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Mechanical and physical properties of laser sintered nanocomposite containing organic and inorganic fillers: a context review

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Abstract. Laser-sintered nanocomposites have attracted many researchers in the automotive, military, and medical industries. This makes it simple to produce intricate parts with superior mechanical performance. Nowadays, nanocomposite has become an economical way to fabricate materials with a low cost, considerable weight, and improved mechanical and physical properties. This paper reviewed the physical and mechanical characteristics of nanocomposite materials. Organic and inorganic filler compounds and their effect on mechanical properties have been discussed. It is seen that nanosized materials perform better than counterpart materials; these materials have much potential in the engineering and medical fields. Much research has been conducted on the incorporation of organic and inorganic fillers on the performance of nanocomposite. Numerous studies have shown that adding nanofiller results in significant improvements and enhancements in the mechanical properties of natural composites. The incorporation of nanofiller materials in small percentages into the matrix makes the weight of nanocomposites lighter than conventional composite. Different factors such as dispersion rate and moisture absorption of nano-filler, and their effect on flexural strength, fracture toughness, and hardness of the nanocomposite have been reported.

Keywords: nano-fillers, nanocomposite, polymer, hardness, strength, density, modulus, flexural property.

Classification numbers: 5.1.1, 5.4.5, 5.4.6

1. INTRODUCTION

Nanocomposites are high-tech materials with superior qualities and are made up of one or more nanoscale phases. Nanocomposites are materials composed of nanoparticles dispersed within a matrix material, and the use of laser sintering can allow precise control over the distribution and arrangement of these nanoparticles within the final product, leading to tailored mechanical, electrical, or thermal properties. This technology finds applications in various industries, including aerospace, automotive, electronics, and biomedical fields. Laser-sintered nanocomposite typically refers to a material fabrication process involving the use of lasers to sinter or fuse nanoparticles or composite materials together. Laser sintered nanocomposites are used in automotive, military, and medical fields [1 - 2]. By incorporating nanoparticles into the polymer matrix, laser-sintered nanocomposites can exhibit improved mechanical properties such as increased strength, stiffness, and toughness compared to pure polymer materials.

Nanocomposites are known to have a high aspect ratio, large surface area, and high surface-to-mass ratio. The significant influence of nanocomposite on the thermal, electrical, density, and mechanical properties of the material matrix was embedded in its uncommon features [3]. Viewed nanocomposites as materials in which filler elements are added to improve either mechanical, thermal, physical, or fire redundant properties of the matrix of the material, it was noted that the properties of the resulting materials do not depend on the original materials but equally depend on their interfacial and morphological characteristics [4 - 5]. The primary aim of nanomaterials is to improve either the physical or mechanical and other properties of the material matrix [6]. Reinforcement materials are nanosized filler materials whose dispersion rate in the matrix determines the improvement that will be added to the parent materials and the properties of the nanocomposite have proven to be 1000 times better than those of the individual parent materials. Nanocomposites are anisotropic by nature which makes their properties dependent on direction, as a result of the special properties of the component and the uniform distribution of the fillers that make the materials outstanding and most sorted for in additive manufacturing (AM) [7-8].

Nanocomposite comes in different types as mentioned by metal nanocomposite, iron chromium/aluminium oxide $FeCr/Al_2O_3$, nickel/aluminate Ni/Al_2O_3, cobalt/chromium Co/Cr, iron/magnesium oxide Fe/MgO, aluminium/carbon nanotubes Al/CNT, and magnesium/carbon nanotubes Mg/CNT, ceramic nanocomposite, aluminium/silicate Al_2O_3/SiO_2, silicon oxide/nickel SiO_2/Ni, aluminium oxide/titanium oxide Al_2O_3/TiO_2, aluminium oxide/silicon carbide Al_2O_3/SiC, and aluminium oxide/cyanide Al_2O_3/CN and lastly, polymer nanocomposite which can either be polymer silicates, thermoplastic/thermoset, polymer carbon nanotubes, or polymer with double layered hydroxides and polyester/TiO_2 and carbon nanotube [5 - 6, 8 - 12]. According to the theory of micromechanics, the property of the material composite does not depend on the inclusion size. However, in the case of the nanocomposite, the theory is not applicable because the thermal, mechanical, electrical, and physical characteristics depend on the surface area of the matrix materials. The postulation of micromechanics theory further highlighted that some properties like Young's modulus, flexural strength, toughness, density, and tensile strength depend on the properties of the components and their arrangement in the matrix of the incorporated materials [13 - 14].

Polymer nanocomposites are made up of polymers and the materials added in little quantities used as reinforcement which must have a high aspect ratio to achieve the desired bonding. The particles which form the matrix are in the nanometer range of 1 to 100 nm in size [15]. The nanoparticles have a large influence on the features of the parent material which makes it acceptable for a wider range of industrial applications such as corrosion prevention [16], electrical [17], aeronautics [18], automotive [19], and parts for medical and industrial equipment [20]. The development of nanocomposite materials using laser sintering techniques in additive manufacturing (AM) is presently attracting many more researchers primarily because of the improvement of the material's properties with well-developed and complex features at least cost [21 - 22]. In AM, materials are produced through a layer-by-layer process which makes it easy to customize products to meet customers' imaginations [23]. AM has a lot of benefits when compared with traditional manufacturing processes, material waste is mitigated and complex products are easily produced with less cost, time, and part assembly process. AM may be (a) Extrusion additive manufacturing like fused deposition modeling (FDM) uses thermoplastics such as polylactic acid and ABS with eutectic metals; (b) Granular AM includes selective laser sintering, selective heat sintering, electron beam melting, and direct metal laser sintering, they all utilize metal/alloy/polymer powder as the host material with plaster-based 3D printing and ink jet head 3D printing; (c) Light polymerized technology which applies digital light processing and stereo-lithography as additive manufacturing technology and photopolymer as the host material [24 - 26].

