Improving the Mechanical Properties of Laser-Sintered Polyamide 12 Through Incorporation of Carbon Nanotubes

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Well-dispersed nanocomposite powder with spherical morphology and suitable particle size for processing by laser sintering was successfully produced by coating polyamide 12 (PA12) powder particles with carbon nanotubes (CNTs). Flexural, impact, and tensile test specimens produced by laser sintering the PA12–CNT powder showed no distortion and good definition. The density of the PA12–CNT laser-sintered parts was higher than that of neat PA12, which the authors propose is mainly due to higher laser absorption by the CNT particles. Compared to the laser-sintered PA12 parts, PA12–CNT parts showed enhanced flexural, impact, and tensile properties without sacrificing elongation at break. This enhancement may be attributed to the good dispersion of the CNT in the PA12 matrix and denser laser-sintered parts. Considering the low weight percentage of CNT used (0.1 wt%), it would seem that the method used in this work is a cost efficient and effective way to produce polymer nanocomposite powders for laser sintering, while maintaining the optimum powder morphology for the laser sintering process and enhancing the mechanical properties of the laser-sintered part. POLYM. ENG. SCI., 53:1937–1946, 2013. © 2013 Society of Plastics Engineers

INTRODUCTION

Additive manufacturing (AM) is a group of technologies that are used to produce end-use parts directly from computer-aided design data, usually on an additive, layer-by-layer basis. AM, which is an outgrowth of rapid prototyping, aims to offer greater flexibility in respect to product design and manufacture compared to traditional manufacturing routes [1]. One of the main advantages of AM is that very complex parts can be produced without any mold tooling, which shortens the design-manufacturing cycle, therefore reducing the production cost and increasing competitiveness [2–4]. Laser sintering is one of the most established and widely used AM techniques. In this process, an object is created layer-by-layer from heat-fusible powdered materials with heat generated from a scanning laser beam [1].

Polyamides 11 and 12 (PA11/PA12) are by far the most commonly used laser-sintering materials at present, mainly due to their ease of processing and history of use in laser sintering [5]. Some other polymers such as polypropylene, polystyrene, polycarbonate, poly(ether–ether–ketone) and couple of thermoplastic have also been supplied as laser-sintering materials. The current limited choice of materials for laser sintering compared to traditional manufacturing processes, such as injection molding, is partly due to complex thermal phenomena during the laser sintering process, and a lack of understanding of how different polymers respond to this. Furthermore, the polymers that are available for laser sintering cannot meet the needs, such as the mechanical, electrical, or thermal requirements, of all products [6, 7]. To further develop laser-sintering technology, there is a need to research and develop more materials which can meet the various requirements of different applications.

Polymer nanocomposites (PNCs) are particle-filled polymers for which at least one dimension of the dispersed particle is in the nanometer range. PNCs have been shown to improve the base polymer’s properties while remaining processable by conventional processing techniques [8], and this potential is also expected for the laser sintering process. With extremely high surface-to-volume ratio, even a very small amount of nanofiller can have an observable effect on the macroscale properties of the...
composite [9]. To enhance the mechanical, thermal, or electrical properties of current laser-sintering materials, much research in recent years has focused on PNCs. Various reinforcing nanofillers combined with base polymers have been investigated for laser sintering, including carbon nanofibers [10–12], carbon nanotubes (CNTs) [13, 14], carbon black [15, 16], nanoclay [17–19], nanosilica [20, 21], and nano-Al$_2$O$_3$ [22]. Different techniques were used to prepare the PNC powders for laser sintering in these studies.

