

Targeting Fused Filament Fabrication Issues By Layered Structured Nanomaterial's

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Abstract

The continuous growth in layered manufacturing (aka, 3D printing) is revolutionizing the manufacturing industry. Fused filament fabrication 3D printing finds applications in various sectors such as automobile, aerospace, biomedical etc. However, the critical issues related to the technique imposes restrictions in its usage for a wider range of applications. Low part strength, mechanical anisotropy, delamination, porosity, low surface finish and limited choice of processable materials are some of the major constraints of the process. The addition of nano-dimensioned materials/particles has potential to improve the performance of 3D printed parts. Nanoclay/layered silicate a versatile nanoparticle, which occurs naturally and have a layered structured nanoparticle seems to be a promising candidate for targeting the shortcomings of the technique. Extensive attempts have been made by the researchers to process clay-based nanocomposites in 3D printing. The addition of nanoclay can influence the mechanical, thermal, electrical, optical and surface finish of 3D printed polymeric parts. The paper presents the current state of the art about the polymer-layered silicate nanocomposites developed for fused filament fabrication based 3D printing and its effect on the critical issues related to the technique.

Keywords: Layered silicate, layered manufacturing, 3D printing, nanoparticles, nanocomposites.

INTRODUCTION:

The nano-dimensional layered material holds the potential to influence the performance of layered-manufactured parts. Researchers across the globe have started investigating the effect

of the layered silicate (nanoclay), a versatile layered structured nanoparticle in layered manufacturing (3D printing) technique [1-3]. The nanoparticle has been found to be aiming the critical issues of layered manufacturing technique which can propagate the utilization of the technique for a wider domain of applications.

Anisotropy in mechanical properties, inferior strength due to partial bonding, inherent porosity and warpage are some of the major concerns in the layered manufacturing of polymers via fused deposition modeling [1,3,7]. On one hand where layered manufacturing gives freedom to produce any complex configurations. However, on the other hand, these unresolved issues limit its industrial applications.

The naturally occurring layered silicate nanoparticles contains 1 nm layers of aluminosilicate which orient themselves within the polymer matrix during the layered manufacturing process and provides a better reinforcing effect in the layered-manufactured parts. The nanomaterial is used for many engineering applications (refer figure 1). The increment in mechanical properties due to layered silicate could be more for layered manufacturing compared to injection molded parts due to orientation and allignment of these nanoparticles during extrusion. The presence of these nano dimensioned material can also decrease the linear thermal expansion ratio and consequently reduces the warpage issue in layered manufacturing [1].

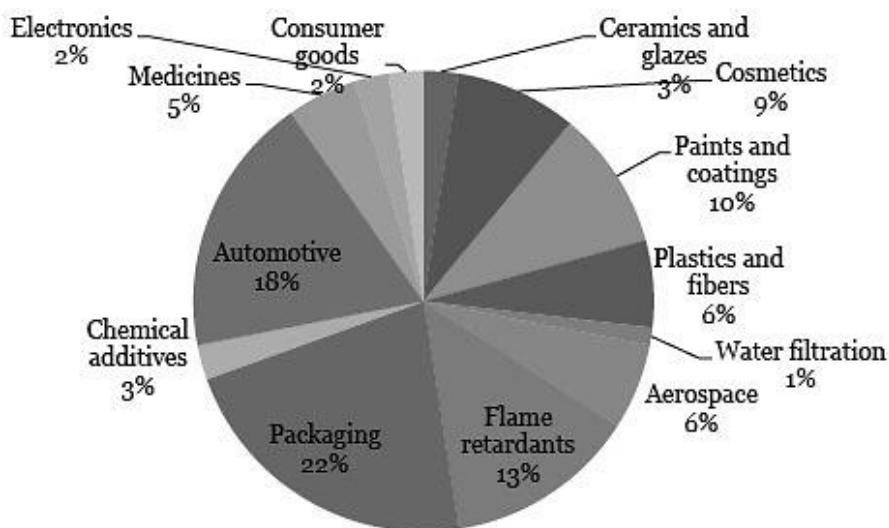


Figure 1 Application of nanoclay in various sectors

Mechanical anisotropy is a major concern in 3D printing. On changing the build and raster orientation significant amount of deviation comes into the picture. However, layered silicate reduces the anisotropy by increasing the effective contact area between the layers which increases the resistant capability of 3D printed parts on the application of external force [2].

