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Procedia CIRP 6 (2013) 510 – 514

www.elsevier.com/locate/procedia

The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)

Study on selective laser sintering of eucalyptus/PES blend and investment casting technology

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Abstract

The paper studies the Selective Laser Sintering (SLS) of Eucalyptus/PES blend and the Investment Casting (IC) technology of the forming part. This blend is suitable for being the raw material of SLS, because not only it has low cost, but also it can be produced by SLS to form the parts with high molding precision and mechanical strength after post processing; also the prototype can be used as the investment pattern.

Combining the Eucalyptus/PES blend (which is a kind of Wood Plastic Composite, WPC), SLS with IC can reduce the production cost, also shorten the product development and manufacture cycle. Meanwhile it realizes the application of low-cost WPC in precision casting production. Mould making in investment casting is an extremely important procedure, from analyzing and calculating the physical and chemical characters of the prototypes during melting. It is known that WPC parts can be burnt off by the process of low-temperature dewaxing and high-temperature roasting before investment casting. After blowing the ash off by high-pressure air, the precision of the cavity is similar to one using a wax pattern. So for single and batch production, the WPC can be used as the investment pattern of IC technology instead of wax or resin. This paper studies the investment casting technology which is suitable for patterns produced by Selective Laser Sintering of Eucalyptus/PES blend.

Selection and/or peer-review under responsibility of Professor Bert Lauwers

Keywords: Selective laser sintering; Investment casting technoloty; Eucalyptus/PES blend; Post processing; Material analysis

1. Introduction

As one of the Additive Manufacturing (AM) technologies, Selective Laser Sintering (SLS) (Deckard, 1986)[1] is widely used because of its advantages such as high processing flexibility, wide scale of material selection and processing almost any shape of the parts. Currently, the materials being used in this technology include nylons, polymers, plastics, metals, etc. The formed parts have dimensional accuracy and properties [2]. But the high cost of the materials is a main factor restricting the development of SLS [3]. Previous research of this project has developed a kind of Wood Plastic Composite (WPC) with low cost, which is about $ 4.8/kilogram, and high forming accuracy that can be used in SLS. In addition, the forming parts after post processing can reach the required strength requirement. One emphasis of this project is to determine how to use the technology in industrial fields to increase the value of the research.

Investment Casting (IC), also called lost wax casting, belonging to Precision Casting Technology (PCT), is a casting method that can obtain the casting with high forming accuracy, good surface quality and complex shape when compared with the original sand casting [4]. Traditional investment casting mostly uses profiling manufacture by corresponding metal moulds to make wax moulds on demand, which raises the processing cost and cycle time. This makes PCT unfit for a fast changing market and single and small batch production. Therefore, combining investment casting, SLS technology with WPC together, can promote the development of each technology better.

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doi:10.1016/j.procir.2013.03.039

This research project selected low cost Eucalyptus/PES blend (which is a kind of WPC) as the raw material of SLS. Accurate prototype parts were quickly obtained by utilizing investment pattern of IC technology with SLS technology according to the 3D model to obtain final metal casting. Thus, it can not only reduce the production cost and greatly shorten the cycle of new products to market, but also can make high complex shaped parts. At the same time the method also provides an example of the industrial field application of Selective Laser Sintering parts with WPC.

2. Selective Laser Sintering of Eucalyptus/PES Blend and Mechanical Testing

2.1. Selective laser sintering experiments

Wood flour is 300 micron mesh eucalyptus powder from De Long New Materials Co., Ltd in JIANGXING City. Hot melt adhesive is 120-180 micron mesh PES-Y1201P80 from Shanghai Yuanzhi Hot Melt Adhesive Co. Ltd. It is thermoplastic copolyester with good fluidity after being heated. This allows it to melt and wrap the wood powder bonding together to form the part. This material has low hygroscopicity and shrinkage rate, high heat resistance and shock strength. There are also some other components such as viscosity breaker to reduce the viscous and aggregation of wood powder, initiator and coupling agents to enhance the bonding of eucalyptus and PES, light stabilizers to improve the molding appearance and life, and other organic fillers.