Mechanical mixing is a common method to prepare PNC powder for laser sintering [10, 13, 15, 16]. However, it is difficult to obtain well-dispersed PNC powder by simple mechanical mixing or milling, and nanofiller agglomerates are normally observed [13, 15]. In the research performed by Athreya et al. [15], PA12/carbon black (4 wt%) nanocomposite powder was prepared by mechanical mixing. After laser sintering, the PA12/carbon black parts showed improved electrical conductivity but decreased flexural modulus compared to neat PA12 parts. Scanning electron microscopy (SEM) showed that the reduction in flexural modulus was due to agglomeration of the carbon black particles in the laser-sintered part. Salmoria et al. [13] produced a PA12–CNT (0.5 wt%) nanocomposite for laser sintering by mechanical mixing, with the parts showing improved tensile strength (10%) compared to neat PA12 parts. However, there was a 9–11% reduction in elongation at break of the PA12–CNT parts compared to the neat PA12, which could be due to the CNT agglomerates acting as defects in the laser-sintered parts. To achieve maximum properties for final parts, the nanofiller should not form aggregates and must be well-dispersed in the polymer matrix [23, 24], otherwise aggregates could act as defects and there will be a weakening effect on the PNCs [25].

Cryogenically fracturing has been used in some work to produce well-dispersed PNC powder for laser sintering [11, 17]. In the research carried out by Goodridge et al. [11], a well-dispersed 3 wt% PA12/carbon nanofiber composite sheet was produced by melt mixing and compression molding. Then, the powder was produced by cryogenically fracturing the composite sheet. The nanoparticles increased the base material’s properties produced by the same cryogenically fracturing method, but not compared to noncryogenically prepared powder. It was observed that the powders produced by this process had irregular powder morphology and wider particle size distribution, which was not suitable for the laser sintering process [5, 26, 27].

Yan et al. [21] used a dissolution–precipitation process to coat nanosilica (3 wt%) with PA12 to prepare a nanosilica/PA12 nanocomposite powder. In their work, modified nanosilica was dispersed uniformly in the PA12 solution. Then, the mixture was gradually cooled, the PA12 crystallized and the nanocomposite powder was formed. The nanosilica was dispersed well in the PA12 matrix; however, the PA12/nanosilica powder prepared by this process also showed irregular particle shape. The composite laser-sintered parts showed increased tensile strength, modulus and impact strength compared to neat PA12 which had been fabricated using the same dissolution–precipitation technique; however, the elongation at break decreased by about 3.65% compared to neat PA12.

In an attempt to produce nanocomposite powders with near-spherical morphology, Wahab et al. [28] prepared a PA6-nanoparticle powder (5 wt%) using a spray drying process, which involved the atomization of a liquid feedstock into a spray of droplets. The PA6 powder and nanoparticles were dissolved separately in organic acid, then the dispersed nanoparticles were added into the PA6 solution, and the mixture solution was spray dried to form spherical powders. Although regular spherical powders were obtained by this approach, it resulted in an unacceptable number of voids in the sintered parts, which reduced part density and strength. The authors proposed that the voids could have been from the trapped gases generated from the residual solvent during the spray drying process.

Based on the previous studies, it is very important to achieve homogeneous and favorable powder morphology, as well as well dispersed nanoparticles when providing PNCs for laser sintering. This paper introduces a novel method to prepare PNC powders for laser sintering. CNT, allotropes of carbon with a cylindrical nanostructure, were used as the nanofiller in this study. Well-dispersed PA12–CNT nanocomposite powders with suitable particle morphology and size for laser sintering were fabricated. The effect of the addition of CNTs on the laser sintering processing and mechanical properties of laser-sintered PA12 parts was examined.

**EXPERIMENTAL**

**Materials**

PA12 powder supplied by EOS GmbH (Germany) trade-named “PA2200”, was chosen as the polymer matrix material due to its established use in the laser sintering process. This PA12 powder has near spherical morphology with an average particle size of 57.5 μm (see Particle size distribution section). Multiwalled CNTs, having an average diameter of 10 nm and length of 1.5 μm, were supplied by NanoAmor Materials.