The bonding between the adjacent layers and rasters is partial in 3D printed parts. This results in the development of voids throughout the cross-section of parts. The rate of sintering during the process greatly depends on the surface tension and viscosity of the melt polymer. Incorporation of layered silicate in low fraction can increase the rate of sintering by influencing the surface tension of the nanocomposite. This increases the neck size between the rasters and decreases the voids volume fraction [3]. Hence the nanoparticle assists in the 3D printing process. The nanoparticle also alters the dielectric properties of the 3D printed polymeric parts due to its ionic nature. The nanoparticles provide additional polarization mechanism in the polymer matrix. Ionic and interfacial polarizations occurs due to the presence of layered silicate which assists in altering the electric properties of the fabricated parts.

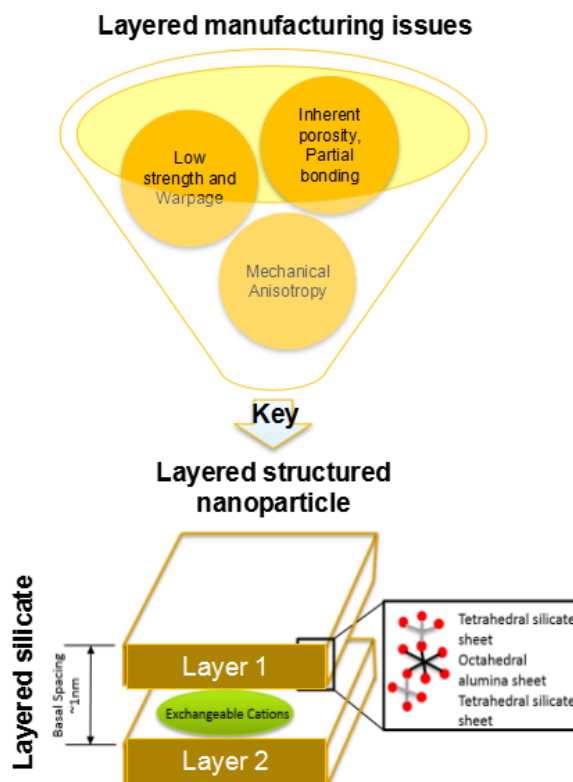


Figure 2. Layered silicate nanoprticle for layered manufacturing

The interaction of layered silicate with polymer chains restricts their segmental motion at elevated temperatures [4]. Therefore, their presence improves the thermal stability of the 3D printed parts. Compared to various other nanoparticles investigated for layered manufacturing, layered silicate is economical attractive which can help in promoting desktop printing of low-cost functional components. However, certain issues such as agglomeration and dispersion of nanoparticles, optimization of process parameters, nanocomposite synthesis method and an optimum fraction of the nanoparticle to be added need to be further investigated for completely utilizing the benefits of layered silicate in layered manufacturing technique.

Dispersion and delamination of clay platelets in printable matrix

It is important that the layered silicate nano particle should be homogeneously dispersed in the printing media. This can be achieved by adopting adequate technique for nanocomposite formation. Since the tendency of nanomaterials to agglomerate is high compared to macro sized particles. Therefore, mixing technique should provide shearing to clay platelets in such a way that delamination of platelets is achieved. This will allow proper dispersion of the nanoparticles in printing media. Figure 3 illustrates a TEM image showing the dispersion of nanoclay in acrylonitrile butadiene styrene (ABS) polymer [1]. Also the delamination of clay platelets are also observed. This delamination aids in better dispersion which in turns influences the mechanical performance of the nanocomposite.