The properties of nanocomposite materials under loading have been thoroughly examined in this work, with particular attention paid to attributes including toughness, tensile strength, hardness and flexural durability.

2. FILLERS

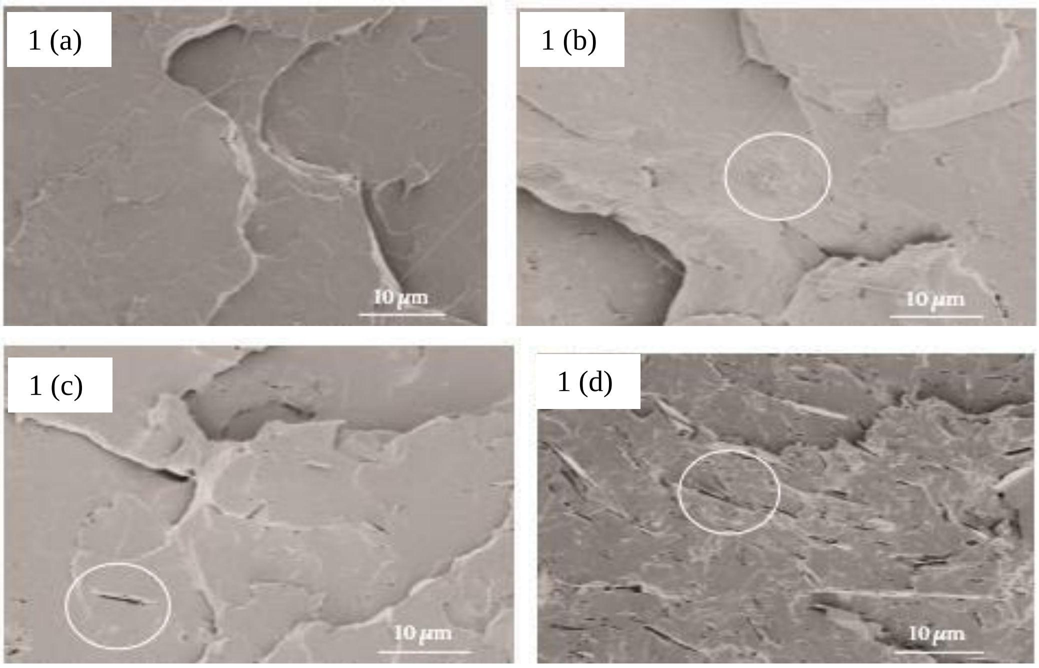
Fillers are traditionally considered additives, primarily for reducing the cost of expensive polymer materials and increasing the properties of parts to produce [27 - 28]. Fillers play a crucial role in laser-sintered nanocomposites, influencing their properties and performance. Fillers can help reduce dimensional changes due to temperature variations or moisture absorption, improving the dimensional stability of the nanocomposite over time.

Numerous studies have shown that adding nanofiller results in significant improvements and enhancements in the mechanical properties of natural composites. Khan *et al*. [29] conducted an extensive review and concluded that the incorporation of filler elements into the nanocomposite matrix improved the physical and flexural strength, impact toughness, and electrical properties of numerous polymers. Bustamante-Torres *et al*. [30] studied the interaction between polymers and reinforcing nanofillers for biomedical applications. The authors reported that polymer magnetic nanocomposites enhance the rigidity, mechanical strength, high-temperature resistance, weight reduction, corrosion resistance, and electrical conductivity of matrix materials.

Lui *et al*. [31] investigated the effect of fillers in polylactic acid (PLA) on crystallization behavior and mechanical properties. It was revealed that the tensile strength of composites depends on the PLA's crystallinity and the filler's and PLA's interfacial characteristics. Sivadas *et al*. [32] reported that nanomaterials can be added unaltered to improve the interface with the matrix polymer. The high surface-area-to-volume ratio of nanomaterials also influences the intrinsic and extrinsic properties of the material. Guru *et al*. [33] presented a methodology that uses molecular dynamics and the finite element method to assess how the interface affects the elastic characteristics of CNT-reinforced nanocomposites. The acquired results can be used to determine the effects of adding CNT reinforcement for potential enhancements in the elastic characteristics of polymeric matrix composites. Dauan *et al*. [34] developed interface characteristics of coarse-grained models for the CNTs/epoxy nanocomposites. The generated models of nanocomposites, according to the authors, can offer helpful insights into the expected mechanical properties or mechanisms.

Treece *et al*. [32] reported that filler efficiency and effectiveness can be calculated as the surface area to volume ratio which needs to be as high as feasible for the reinforcement to work. Therefore, when improving the overall properties of the material matrix, the surface area to volume ratio and aspect ratio must be very high. When developing reinforcement fillers, the particle aspect ratio is increased by modifying the materials, hence improves the filler's interfacial adhesion and compatibility in the polymer matrix. To attain these new properties, the existing fillers are either changed or modified, thereby expanding their range of applications. Consumption reports showed that over 15 million tons were estimated as the global demand for reinforced fillers such as calcium carbonate, talc, and kaolin [33 - 34]. Inorganic fillers are effective additives that improve the mechanical, electrical, thermal, and physical properties of polymers. This can be demonstrated by the addition of carbon fiber and glass. The property of the composite is determined by the dispersion rate, surface quality, and particle size of the fillers and this can be seen in the case of carbon black filler dispersion in polymer composite as reported. When fillers in the composite are well dispersed, it will exhibit a noticeable improvement in the desired properties of the nanocomposite [35 - 36].

