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Tribological and mechanical properties of MoS_2 enhanced polyamide 12 for selective laser sintering

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ABSTRACT

The solid lubricant MoS_2 was used as the reinforcement filler for the Polyamide12 material for the additive manufacturing process – selective laser sintering. The tribological and mechanical properties of the laser sintered PA12/MoS_2 and PA12 were investigated by the linear reciprocating ball-on-flat wear and impact tests. Results show that by incorporating the MoS_2 filler into the PA12 matrix, the impact properties was improved. The coefficient of friction and wear rate of the laser sintered PA12/MoS_2 were reduced significantly. The worn surface formed in the wear test was shallow and smoother for the PA12/MoS_2, where only mild wear occurred. The XPS testing suggested the involvement of the mechanical-chemical reaction, which resulted the decomposing of the MoS_2 and the enhancement of the wear properties of the PA12/MoS_2.

1. Introduction

Additive Manufacturing, also named as 3D printing, is a form of manufacturing process in which the physical components can be built layer by layer directly from polymer, metal or ceramic materials (Chua and Leong, 2017). Unlike the subtractive process such as computerized numerical control (CNC) machining which removes material, Additive Manufacturing is a process of adding materials, which puts forward the main advantages of design freedom, reduced wastage and customization. Selective laser sintering (SLS), is a powder based AM process, which uses laser as a heat source to melt/sinter polymeric powder particles only over specific areas into solid components (Chua and Leong, 2017; Hopkinson et al., 2006; Yuan et al., 2016). The no-support-structure advantage gives selective laser sintering even more design and manufacturing freedom compare to other AM techniques, and makes it one of the most widely used AM technology nowadays.

Polymer powder particles are the main materials used in the selective laser sintering process (Stichel et al., 2018), and Polyamide (Nylon) and its composite are the most common ones (Goodridge et al., 2012; Shen et al., 2018). Salmoria et al. (2017) added multi-walled carbon nanotubes into a polyamide 12 matrix to make graded composition material. It was found that the graded composition of the CNT in the PA12 matrix led to the mechanical and electrical properties variations. Yuan et al (Yuan et al., 2016) proposed a dual experimental-theoretical method to examine the processability of polymer nanocomposite for SLS. The thermal conductivity, melt viscosity, phase transition and temperature-dependent density and heat capacity of the PA12/CNT nanocomposite powders were examined. The microstructures of sintered composites revealed that the CNTs nanofillers remained at the powder boundaries and formed network architectures, which resulted the significant enhancements in tensile strength, elongation at break and toughness.

It is well known that Polyamide is an important engineering materials and could be used in friction and wear applications (Bai et al., 2015b; Wang et al., 2003). However, it normally has high coefficient of friction under dry condition against other materials. Bai et al (Bai et al., 2015b) evaluated surface orientation effects on the tribological properties of the laser sintered PA12 components. Anisotropic tribological properties in the different surface orientations were observed and analysed. In order to further expand the applications of the laser sintered Polyamide (PA) components in the wearing domain, decreasing the coefficient of friction and improving the anti-wear property is very important (You et al., 2014).

Solid lubricants are more commonly used for polymeric materials (Li et al., 2013; Sun et al., 2008), as the liquid lubricant may cause swelling and harmed tribological properties for polymers (Brostow et al., 2010). It has been reported by various researchers that by incorporating inorganic fillers or fibres, the tribological properties of the polyamide can be improved (Ren et al., 2013; Sun et al., 2008; You et al., 2014). MoS_2 is one of the common solid lubricant fillers used to

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enhance the friction and wear behaviour of polyamide in the traditional manufacturing processes. Wang et al (Wang et al., 2003) examined the effect of MoS_2 on the tribological properties of PA1010/Carbon fibre composite. It was found that the MoS_2 can decrease the coefficient of friction of PA1010 successfully, however the wear rate was reduced for the MoS_2 filled PA1010. In the present work, the MoS_2 filled PA12 composite was prepared and process by selective laser sintering. The SLS processing parameters were optimised to achieve good processability for the new developed PA12/MoS2 composite. The effect of the MoS_2 on mechanical and tribological properties of the laser sintered polyamide was evaluated systematically.

2. Experimental

2.1. Materials

Polyamide 12 (PA12), which is the most widely used material for SLS, was chosen as the processing material in this work. The near spherical PA12 powders (PA2200), purchased from EOS GmbH Germany, has an average particle size around 59 μm, which is in the suitable powder size range for the SLS process (Goodridge et al., 2012). The Molybdenum Disulfide (MoS_2) powder was supplied by Chengdu 857 New Materials Co., Ltd China. The average size of the MoS_2 was 1.5 μm, which was suitable for coating the 59 μm size PA12 powders. The MoS_2 particles were coated uniformly onto the surface of PA12 powders by blending them in a rotary tumbler mixer at 60 rpm for 24 h. 1 wt % of MoS_2 filler was applied in the composite to make sure that the PA12 powder were fully coated by the MoS_2 fillers, and also to avoid agglomerates formed from exceeding MoS_2 loading which could weaken the properties of the laser sintered components.