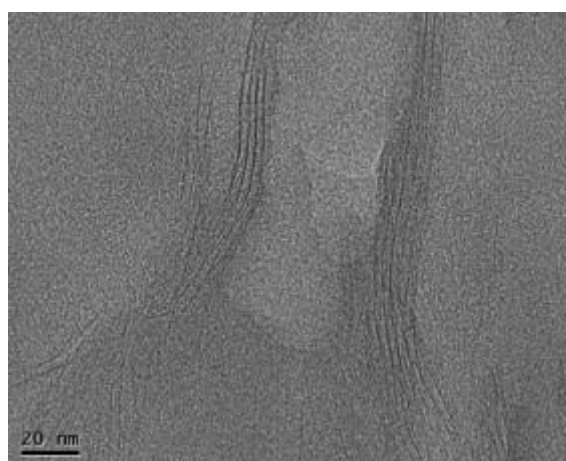


Figure 3 TEM image showing dispersion of nanoclay in ABS matrix [1]

Figure 4 shows a SEM image demonstrating the dispersion of the nanoclay in ABS matrix [3].

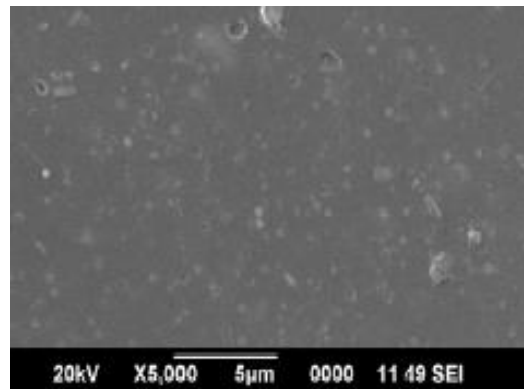


Figure 4 SEM image demonstrating the nanoclay dispersion in ABS matrix [3]

Effect of nanoclay on performance of FFF parts:

It has been reported that the addition of nanoclay have enhanced the performance of the FFF parts. The presence of these nanomaterials influences the mechanical, thermal and dielectric behaviour of the FFF parts.

Effect on Mechanical properties

Due to the better dispersion of the nanoclay in printing media, better mechanical properties have been achieved. With the addition of 5 wt% of nanoclay, an increment of 43% is reported by Weng et al. Moreover, low clay loading upto 0.10 wt% can also influence the mechanical performance of the fabricated parts (Figure 5a). Francis et al. reported an increase of 14.5% in tensile strength and 21% increment in tensile modulus (Figure 5b). The increase can be attributed to the better dispersed and interacted clay platelets with polymer matrix. These clay restricts the segmental movement of the printing media and provides improved stiffness to the nanocomposite. Also, the dispersion of clay nanoplatelets can also enhance the performance of the other printing media than ABS. Coppola et al., demonstrated increment of poly lactic acid (PLA) matrix.