Numerous polymers such as polyamide-6, polystyrene, and polyethylene terephthalate were investigated by various researchers. Song *et al*. [37] developed a strategic method to improve properties of nanocomposite using hydroxyapatite nanoparticles with polylactic acid. The annealing and orienting processes significantly improved the mechanical, electrical, and physical properties [38]. Crystallization and relaxation of the polylactic acid chain are achieved by the annealing method, while crystalline structures of polylactic acid are optimized by the orientation method. Researchers [39 - 41] suggested that one of the major keys to improving the properties of polylactic acid is to monitor the phase transition. Scanning electron microscope (SEM) images in Figure 1 show the dispersion of inorganic filler in a polylactic acid matrix, hydroxyapatite (HA) (Figure 1(a)). Figure 1(b) shows the assemblage of HA and Figure 1(c) displays a lamellar structure. The existence of voids in the HA/PLA matrix in Figure 1(d) indicates that the filler between the interfaces needs better improvement since the voids expose the composite to early failure due to a decrease in the properties of PLA based materials. Good dispersion of inorganic fillers take place in the polylactic acid PLA matrix at the melting stage of the compound [41].



1 (c) 1(d)

Figure 1. Polylactic acid with hydroxyapatite, (adapted with modification from [41]).

3. SINTERING

In additive manufacturing, thermal energy from a laser source is utilized by selectively fusing the materials of powder particles in layer-by-layer processes forming a three-dimensional or more complex shape. Materials like alloyed metals and thermoplastics in the form of powder can be processed by selective laser sintering SLS method [42]. Figure 2 shows the applications of laser-sintered nanocomposites. Hooreweder *et al*. [43] evaluated the mechanical properties of polymer produced by SLS and injection molding. The outcome of the research shows no noticeable improvement in the tensile, toughness, flexural, and other mechanical properties of the polymer.

Tang *et al*. [44] proposed a new computational framework to evaluate the mechanical behavior of SLSed CFRP based on the representative volume element (RVE) model. The effects of fiber volume fraction and fiber orientation distribution on the mechanical behavior of SLSed CF/PA12 composite are quantitatively explored and ranked concerning their influence on stiffness and failure strength.

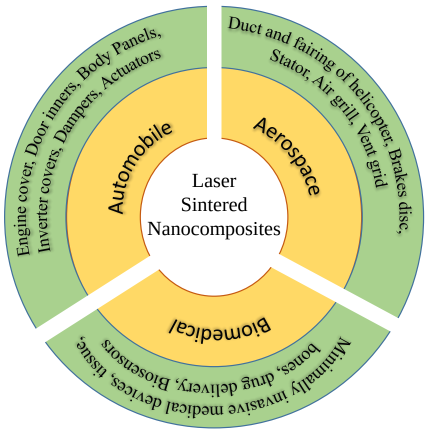


Figure 2. Application of laser-sintered nanocomposite.

Yu *et al*. [45] developed the silicon carbide (SiC) particle-reinforced polyamide12 (PA12) matrix composites by selective laser-sintering system as well as the pure PA12. The results indicated that the friction and wear resistance of the composite was improved compared with the PA12 matrix. The compressive strength increased by about 8.5 %, and shored hardness increased by about 6 %. Selective laser sintering of carbon fibers and polyamide12 matrix was studied; the effective bonding between the polymer matrix increased the flexural strength and modulus of the polymer which makes it better than the pure polyamide12 fabricated by the same SLS [46]. Glass beads and PA12 were reinforced through selective laser-sintering at low scan speed and low scan space. The tensile strength was improved by 39.12 MPa, which is in line with past studies that equally showed an improvement in the mechanical properties of PA12 nanocomposite fabricated using SLS. Some other findings proved that another important factor in the reinforcement of polyamide12 is the interfacial characteristics that exist between the matrixes of the polymer [47 - 49].

Figure 3(a-c) shows a laser-sintered polymer with a visible microstructure and layer thicknesses of 0.13 mm and 0.17 mm. This study shows that laser energy decreases as layer thickness increases which leads to inadequate bonding between layers. The decline in the degree of sintering for the single layer was due to the lesser energy absorption of materials caused by layer thickness increment. However, to achieve adequate bonding between the material matrixes, an increase in the layer thickness should lead to a simultaneous increase in the laser energy [49].