2.2. Specimens preparation

The MoS_2 filled PA12 composite and pure PA12 were processed on an EOS P395 (EOS GmbH, Germany) selective laser sintering system. Processing parameters, namely powder bed temperature and laser power, were optimised to achieve good process ability and mechanical properties. For instance, the powder bed temperature was set as high as possible to the powder's melting point to prevent curling during the SLS process. The tribological test block specimens were fabricated with a dimension of 35 × 15 x 10 mm.

2.3. Characterisation

To characterise the powder morphology, field-emission scanning electron microscope (FESEM) (JSM-7600 F, JEOL Ltd., Japan) was used in this work. With particle size around 58 μm, the PA12 powder particle has near spherical morphology, which is advantageous for the SLS process. Linear reciprocating ball-on-flat wear tests (Multi-functional Tribometer, CETR-UMT, US) were employed to evaluate the tribological properties of the material in normal lab environment at room temperature. The upper pin used was a 304 stainless ball (Grade 200) with a diameter of 9.525 mm. The 304 stainless steel balls are an austenitic, unhardened stainless steel with about 18.0% chromium. All tests were performed under the indoor laboratory conditions (20–25 °C, 50 – 6-% humidity). The applied normal force on the specimen used was 35.0 N, and the test duration ranged from 0 min to 45 min with a stroke length of 10 mm at a velocity of 0.33 m/s. Three tests were carried out for both laser sintered PA12/MoS_2 and PA12 specimens and the mean value was calculated.

The wear volume of the worn surface is calculated as (Sharma et al., 2013)

$$V = L[\frac{\pi}{180} r^2 \sin^{-1}\left(\frac{w}{2r}\right) - \frac{w}{2}\left(r^2 - \frac{w^2}{4}\right)^{1/2}]$$

where V is the wear volume in mm^3, w is the width of the wear scar in mm, L is the stroke length 10 mm, r is the radius of the pin in mm.

The wear rate is defined as:

$$k = \frac{V}{N\,x\,D}$$

where k is the wear rate in mm/Nm, V is the wear volume in mm^3, N is the applied normal force in N, D is the sliding length in mm.

Impact test specimens (63 × 12 × 6 mm3) of both PA12 and PA12/MoS_2 were built to establish the impact strength according to ASTM D256, and tested on a Universal Pendulum Impact System (Ray-Ran, UK). The optical microscopy (Olympus DP72, MA, USA) was employed to investigate the microstructures of the laser sintered PA12/MoS_2 composites, which were properly polished to achieve smooth surfaces. 3D optical non-contact metrology system (Infinite focus, Alicona, Austria) was used to examine the worn surface of the PA12 and PA12-MoS_2 specimens. The element chemical statues of the transfer film was analysed by X-RAY photoelectron spectroscopy (XPS, PHI, US).

3. Results and discussion

3.1. Selective laser sintering

Both neat PA12 and PA12/MoS_2 powder materials were processed by selective laser sintering to fabricate testing specimens. Fig. 1a shows the SEM images of the PA12/MoS_2 composite powder particles, it can be seen that the morphology of the PA12/MoS_2 particle was spherical, which can facilitate powder flow, and ensure that an even and thin powder layer is deposited during the selective laser sintering process. Fig. 1b shows that the MoS_2 fillers was well dispersed in the PA12 polymer matrix without agglomeration. It is well-known that achieving good dispersion of the fillers within the polymer matrix is crucial for the successful preparation and properties enhancement of the polymeric composite materials.

Fig. 2 illustrates the selective laser sintering process, in which the laser beam is applied on the new deposited top powder layer to sinter/fuse the powder particles into pre-defined geometry. After each laser

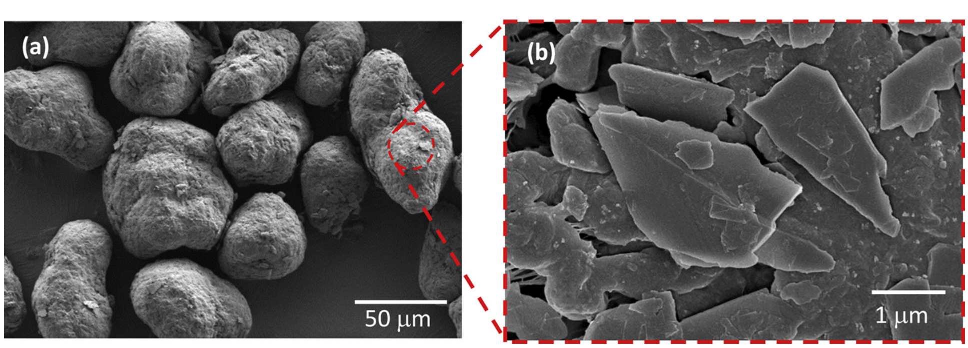

Fig. 1. SEM image of MoS_2 powders and MoS_2 dispersed in the polymer matrix.