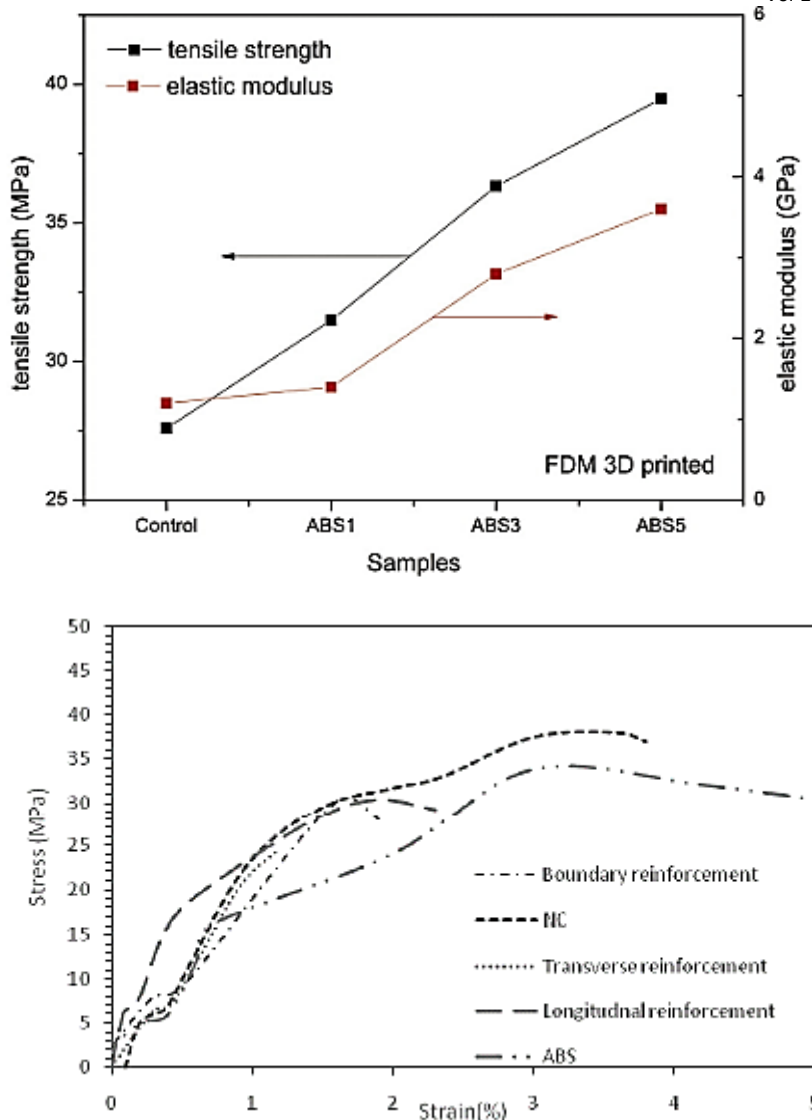


Figure 5 Mechanical performance of 3D printed parts on addition of nanoclay [1, 6]

Effect on Thermal Properties and interfacial bonding

Nanoclay also acts as thermal insulators thus affecting the thermal properties of the printing media [9-10]. On observing the effect of nanoclay on thermal performance of 3D printed parts. It has been reported that, it improves the thermal stability of the polymer (Figure 6). Also, its effect on glass transition tempertaure is also reported. This can improves the application domain of the 3D printed parts for high temperature applications. The increase in glass transition temperature from 98° C to 112 ° C has also been reportrred by addition of 5 wt% nanoclay.

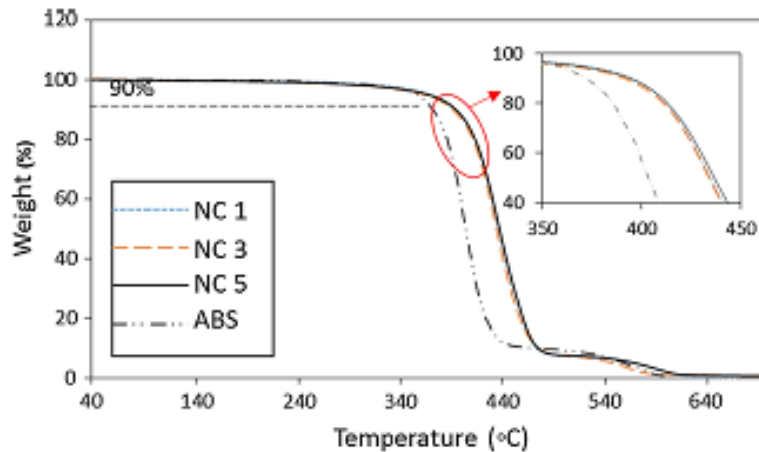


Figure 6 Increased thermal stability due to layered silicate [8]

Moreover, the presence of clay nanomaterials may affect the sintering process of the deposited rasters. Since the presence of nanomaterials can affect the viscosity and surface tension of the printing media. Which in turn could influence the bonding between the rasters [3].

Conclusions

Addition of nanomaterials in 3D printing media is a logical and appropriate approach to overcome some of the limitations encountered in fused filament fabrication process. However, the selection of nanomaterials plays an important role in deciding the performance of the printed parts. Among the few investigated nanoparticles for FFF process, nanoclay is one of the contenders that has demonstrated excellent results. Some of the major issues in FFF process can be reduced by addition of layered structured nanoclay. However, in order to fully utilize the benefits of nanoclay for 3D printing, extensive work needs to be done. Strategic research in this direction can lead to enhancement of the application domain of 3D printing process.

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