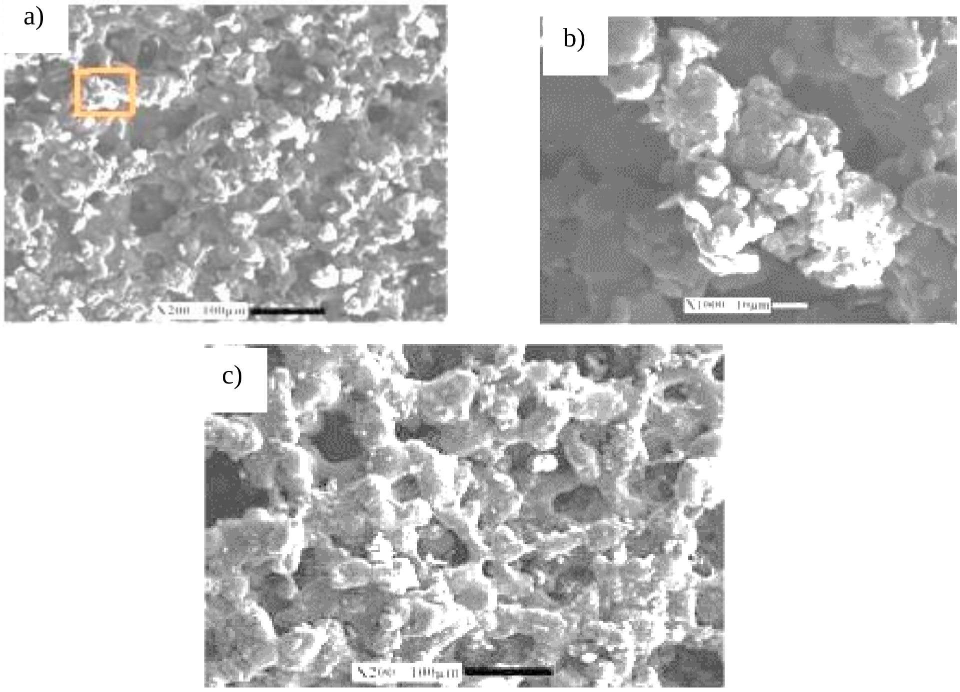


Figure 3(a-c). Polymer microstructure and layer thickness, (adapted with modification from [49]).

SEM images helps in identifying the existence of porous structure in the laser-sintered part. The voids are identified using images captured by SEM. The level of porosity depends on the loading condition. At a low loading condition, a high porosity level of the sample was identified, and at a high loading condition, less porosity was observed. Studies have shown that at elevated temperatures energy is absorbed by the nanoparticles and released to the matrix material. For a good sintering to take place, the operating temperature must be moderately low to avoid melting the sample, the morphology and porosity testing determines the level of sintering in the sintered parts [50].

4. MECHANICAL AND PHYSICAL CHARACTERISTICS

The behavior of nanocomposite materials under loading is of great concern. Several studies were carried out to determine the density, thermal, electrical, fire-retardant tensile strength, toughness, flexural strength, and other desired properties of a fabricated composite. In the study [51], polylactic acid (PLA) and hydroxyapatite (HA) nanocomposites were found to be bioabsorbable materials, as a result, these materials became the most sorted materials when considering tissue engineering applications [52].Hydroxyapatite is used to implant polylactic acid making it an osteoconductive material. The acidity of polylactic acid is neutralized by hydroxyapatite present in the nanocomposite matrix that improves mechanical properties [53, 54]. The interfacial consolidation and adhesion of hydroxyapatite were caused by the polymer implant, and the improvement in the bonding affinity in the matrix was established by the implant [55 - 58]. Yan *et al*. [59] developed a hybrid of calcium phosphate and phosphonate.

The particles of the HA that constitute a hydroxyl group encouraged polymer implant. The tensile strength properties of the polymer were necessary to be improved above 100 MPa.

According to a recent study by Barkhad *et al*. [60], the crystallization pattern of polylactic acid was determined by the fillers present in the matrix. This was observed in the physical, thermal, and mechanical properties of amorphous and semi-crystalline polylactic acid matrices using talc and hydroxyapatite as fillers and with injection molding fabrication process [61]. When talc is used as a filler, the polylactic acid crystalline properties of the polymer are compromised, which invariably affects the tensile strength of the nanocomposite. In conjunction with this, Negi *et al*. [62] revealed that the flexural strength decreases when there is an increase in the laser power from 28 watts to 36 watts, contrarily the flexural strength decreases as the scan speed and scan pace were increased from 2500 mm to 4500 mm and from 0.25 mm to 0.35 mm, respectively. Ali *et al*. [63] examined the physical and mechanical properties of a ceramic and polymer mixture used as a damaged bone substitute. The result showed that an increase in properties like compressive strength, Young's modulus and hardness as displayed in Figure 4, Figure 5 and Figure 6 indicates the effect of varying percentage of reinforcement on compressive strength, Young's modulus and hardness, respectively.

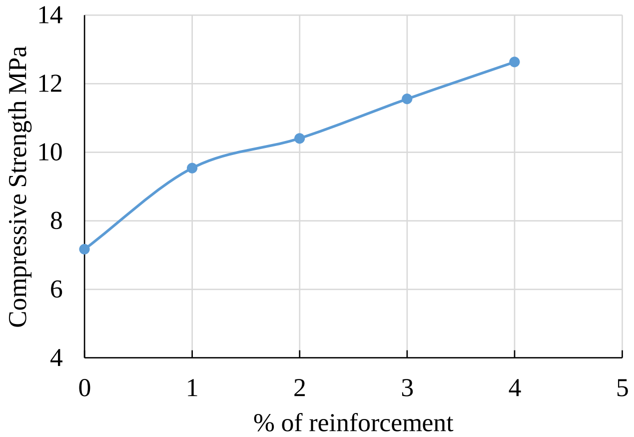


Figure 4. Effect of reinforcement on compressive strength (adopted and revised from ref. [63]).