**Production of the PA12–CNT Nanocomposites Powder**

A patented method developed in the Department of Materials at Loughborough University, UK, was used to fabricate PA12–CNT nanocomposite powders [29]. This method allowed CNT particles to be coated on the surface of the individual polymer powder particles without any change to the morphology of the particle (see Characterization of PA12 and PA12-CNT powders section). Compared to other work [10–22], only a small amount of filler (0.1 wt% CNT) was used to prepare the nanocomposite powder in this study.
Laser Sintering

Both PA12 and PA12–CNT nanocomposite materials were laser sintered on an EOS P100 Formiga system. Processing parameters, namely powder bed temperature and laser power, where optimized for each material to achieve good process ability and mechanical properties. The suitable powder bed temperatures for PA12 and PA12–CNT were determined as 171°C and 172°C, respectively. Different laser powers were investigated, with the laser scan speed and laser scan spacing being maintained at 2500 mm/s and 0.25 mm, respectively. Attempts to build parts using relatively low laser powers, 13 W and 15 W, resulted in curling of the edges of the part during the initial layers, which lead to failure of the build as the recoating blade could not pass over the raised section. When the laser power was increased to 17 W, there was considerably less curl and parts were built successfully. Then, the laser power was increased in 2 W increments up to 25 W, which is the highest laser power that the EOS P100 laser sintering machine can achieve.

Flexural test specimens were built according to ASTM D790, tensile test specimens were produced in accordance with ASTM D638-99, and impact test pieces were built according to ISO 180-2000. All test specimens were oriented with the longest dimension aligned perpendicular to the direction of the movement of the recoating blade, as shown in Fig. 1.

Characterization and Mechanical Testing

The particle size distributions of the PA12 and PA12–CNT powders were analyzed using a Malvern Mastersizer 2000 particle size analyzer. The morphologies of the PA12 and PA12–CNT powders were imaged by SEM (LEO 440 SEM, Leo Electron Microscopy). The powders were coated with gold before SEM characterization to prevent charging. The flexural properties of laser-sintered parts were measured on a Zwick 103 (Zwick/Roell Corporation) testing machine using a 3-point bending test method at a test speed of 5 mm/min (five samples for each experiment). Tensile tests were carried out using a Zwick 103 testing machine with a 10 kN load cell and a cross-head speed of 5 mm/min (five samples for each experiment). Impact tests were carried out on a RAY-RAN Universal Pendulum Impact System, with a hammer weight of 1.796 kg and impact velocity 3.5 m/s (ten samples for each experiment). The melt flow index (MFI) of PA12 and PA12–CNT powders was measured using a Tinius Olsen MP600 Extrusion Plastometer at 220°C with a 2.16 kg weight. The thermal behavior of both PA12 and PA12–CNT powder was studied by differential scanning calorimetry (DSC) using a SHIMADZU DSC-60. Samples weighing 5 mg were heated and cooled at a rate of 20°C/min. Thermal conductivity of the PA12 and PA12–CNT powders were measured at 150°C by a thermal conductivity apparatus P5697 (Cussons Technologies, UK). The sample specimen was designed as a hollow cylinder (height = 38 mm, diameter = 20 mm, and wall thickness = 0.5 mm) and produced by laser sintering, in which the testing powders were stored.

RESULTS

Characterization of PA12 and PA12–CNT Powders

Particle Size Distribution. The particle size distributions of PA12 and PA12–CNT are shown in Fig. 2. The two curves are identical, indicating that there was no change in the powder size distribution of PA12–CNT compared to PA12; both had an average particle size of 57.5 µm, which lies in the optimum particle size range for laser sintering [26]. This evidence suggests that the method used in this work to prepare the PA12–CNT
nanocomposite powders did not alter the powder size or size distribution of the original PA12 powder.

