. Thermal conductivity increases only when the metal filler particle concentration increases up to 30 %. On the other hand further increase of filler material (ABS/copper) tends to weaken the matrix due to agglomeration of filler particles [7].

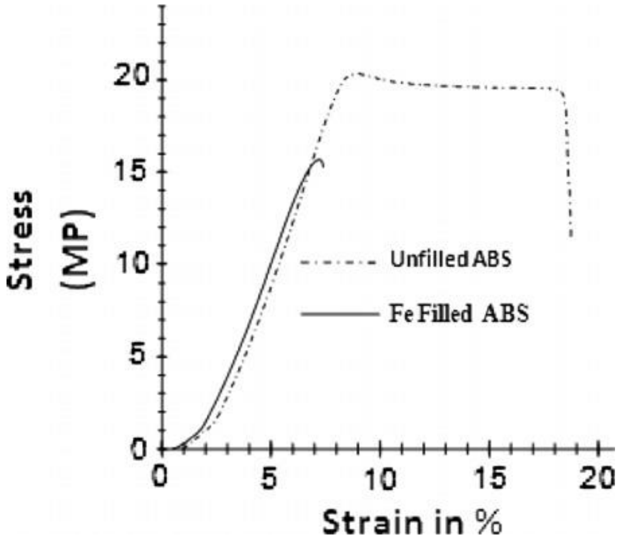

Figure 3 Effect of iron particles on tensile strength on ABS

Influence of electroplating on impact strength and hardness of ABS were also examined. ABS samples were electroplated with Nickel, by 60, 70 and 80 microns Electroplated specimen with (80 microns) plating shows greater resistant to impact. Hardness of electroplated specimens were increased compared to ABS specimen. Electroplating tends to give smoother surface finish.

Table 2 Impact resistant of different specimens and Hardness values of different specimens

Condition⇨	Normal	60 µm	70 µm	80 µm
Load, Kg ⇩	Energy Absorbed, Joules			
0.89	7.22	5.39	17.88	24.27
1.395	12.39	8.62	22.75	44.37
2.33	33.71	21.75	65.68	87.43

Condition of FDM Samples	Materials			
	ABS	60 µm	70 µm	80 µm
Normal	95	--	--	--
Electroplated	--	101	103	107
	Rockwell hardness, HRR			

Nanocomposites Developed for Additive Manufacturing

According to the literature, several attempts have been made to process nanocomposites using different AM processes. Among the available nano fillers, the majorly used nano fillers are clay, carbon nano tube, carbon fibre and graphene. Table 3 shows the list of different nanofillers used in AM process [17-28]

Table 3 list of nano fillers used in AM technology

Nano Fillers	**Polymer**	AM Process
Clay, carbon nano tube, nanosilica	Nylon 11	SLS
Clay	Nylon 12	SLS
Clay	Nylon 6	SLS
Clay	Nylon 12	SLS
Carbon fibre	ABS	FDM
Carbon fibre	Nylon 12	SLS
Carbon nano tube	Nylon 12	SLS
Graphene	Nylon 11	SLS
Graphene	Hydroxyapatite (Hap)	3D Printing

Additive manufacturing, formerly known as rapid prototyping, has emerged rapidly over the short span of time and is now widely used for manufacturing of functional parts. From the usage perspective the most important characteristics in the parts are accuracy, surface roughness, mechanical strength, elongation, cost, and build time. Efforts have been made in the direction of improving the AM technology to meet the functionality requirements, however little efforts are made to develop new viable materials which can be processed by AM technology possessing greater material properties. One of the major drawbacks with Fused Deposition process is interlayer porosity. The tensile properties of the material are greatly reduced due to this inherent property. Hence the mechanical properties of these materials are not as high as their injection molded counterparts. Particularly strength of the part is reduced as the load bearing capacity of the material is reduces due to porosity. Figure 4 shows the porosity in FDM tensile specimen build using ABS.

However in this scenario use of materials with enhanced mechanical properties can compensate to some extend the loss incurred due to porosity. Nanocomposites such as or clay-based nanocomposite have attracted a lot of attention.

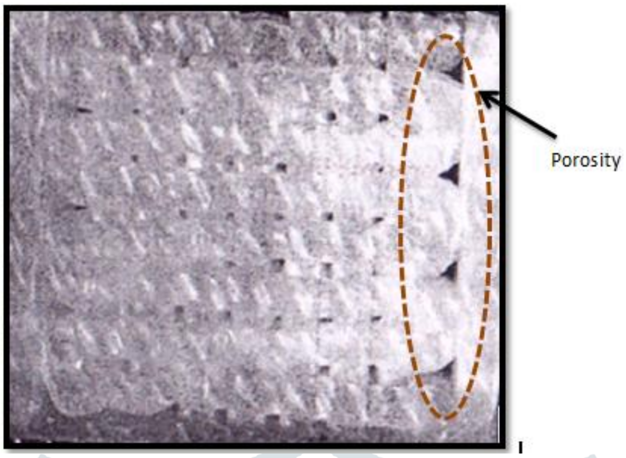

Figure 4 Porosity in FDM part

Due to these encouraging results, attempts have been made to apply polymer/clay nanocomposites to the AM process, particularly in SLS. Decent progress has been reported by the past studies. Therefore developing such nanocomposites for FDM process, can contribute greatly in the fabrication of functional parts.

Nanofiller content plays an important factor in developing of nanocomposites. This decides to what degree the addition of nano fillers will influence the mechanical properties of the nanocomposite. Figure 5 shows the two different dispersions namely intercalation and exfoliation of polymer [18].

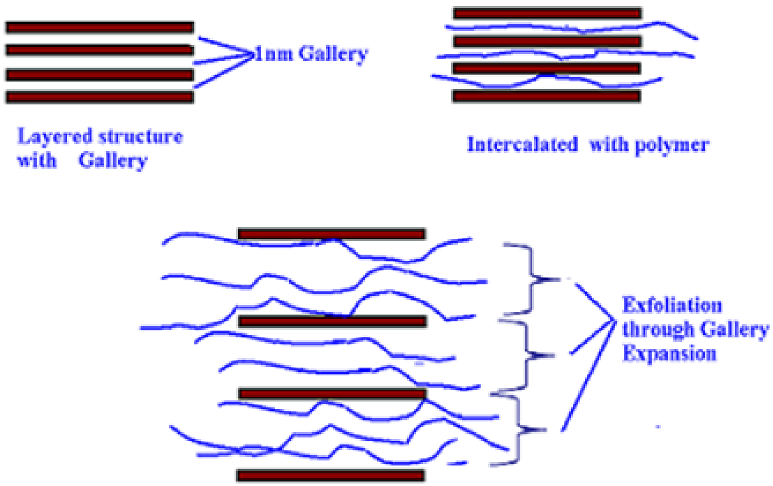

Figure 5 Degree of dispersion of clay in polymer matrix

To reach maximum exfoliation, exhaustive study of different parameters affecting the dispersion of polymeric chains into the clay galleries has to be investigated.

Conclusions

The potential of the additive manufacturing technology is limited due to the limited materials available. Development of composites and nanocomposites materials have increased the application area of additive manufactured parts. Moreover, the prospects of developing clay-based nanocomposite for additive manufacturing can be proved to be viable option for fabricating high performance additive manufactured parts.

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