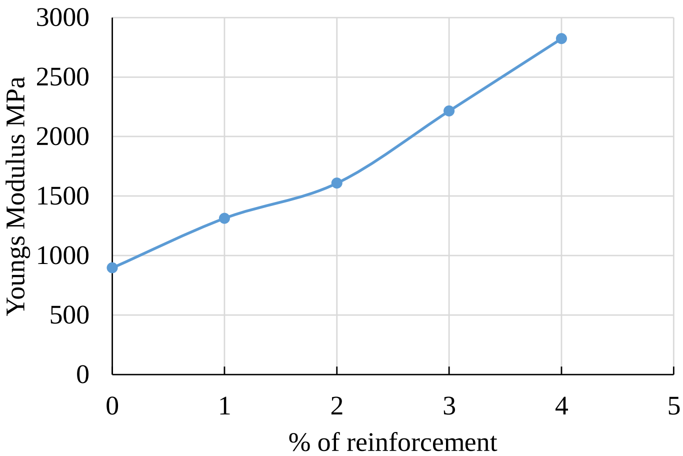


Figure 5. Effect of reinforcement on Young's modulus (adopted and revised from ref. [63]).

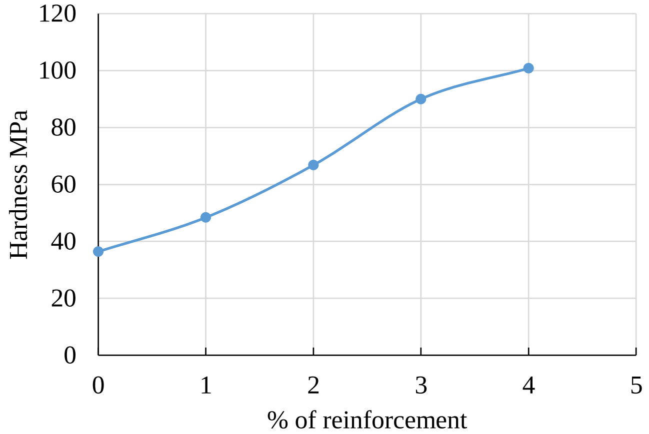


Figure 6. Effect of reinforcement on hardness (adopted and revised from ref. [63]).

4.1. Flexural and fracture toughness

The flexural property represents the bending strength of the materials whereas the fracture toughness represents the strain energy absorbing capacity of the materials [64]. The most efficient method to improve the mechanical and overall characteristics of polymer is by incorporating inorganic particles such as calcium carbonate, calcium sulfate, and silica with other carbon-based fillers. Industrial fillers such as fly ash are used as reinforcing agents whose properties can improve the modulus, impact resistance, and thermal resistance of polymers; other industrial advantages and special properties are low cost, availability, high mechanical strength, and chemical corrosion resistance [65]. Titanium carbide TiC and fly ash are known for their special mechanical characteristics and high thermal stability. Their electrical insulation and better surface area properties are also superior when placed side-by-side with other fillers [66]. Mustafa *et al*. [67] found that the epoxy resin-based nanocomposite sample with 1 wt.% of zirconium dioxide nanoparticles showed the highest Young's and bending moduli, as well as the toughness. Excellent performance of epoxy resin-based nanocomposites with yttrium oxide nanoparticles was achieved by adding 1.5 wt.% of dopant. The improvement in toughness by 23.4 % for ZrO_2 and 19.6 % for Y_2O_3, was observed. Tang *et al*. [68] reported that the impact strength, flexural modulus, and flexural strength were increased by 23 %, 29 %, and 20 %, respectively, when 5 wt.% of nano clay filler was added to the polymer matrix. The authors [69-71] observed that when epoxy was reinforced with aluminum oxide Al_2O_3 in the nanocomposite matrix, the flexural strength, fracture toughness, and flexural modulus were increased by 15 %, 120 %, and 40 %, respectively. The increase in fracture toughness of the matrix was observed as the ductility of the nanocomposite increased, showing the plasticization effect due to the absorption of water after immersing it for one month. Kim *et al*. [72] clearly showed that scan space and scan speed are the most important parameters that have a major impact on the matrix flexural strength in the SLS process, the higher the laser power, the higher the flexural strength (Figure 7). Similar observations are also reported by Negi *et al*. [62].

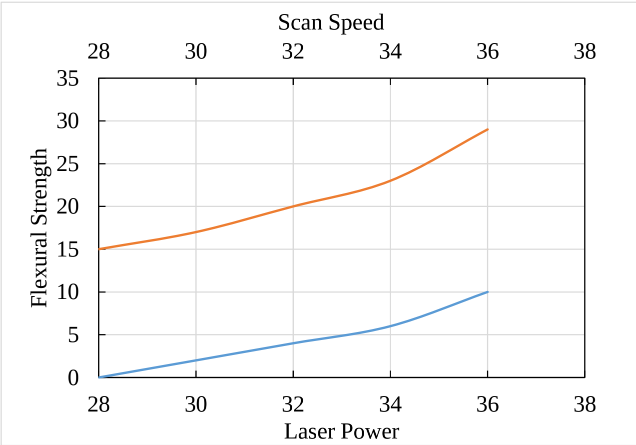


Figure 7. Effect of laser power and scan speed on flexural strength (adopted and revised from ref. [72]).