**Powder Morphology.** SEM micrographs of the PA12 and PA12–CNT powders are shown in Fig. 3. The commercial PA12 powder had a near-spherical morphology (Fig. 3a). Figure 3b shows the micrograph of the PA12–CNT powder, from which it can be seen that the powder maintained the same near-spherical morphology as the PA12 powder. Combined with the results shown in Fig. 2, it is reasonable to suggest that the method used to prepare the PA12–CNT nanocomposites did not change the size, size distribution, or morphology of the original PA12 powder.

**Dispersion of CNTs.** High magnification SEM micrographs of a PA12 and PA12–CNT powder particle are shown in Fig. 4. In Fig. 4b, single CNTs (visible as white strands) can be easily seen and no agglomerates were detected, which indicates that the CNTs were dispersed uniformly on the surface of the PA12 particle. Nanofillers tend to form agglomerates very easily, which can weaken the mechanical properties of the final nanocomposites part, and thus achieving uniform dispersion of the nanofiller is crucial when producing PNCs.

**Thermal Analysis.** DSC curves for the PA12 and PA12–CNT composite powders are shown in Fig. 5.
There was only a small difference in melting point between the PA12 (183.4°C) and PA12–CNT (184.0°C) powders. However, the crystallization temperature of the PA12–CNT nanocomposite powder was 5°C higher than PA12, which suggests that the CNTs acted as a nucleating agent and had a nucleation effect on the PA12, similar to that observed by Yan et al. [30]. The results of the thermal conductivity \( k \) of the PA12 and PA12–CNT powders are shown in Table 1. Compared to PA12, PA12–CNT powders showed 18.0% higher thermal conductivity, which could be explained by the remarkable higher thermal conductivity of CNT.

**Melt Flow Index.** The MFI was measured for the PA12 and PA12–CNT nanocomposite powders to assess their rheological behavior. Compared to PA12, the viscosity of the PA12–CNT powder was higher, suggesting that the CNTs decreased the melt flow rate for PA12 (Table 2). This may be due to the interfacial force between the CNTs and PA12 hindering the movement of PA12 chains, which could cause increased resistance when a load is applied.

**Characterization of Laser-Sintered Parts**

**Laser Sintering of Mechanical Test Specimens.** The laser-sintering process of PA12 and PA12–CNT are shown in Fig. 6. It can be seen that the mechanical test specimens for both PA12 and PA12–CNT were built successfully with good definition. Apart from the color difference, there were no obvious differences between the PA12 and PA12–CNT laser-sintered parts visible by eye.

**Flexural Properties.** The effect of laser power on flexural modulus and strength for both PA12 and PA12–CNT laser-sintered parts is illustrated in Fig. 7. At all laser powers investigated, an increase in modulus and strength was observed for the nanocomposite compared to the base polymer. PA12–CNT laser-sintered parts exhibited an improvement of 13.0% in flexural modulus and 10.9% in flexural strength compared to PA12 laser-sintered parts according to the highest values.

**Impact Properties.** Figure 8 records the impact strength of PA12 and PA12–CNT laser-sintered parts. Compared to PA12, which had a maximum impact strength of 49.8 kJ/m² when 25W was used as the laser power, the maximum value for PA12–CNT increased by 123.9% to 111.6 kJ/m². This significant increase demonstrated that more energy was absorbed by PA12–CNT compared to PA12, and adding CNT into PA12 can improve the toughness of laser-sintered parts.

**Tensile Properties.** The Young’s modulus and ultimate tensile strength (UTS) of PA12 and PA12–CNT laser-sintered parts are recorded in Fig. 9. When comparing the highest values for both materials, the Young’s modulus of PA12–CNT parts increased 54.0% and UTS increased 6.2%. Combined with the results in Flexural properties and Impact properties sections, it appears that CNTs have a significant reinforcement effect on PA12 laser-sintered parts.