The experimental equipment is an HRPS - Ⅲ laser forming machine of Huazhong University of Science and Technology. The powder material is put in work bins on the both sides of the machine. Then the leveling roller evenly spreads the powder in the intermediate processing area. By repeatedly spreading and sintering, parts are formed. Experimental processing parameters are as follows: subarea scanning, laser power is 30 ~ 50 W, moving rate of the laser beam is 1800 mm/s ~ 2000 mm/s, characteristic radius of the laser spot is 0.3 mm, scanning interval is 0.15 mm, layer thickness is 0.1 ~ 0.2 mm. The temperature of the powder bed is also a very important processing parameter. Through experiments it was determined that 70°C was optimal. Fig. 1 shows the 3D model of helical gear. The forming helical gear of WPC is shown as Fig. 2. D_1 and D_2 are addendum circle diameters of 3D model and the green part, respectively; b_1 and b_2 are tooth widths, which could show the high forming accuracy. The green part also had specific surface roughness, compactness and strength.


Fig.1 Helical gear three-Dimensional model (D_1=80mm, b_1=20mm)


Fig.2 Formed helical gear of WPC (D_2=79.85mm, b_2=19.73mm)

2.2. Mechanical testing

A CMT4204 electronic universal testing machine produced by Chengde Chemical Machinery Factory was used for mechanical property testing. Tensile strengths were obtained according to GB/T1040-2006. The bending properties were obtained according to GB/T9341-2000. The results of the testing showed the tensile strength to be 0.220 MPa and the flexural strength to be 0.360 MPa.

The Eucalyptus/PES blend applied in Selective Laser Sintering is a technical breakthrough for materials processing and it provides the possibility for subsequent processing. After post-processing, the strength and other mechanical properties of formed parts can be improved greatly to satisfy the specific use requirements.

3. Post Processing and Mechanical Testing

3.1. Post processing

Selective Laser Sintered Eucalyptus/PES blend parts possessed adequate mechanical properties, but the part surface and internal density were low and porous, leading to poor strength. To improve this deficiency, a post-processing wax was chosen to fill the part's inner pores to increase its strength [5]. The melting point of the wax was low. After reaching an appropriate temperature, the viscosity of the melted wax was low, and the leveling was good, so it was easy to penetrate and fill pores of the WPC model using capillarity effects. According to the Rideal and Washburn theory [6]:

$$h = [\frac{\eta}{2\sigma}(r_c \cos\theta)t]^{1/2} \quad (1)$$

h—— Penetration Distance;
r_c—— Capillary Radius;
θ—— Contact Angle;
t—— Penetration Time;
η—— Melt Viscosity;
σ—— Surface Tension Coefficient.

The more stable the wax viscosity is, the better the post-processing repeatability is, but the viscosity was too small to get better results. When the viscosity is too low, the adhesivity of the wax liquid degrades. Moreover, a low viscosity of wax liquid requires high temperature that may result in a softening of the formed part. At less than 70°C, the part was immersed into wax liquid, which permeated the part filling the internal pores rapidly. After complete penetration, parts were removed and cooled. The wax was observed to have fill the internal pores, making the part denser and thus increasing the strength. Fig. 3 shows the part after post-processing. The dimensions of the part in the X, Y, Z directions increased slightly comparing D_3 and b_3 with D_2 and b_2, respectively. Meanwhile, the density was improved by 1.4-1.8 times. If the demand is higher for dimensional accuracy, buffing can be used to improve not only the dimensional accuracy, but also the surface quality. Through buffing the surface quality decreased from17μm to below 5μm.

Fig.3 Formed part after post-processing (D_3=79.25mm, b_3=19.52mm)

3.2. Mechanical testing

According to the testing equipment and standards used above, mechanical properties of the part after post processing were tested. The tensile strength was 2.400 MPa and the flexural strength was 2.820 MPa. Comparing the two groups of data of mechanical properties before and after post processing, it can be concluded that infiltration with wax has significantly improved the mechanical properties. The tensile and bending strength have been increased by about 11 and 7.8 times, respectively. After grinding, the part's surface accuracy will be also improved. Therefore, infiltration with wax can be used as an enhancement process for the Selective Laser Sintering of the Eucalyptus/PES blend.