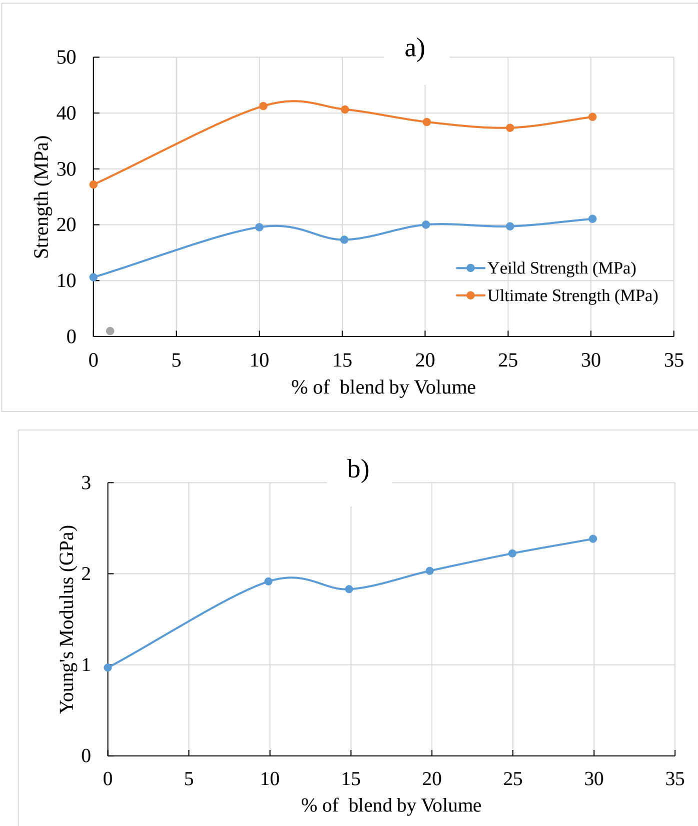


Figure 8(a-b). Mechanical properties of composite polymers with varying % of filler (adopted and revised from ref. [69]).

The mechanical property of a nanocomposite material was investigated by adding different volumes of diatomaceous earth filler to nylon-11. A selective laser-sintering system was used, and the outcome is shown in Figure 8. It is observed from the graph that an increase in the percentage of the filler from 10 % to 30 % leads to an increase in elastic modulus, ultimate strength, and yield strength while the elongation decreases due to the material becoming stiff, less elastic, and more brittle. The ultimate strength increases as the material becomes stiff and the elastic modulus increases as the material elasticity decreases. The result from the study shows that bonding between the matrixes is porous and broke cleanly along the edge during testing which is an indication of poor bonding and the need for adding a coupling agent to the composite for better bonding [73].

Table 1. Summary of mechanical properties.

Ref.	Material	Properties studied	Findings/Limitations/Suggestions
[77]	Jute-epoxy laminated composite	Tensile strength and microhardness	Fiber orientation at 30 degrees showed a substantial increase in tensile strength.
[84]	Aluminum mixed polyamide	Flexural modulus and strength, fracture toughness with orientation angle 0^0, 45^0 and 90^0	The study does not take cognizance to pinpoint and state clearly the exact angle of orientation to achieve the required and acceptable mechanical properties when manufacturing parts to avoid geometrical and mechanical failure.
[85]	Short carbon fiber and nanofiller-reinforced polypropylene hybrid nanocomposites with 15 wt.% total loading of fillers	Ultimate tensile strength (UTS), flexural modulus, flexural strength, and impact toughness	The hybrid of polypropylene PP with a combination of SCF, GNP, and TiO_2 shows a higher improvement in the impact toughness, flexural strength, and modulus when compared with a single matrix of PP/SCF or PP/GNP nanocomposite.
[86]	Polypropylene composite filler content was fixed at 4 vol.% loading	Flexural and tensile strength	The SEM micrographs show a high presence of void caused by poor compatibility among the hybrid fillers in the matrix, which leads to low flexural and tensile strength.
[87]	Coated polyamide 12 (PA12) powder particles with carbon nanotubes (CNTs)	Flexural, impact, and tensile	The influence of CNT on elongation was not taken into consideration; CNT addition increases the nanocomposite impact resistance which leads to an increase in the brittleness of the matrix and a decrease in elongation.
[88]	Fiber-reinforced polymer nanocomposite (FRPN) with silica nanowires (SiO_2 NWs) as nanofillers	Young’s modulus and nano-hardness	The result of the indentation test showed that the young modulus and nano-hardness of FRPN is 10 times higher than bare polymer.
[89]	Al_2O_3-NbC nanocomposites	Flexural strength and microhardness	The hardness of nanocomposites is found to increase due to the presence of niobium carbide.
[90]	Carbon nanotubes (CNT)/polyether sulfone (PES) polymer composites	Tensile strength and bending strength	The fracture surface showed fewer pores and better interfacial bonding between adjacent polymer particles.
[91]	Graphene oxide (GO) filler and poly(vinyl alcohol) (PVA) matrix composite	Young’s moduli and yield stresses	Developed polymer-matrix nanocomposites with significantly improved mechanical performances.
[92]	Porosity ratio, crystallinity, and tensile strength of sintered specimens	Tensile modulus, strain at break, and ultimate tensile	The densification process and energy accumulation effect were beneficial in reducing the porosity ratio of specimens,

		strength	thereby improving their tensile strength in the early period of laser sintering.
[93]	Hydroxyapatite (HA)/polyether ether ketone (PEEK)nanocomposites	Tensile strength, impact strength, and flexural strength	The study revealed that mechanical properties increased and enhanced thermal stability.
[94]	Laser-sintered cellulose/PLA mixture composite	Tensile strength and flexural strength	Improved the surface quality, density, and crystallinity of laser-sintered 10 % CPLA parts and improved mechanical properties.
[95]	Aluminum matrices reinforced with carbon nanotubes (CNTs)	Tensile, vickers microhardness, and nanoindentation	The presence of CNTs has a substantial effect on hardness with reduced Young´s modulus.
[96]	Graphene platelets (GnPs)-coated polyamide (PA) nanocomposite	Young’s modulus, thermal conductivity	The study revealed that Young's modulus increased by 81 %.
[97]	Polystyrene (PS)/ Al_2O_3 nanocomposites	Impact strength and tensile strength	Sintered parts mixed with nano-sized inorganic particles are improved greatly.