The elongation at break of the PA12 and PA12–CNT laser-sintered parts can be seen in Fig. 10. It has been reported in the literature that elongation at break can decrease when filler is added into laser-sintering polymer powder [13, 21]. Poor dispersion of the filler may cause filler agglomerates, which can become defects when a
force is applied. In this research, it can be seen that compared to neat PA12, elongation at break of the PA12–CNT laser-sintered parts did not decrease. This may be attributed to the good dispersion and small amount of CNTs in the PA12 matrix. In Figs. 7–10, the error bars for each data point were plotted for both PA12 and PA12–CNT nanocomposites. No obvious difference of the error bars was noticed between PA12 and PA12–CNT, which suggests that CNT do not have influence on the repeatability of the laser-sintered parts.

**Density.** The density of the PA12 and PA12–CNT laser-sintered parts is shown in Fig. 11. It can be seen that the density of PA12–CNT laser-sintered parts was higher than that of neat PA12 under each laser power. Compared to the PA12 laser-sintered parts with an average density of 959.59 kg/m³, the average density of PA12–CNT parts increased 4.1% to 999.32 kg/m³. Density has been found to have a major influence over the mechanical properties (fracture, strength, ductility, and modulus) of laser-sintered parts, with higher density parts having better mechanical properties [1], which corresponds to the results recorded in the previous Flexural properties and Impact properties, and Tensile properties sections.

DSC analysis of the PA12 and PA12–CNT laser-sintered parts, shown in Fig. 12, may explain the reason for the increase in density of the PA12–CNT parts. The PA12 parts showed two melting peaks whereas the PA12–CNT parts only showed one. Double melting peaks were previously observed by Zarringhalam et al. [31], who suggested the smaller peak was the unmolten PA12 powder remaining in the laser-sintered parts. In this study, the PA12–CNT sintered parts did not show this smaller peak that correlates to unmelted powder, which indicates that the CNTs increased the laser absorption and melting of the PA12 powder, resulting in denser laser-sintered parts with enhanced mechanical properties.

**Fracture Surface.** The difference in density was further observed in SEM micrographs of the fracture surfaces of the PA12 and PA12–CNT laser-sintered parts, shown in Fig. 13. Voids were clearly visible in the neat PA12 sintered parts; however no obvious defects were detected in the PA12–CNT parts. Figure 14 shows a higher magnification SEM image of the fracture surface of a laser-sintered PA12–CNT part. Only a few CNTs can be observed in the center of Fig. 14; it is thought that most of the CNTs were encased within the PA12 matrix and therefore cannot be detected.

**DISCUSSION**

It is well-known that achieving good dispersion of nanoparticles within the polymer matrix is crucial for the successful preparation of PNCs [11–13, 15]. For laser sintering, it has also been shown that maintaining the correct powder morphology can be just as crucial [5, 11, 27]. In this study, a novel method was used to prepare PA12–CNT nanocomposite powder by coating the CNTs onto the surface of PA12 powder particles. This allowed the optimized size and near-spherical morphology of the commercial laser-sintering PA12 powder to be retained.

Powder morphology, size, and size distribution have been found to play a key role in both the ability to process powders by laser sintering (e.g., ease of deposition
and spreading over the powder bed) and the quality of laser-sintered parts (e.g., surface roughness, density/porosity) [5, 26]. Powder particles with too small diameter exhibit poor bulk flow at high temperatures, presumably due to the higher interparticle friction found in extremely fine powders. On the other hand, particles that are too large have a negative influence on surface finish and part density. The optimum particle size in terms of processing ability is generally around 45–90 μm for laser sintering of macrosized parts [26]. Besides particle size, the ideal powder for laser sintering is normally near-spherical with a regular morphology. Powders trend to arrange themselves more efficiently with spherical morphology, which increases the density of parts, whereas powders with irregular morphology are not able to achieve this form of efficient arrangement resulting in low density parts. Moreover, spherical morphology can facilitate powder flow, by ensuring that a flat and thin powder layer is deposited during the sintering process [5]. The PA12 powder used in this study was PA2200<sup>1</sup>, produced by EOS, which had near spherical particles and suitable particle size (Figs. 2 and 3a) for laser sintering. After the process used to coat the CNTs onto the surface of the PA12 powder, the spherical morphology and particle size distribution of PA12–CNT composite powder remained the same as the as-received neat PA12 powder (Figs. 2 and 3). Both PA12–CNT composite and neat PA12 showed a smooth, uniform powder bed from which laser-sintered parts with a fine surface finished were produced (Fig. 6).