4. Part Investment Casting Technology

4.1. Thermo-gravimetric analysis of SLS part

Low temperature and medium temperature wax which can be removed using hot water or steam are commonly used as the raw material for wax patterns in investment casting. While this research used Eucalyptus/PES blend, which is a high polymer, as the material to make investment pattern based on SLS. Its melting point is relatively high; also the melt viscosity is high compared to traditional wax. Hot water and steam can only remove the wax which has penetrated into the WPC part's inside. It is considered that the rest of WPC must be removed by combustion and decomposition through burn-out. Therefore, the eucalyptus powder, PES powder and wax-infiltrated prototype were separately assessed using thermo-gravimetric analysis. The TG curves are shown in Fig.4 and Fig.5. The relationship between decomposition of the pattern material and temperature is shown.

All testing was performed using nitrogen atmosphere. The initial setpoint was 40 ℃, heating rate was 20 ℃ per minute, and maximum temperature was 800 ℃.

As shown in Fig. 4, when the temperature is less than 180 ℃, the weight reduction of eucalyptus powder is 5%. The wood powder does not have melting point and its ignition temperature is low, so weight loss is slight. For temperatures between 180 ℃ and 350 ℃, weight of the powder drops rapidly which reduces to 40% of the original weight. When the temperature is increased up to 800 ℃, the weight reduction is minor, and the ultimate weight of the ash becomes less than 20%.

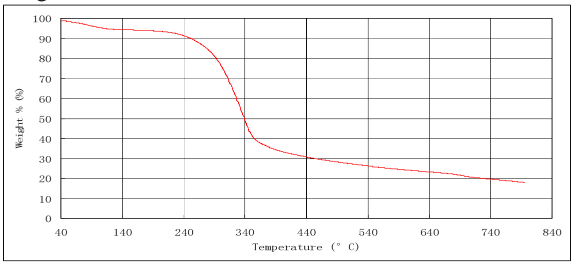

Fig. 4 TG curve of eucalyptus powder

Fig. 5, the TG curve of PES shows that, beyond 300 ℃, the weight of the sample remains relatively stable; from 300 ℃ to 490 ℃. The weight quickly decreases to 30%, while from 490 ℃ to 800 ℃, the residual weight slowly drop to below 20%.

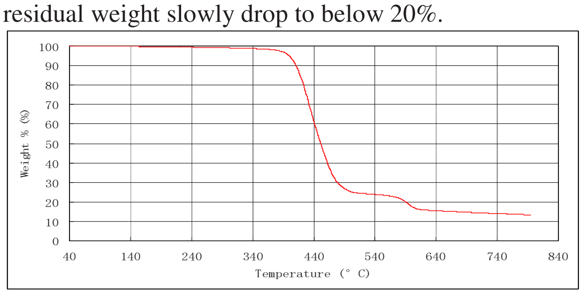

Fig. 5 TG curve of PES powder

Fig. 6 shows the TG curve of the wax-infiltrated prototype, that within 160 ℃, the specimen's weight is invariant. At this time just the internal residual wax is melting and PES is softening, so the weight has not changed. With the temperature rising from 160 ℃ to 290 ℃, a small amount of the weight reduction is experienced, which is mainly due to wax and wood powder loss. When the temperature is above 290 ℃, the sample's weight decreases rapidly, the wax outflows and gasifies. Also the loss on ignition of the wood powder and PES is very high; between 490 ℃ and 800 ℃, the weight drops slowly and tends to be stable. Finally, the weight is below5%.

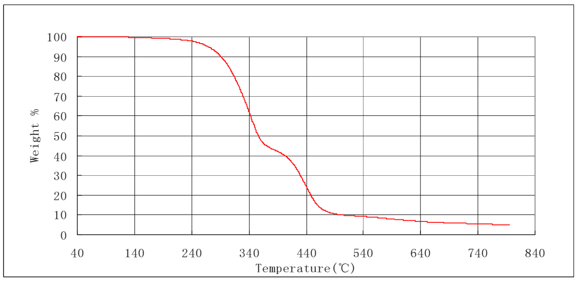

Fig. 6 TG curve of wax-infiltrated prototype

4.2. Investment casting process

In this paper SLS technology is used to make patterns with Eucalyptus /PES blend instead of wax, which can shorten the product manufacturing period. It is more suitable for rapid changeable markets and single and small batch casting. The specific process is as shown in Fig. 7.