4.2. Hardness and tensile strength

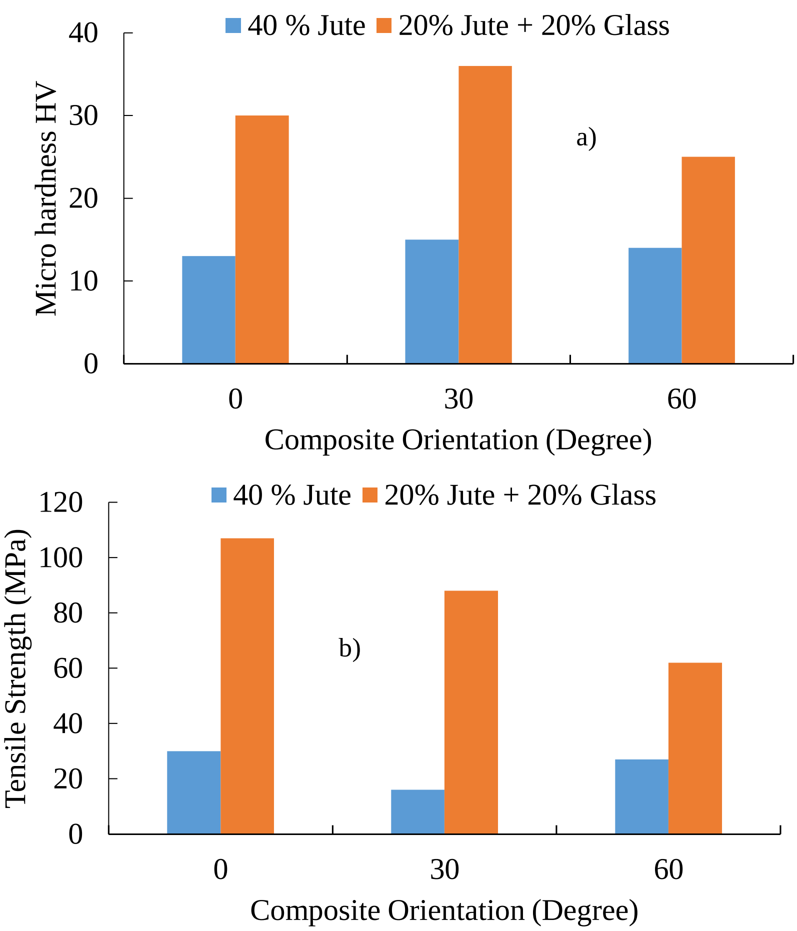


Figure 9. (a) Macrohardness vs. composite orientation (b) Tensile strength vs. composite orientation (adopted and revised from ref. [77]).