In addition to powder size and morphology, to achieve maximum properties for laser-sintered parts the nanofiller should be well-dispersed in the polymer matrix, otherwise they may have a weakening effect on some properties [13, 15, 16]. In the current work, well-dispersed CNTs in the nanoscale were coated uniformly on the surface of PA12 powder (Fig. 4b). MFI tests (Table 2) showed that the viscosity of the PA12–CNT composite powder was higher than the neat PA12, which may indicate the interfacial interaction between the CNTs and PA12. Furthermore, the significantly enhanced mechanical properties of the PA12–CNT laser-sintered parts (Figs. 7–10) also indicate that good dispersion and good interfacial interaction of the CNTs in the PA12 matrix was achieved.

According to the rule of mixtures for discontinuous and randomly oriented fiber composites [32]:

\[ E_c = KE_f V_f + E_m V_m \]

where \( E_c \), \( E_f \), and \( E_m \) are the modulus for composites, fiber (here nanotube: 0.95 TPa [33]), and matrix (here
PA12: 1.5 GPa), \( V_f \) and \( V_m \) are the volume percentage for fiber and matrix, and \( K \) is a fiber efficiency parameter (here assume \( K = 0.6 \) [32]), there should be a 2.0% increase in modulus which is less than the 13.0% increased observed (flexural modulus for instance). Therefore, the most contribution for the observed increase in mechanical properties is related to the increased density of the PA12–CNT composite parts (Fig. 11). The density of CNT used in this study is 2100 kg/m³, and addition of CNT’s to PA12 would increase density of material by 0.1%. Therefore, 4% density increase for PA12–CNT, which also would suggest 4% of porosity remove, was due to the improved sintering efficiency by presenting the CNTs during the laser-sintering process. Thermal analysis (Fig. 12) and SEM of the fracture surface (Fig. 13a) indicated the presence of unmelted powder and voids remaining in the neat PA12 sintered parts, which were not observed in the PA12–CNT parts (Fig. 13b).

Laser sintering is a thermal heating process, and thermal conductivity is a very important parameter to examine the performance of the materials during sintering process. It was reported that the thermal conductivity \( k \) of CNT is as high as over 3000 W/mK [34, 35]; this value is remarkably higher than that of PA12 powder which is about 0.1 W/(mK) [36]. It appears that by adding the CNTs into the PA12 powder, the thermal conductivity increased 18.0% (Table 1). Increased powder thermal conductivity can improve the heat conduction during the laser-sintering process, resulting more efficiently laser heat absorption. Increased heat conduction and absorption could enhance the fusion and flow of melted PA12, resulting in denser and stronger parts.