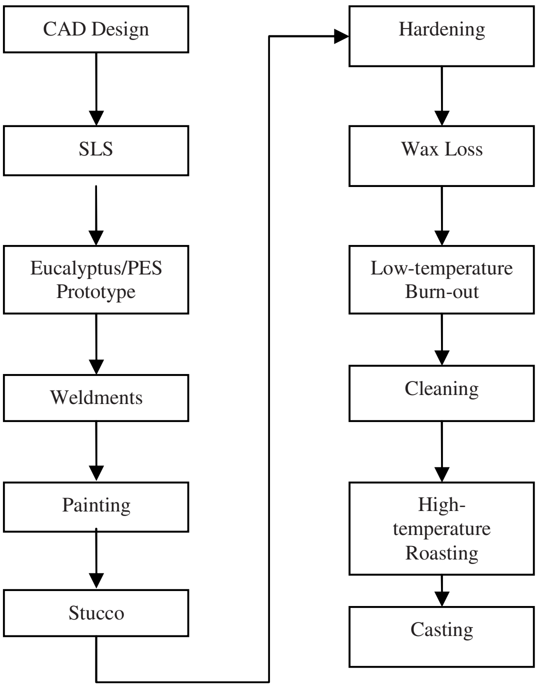

Fig.7 Investment casting process

The solid parts processed by SLS with Eucalyptus/PES blend are useful as investment casting patterns. An investment casting sequence is described.

(1) A mould cavity was prepared using an appropriate gating system. Reasonable design of the gating system ensures adequate liquid metal filling of the mould cavity and results in a complete casting.

(2) The casting pattern was immersed into premade investment which is a blend of fine refractory materials and binders such as zircon sand and sodium silicate. After coating, the mould is reinforced with sand in the usual way, followed by drying in air. This process was repeated seven times to obtain an adequate mould wall thickness, using fine sand initially to create a good surface and coarse sand later to minimize cost.

(3) The SLS pattern and wax gating system were melted out by heating the assemblage in steam at approximately 100°C.

(4) A low temperature burn out in an oil furnace at 500-600°C removed residual wood powder and PES. After cooling, a high-pressure air blast was used to blow out the residue. The mould is now prepared for casting.

(5) The mould was heating to approximately 1000°C to oxidize any residual residue. Molten steel was poured into the mould and allowed to solidify. After cooling, the part was removed from the gating system and finished. This part is shown in Fig. 8. And its surface roughness is 15μm before polishing.


Fig.8 Investment casting gear (D_4=78.41mm, b_4=19.66mm)

5. Conclusions

SLS technology can quickly and accurately manufacture parts to be used as investment patterns according to the CAD model. It has outstanding advantages especially for complex parts. Based on the previous studies, it was determined to use SLS of Eucalyptus/PES blend to make investment pattern, which can greatly reduce the manufacturing cost of the investment pattern. Combining SLS with investment casting has a broad prospect for application. Final metallic part was very similar to the investment pattern, and the WPC investment pattern fabricated by SLS had high precision. So this technology has obvious advantages especially in precision casting of small batch parts, which are precision, small and complex.

Material analysis of WPC prototypes produced by SLS was preformed and the investment casting process was analyzed. This paper defines the route and illustrates the advantages of Selective Laser Sintering of WPC applied in IC technology. The demould processes for the WPC prototype after wax penetration was defined, combining wax lost by steam and low- temperature burn-out with high-temperature burn-out to make the investment pattern cavity. Finally a high grade casting was produced which had good internal quality and no slag.

Acknowledgments

This work was supported National Natural Science Foundation of China (51075067), China Scholarship Council, Natural Science Foundation of Heilongjiang Province of China (E201050), Educational Commission of Heilongjiang Province of China (12511145).

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