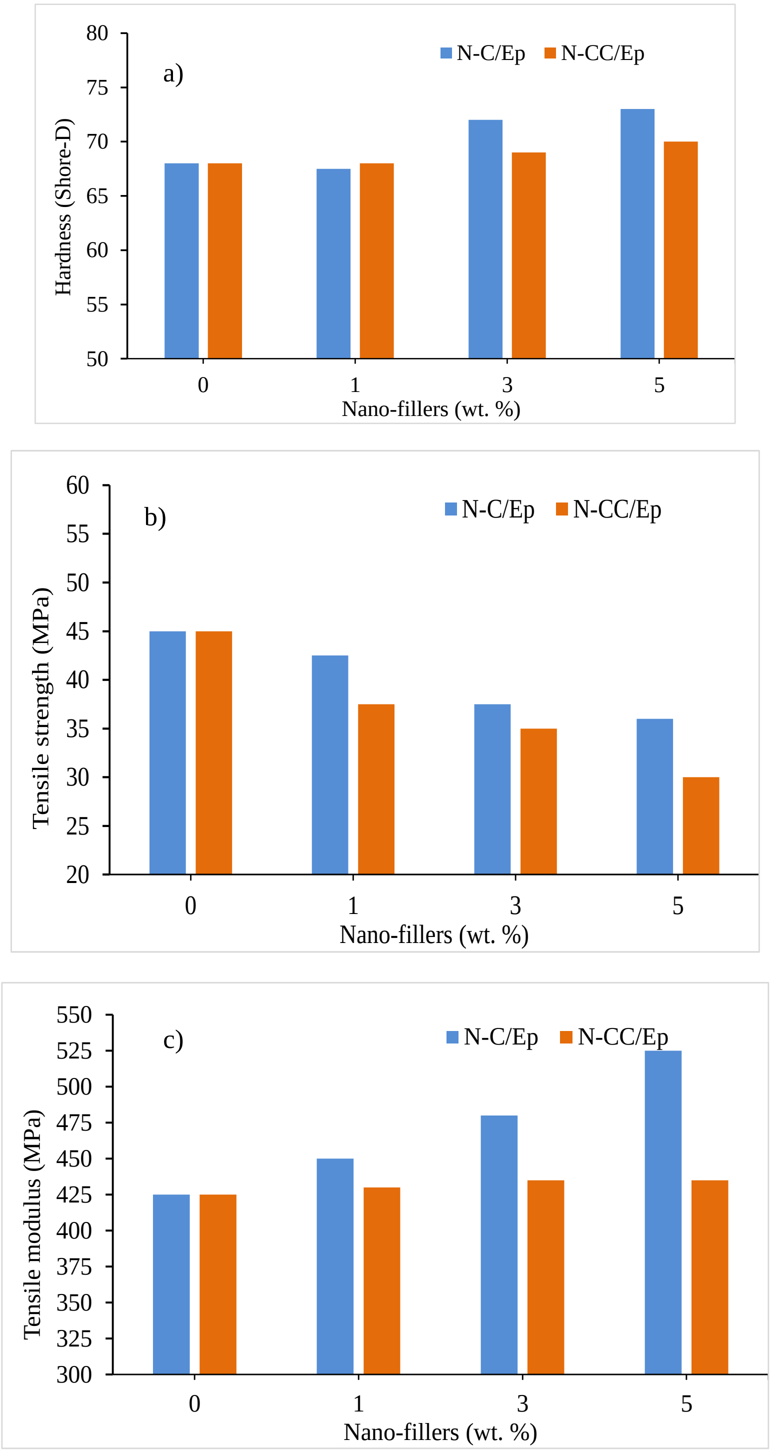


Figure 10(a-c). Effect of nano-filler on (a) Flexural strength (b) Tensile strength and (c) Tensile modulus, (adapted with modification from[83]).

Metal matrix composite (MMC) is the most promising solution for different structural applications in additive manufacturing because of its mechanical properties when compared with unprocessed materials. Gupta *et al*. [76] studied pure magnesium using different ceramics and graphite nanoparticles. Uniformly, 3 vol.% of each nanoparticle with magnesium $Mg+Al_2O_3$ (Mg+ and 3 vol.%), $Mg+ZrO_2$ (Mg+ and 3 vol.% zirconium), Mg+BN(Mg+ and 3 vol.% HBN) and Mg+Gr (Mg+ and 3 vol.% graphite) were used in preparing the nanocomposites. Vickers microhardness (HV) was carried out across all the samples. The addition of nano-size reinforcements leads to an increase in the hardness of the magnesium matrix. Dehury *et al*. [77] investigated jute/glass/epoxy hybrid composites laminate with 40 wt.% fiber and with various fiber orientations. The findings revealed that maximum hardness was obtained with 300 fiber orientation of hybrid composite. Figure 9(a) shows the effect of fiber orientation on microhardness. The maximum tensile strength was observed at 0° fiber orientation as shown in Figure 9(b).

The mechanical properties of magnesium nanocomposite have been studied by Seyda *et al*. [78]. The study reported a maximum tensile strength of 110 MPa and hardness of 374 HV [79]. The study also reported the issue of nanoparticle dispersion in the matrix was not homogenous. This opened the door for further research on homogenous nanoparticle dispersion in the material matrix. Some earlier works [80, 81] have recorded that the distribution of particle size in the material matrix has a direct impact on mechanical, surface quality, and physical characteristics of the part fabricated through selective laser sintering SLS, the material powder fluid-ability depends on the particle size. When the size of the particles is small, it enables the material to have the nanoparticle homogenously distributed within the matrix, thereby producing a part with better mechanical properties. [83]. Figure 10(a) shows the effect of nanofiller on hardness. However, the decrease in tensile strength was observed with increasing percentage weight of the nano-fillers, as can be seen in Figure 10(b). Figure 10(c) shows a good improvement in flexural strength with an increase in nanofillers.

5. FUTURE SCOPE

There are several studies available for the estimation of the mechanical properties of composite materials. These studies mainly include the effect of the increasing percentage of filler on mechanical properties, the effect of fiber, and its orientations as well as reinforcements on mechanical properties. The particle size of the nanofillers determines the bonding strength and dispersion rate in the matrix which affects the mechanical properties. Therefore, the optimum percentage of fillers or blends needs to be investigated for optimum mechanical properties. Predictive models for predicting mechanical properties with varying percentages of fillers need to be developed. Future studies are also needed for the modification of fillers to fit a higher range of application areas, and better methods to achieve a homogenous dispersion and compatibility of fillers in the polymers for improving mechanical, physical, and fire retardant properties.

6. CONCLUSIONS

In this work, nanocomposite materials under loading have been extensively studied, with a focus on properties such as density, thermal conductivity, electrical conductivity, fire-retardancy, tensile strength, toughness, and flexural strength. Polylactic acid (PLA) and hydroxyapatite (HA) nanocomposites have emerged as highly desirable materials for tissue engineering applications due to their bioabsorbable nature. Improvements in mechanical properties have been observed with the addition of various nanoparticles, including zirconium dioxide, yttrium oxide, nano-clay, carbon nanotubes, and graphene oxide, leading to enhancements in tensile strength, bending modulus, and impact strength. However, challenges remain, such as achieving homogeneous dispersion of nanoparticles within the matrix to prevent issues like poor bonding and brittleness. Further research is needed to optimize filler content, distribution, and processing parameters to maximize the mechanical performance of nanocomposites while maintaining other desired properties.

CRediT authorship contribution statement. Uchechukwu Nwangwu: Methodology, Investigation. Osita Obiukwu: Investigation, Formal analysis, supervision. Nitin Ambhore: Formal analysis, Investigation, Supervision.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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