When comparing nanofillers with conventional fillers, one of the most important differences is the surface-to-volume ratio. Nanofillers have an exceptionally high surface-to-volume ratio and the area at the interface between the matrix and reinforcement phase is much greater than conventional composite materials. This large reinforcement surface area means that a relatively small amount of nanoscale reinforcement can have an observable effect on the macroscale properties of the composite [9]. However, this advantage has not previously been fully observed when processing PNCs by laser sintering. Previous researchers have either found an increase in Young’s modulus and UTS, but a decrease in other properties, such as elongation at break [19, 30, 37] or even a reduction in all properties [15]. Some researchers who have observed an increase in properties have reported that...
increase against a control PA12 with lower mechanical properties normally achievable by laser-sintered PA12 [37]. Goodridge et al. [11] have previously highlighted this ability to increase mechanical properties through incorporation of nanoparticles, but reduce properties from the commercial standard as a result of the method used to produce the powders. Yan et al. [12] prepared PA12/carbon fiber composite by dissolution–precipitation method. The laser-sintered composite parts exhibited significant enhancement in flexural strength and modulus only after a high volume of carbon fiber, from 30 wt% to 50 wt%, was used. No other mechanical properties, including elongation at break, were reported. In the present work, the weight percentage of CNT used to prepare the PA12–CNT nanocomposite was small. Just 0.1 wt% CNT saw a significant improvement in all mechanical properties tested in Flexural properties and Impact properties, and Tensile properties sections. With such a small amount of CNTs, beside good dispersion and interfacial bonding of the CNT in the PA12 matrix, the increased part density, which was due to increased heat transfer, was believed to be the main reason for the evident mechanical improvement. As the cost of materials has a direct influence on the costs of laser-sintered parts, the current method of coating the PA12 powder surface with small weight percentage of CNTs provides a more cost efficient and effective way to produce PNC powder for laser sintering.

Another noticeable result is the elongation at break of the PA12–CNT composite parts compared to neat PA12 parts (Fig. 10). It has been previously reported that when applying nanofiller to make polymer composite parts via laser sintering, an obvious decrease in elongation at break has been observed for the nanocomposite parts compared to the neat polymer parts, even though other mechanical properties, such as Young’s modulus, UTS, flexural strength, flexural modulus, or impact strength, were improved [13, 14, 18, 19, 21, 30, 37]. One reason for the decrease in elongation at break could be the poor dispersion of filler in the polymer matrix, where filler agglomerates act as defects when a force is loaded [18]. Even when the filler is well dispersed, the large amount of filler existing in the matrix could become a force defect [14]. In this work, the elongation at break of PA12–CNT composites parts remained the same as that of neat PA12 parts due to good CNT dispersion and the small amount of CNT existing in the polymer matrix.

**CONCLUSIONS**

The study was performed to investigate the methods for producing PA12–CNT nanocomposites for laser sintering, and the following conclusions can be drawn from this work:

- Well-dispersed PA12–CNT nanocomposite powder with spherical morphology was successfully produced by coating the PA12 powders with CNTs. The particle size, size distribution, and morphology of the PA12 powder did not change during the process of producing the PA12–CNT nanocomposite powder.
- The crystallization temperature of the PA12–CNT powder was higher than that of PA12, which suggests that the CNTs acted as nucleating agents on the PA12. MFI showed that the viscosity of the PA12–CNT powder was higher than PA12, which may be due to the interfacial force between the CNTs and PA12 hindering the movement of PA12 chains.
- Flexural, impact and tensile tests specimens for both PA12 and PA12–CNT were laser sintered with good definition and no distortion. Results showed that compared to the best PA12 laser-sintered parts, PA12–CNT laser-sintered parts had 13.0% greater flexural modulus, 10.9% greater flexural strength, 123.9% increased impact strength, 54.0% greater Young’s modulus and 6.2% higher UTS without sacrificing elongation. This enhancement may be attributed mostly to the good dispersion of the CNT in the PA12 matrix and denser laser-sintered parts.
- The density of the PA12–CNT laser-sintered parts was 4.1% higher than that of PA12, which might be due to the increased percentage of laser absorption and melting with CNT nanoparticles.
- Considering the low weight percentage of CNT (0.1 wt%) used, it would seem that the method used in this work is a more effective way to coat CNT on the PA12 powder, while maintaining the optimum powder morphology for the laser-sintering process and enhancing the mechanical properties of the laser-sintered parts.

This study has identified a feasible route to prepare PA12–CNT nanocomposite powders with small amount of CNT, which result in improved mechanical properties of laser-sintered parts. Future work should include the investigation of the influence of CNT on the thermal transfer progress between powders during laser sintering, and the simulation of mechanical properties of laser-sintered PA12–CNT nanocomposite parts.

**REFERENCES**


