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PREPARATION AND SELECTIVE LASER SINTERING OF RICE HUSK-PLASTIC COMPOSITE POWDER AND POST PROCESSING

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A mixing process was successfully developed to prepare Rice husk-Plastic Composite(RPC) powders. Before mix, the rice husk powder is dried for reducing the hydrophilic nature of rice husk fiber and improving the wettability and the adhesion actions of the interface. Green parts were formed from RPC by selective laser sintering (SLS) process, when the applied laser energy density was 283W/mm^2, the SLS green parts had sufficient strengths for features as small as 0.1mm to be built and post-processed, and relatively high dimensional accuracy. In order to further improve the properties of the pattern, the post-processing – infiltration with wax – is applied. Through post-processing, the void fraction is significantly decreased and the mechanical properties are significantly improved, the average tensile strength, bending strength, and impact strength are 1.47 MPa, 3.86 MPa and 3.74KJ/m^2. Compared with those of Wood Plastic Composite (WPC), the tensile strength is increased by 21% and the bending strength is increased by 41%, while the impact strength is 2.65 times.

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1. Introduction

The rapid prototyping technologies are manufacturing techniques for building objects from three-dimensional computer aided design (CAD) models. The product to be fabricated is presented as an multilayered CAD model, where successively each layer is converted into a physical layer then bonded to the preceding layers, until the product is completed. Since the mid-eighties, a variety of rapid prototyping technologies have been developed, including the stereolithography (SLA) (Charles, 1986)[1], the selective laser sintering (SLS) (Deckard, 1986)[2], the fused deposition modelling (FDM) (Crump, 1988)[3], the laminated object manufacturing (LOM) (Feygin, 1988)[4], and the three-dimensional printing (Pham and Gault, 1998; Rochus et al., 2007)[5,6]. Selective Laser Sintering(SLS) is a powder-based rapid prototyping (RP) process, a method of sintering and building up powder heated with a laser beam, and was conducted for the first time by C.R.Dechard from the University of Texas in 1989[7]. SLS directly forms solid components according to a three-dimensional CAD model by selective sintering of successive layers of powdered raw materials (Kumar, 2003)[8]. Currently, SLS is in a rapidly developing trend and is widely used in investment casting[9,10].

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A wide range of materials can be used in SLS, such as nylon, polycarbonate, ABS, sand, wax and metal[11], but the high price of materials is the bottleneck to constraining widespread application of SLS, so reducing the cost of materials has always been a research focus. Rice husk-Plastic Composites (RPC) is a green biological material, it has many advantages such as good mechanical properties, high hardness, anti-aging, dimensional stability, easy to color and is also recyclable, with an important advantage of its low-cost. In this paper, RPC is adopted as an SLS material to make parts with good mechanical properties as well as with good laser sintering property, the cost of the material is very low. In order to further improve the properties of the pattern, the post-processing – infiltrating with wax – is introduced. Mechanical properties of RPC by SLS is also Compared with those of WPC by SLS[12].

2. Laser sintering characteristics and energy distribution

SLS is a solid freeform fabrication technique. It consists of a high-melting-point powder material and a low-melting-point powder material, and under the laser radiation, the low-melting-point powder melts, the liquid formed by the molten material binds the high-melting-point powder and solidifies when the temperature decreases, which leads to consolidation and the formation of parts. The goal of this rapid prototyping process is to produce a finished product from a three-dimensional (3D) CAD model in a single manufacturing process. The outstanding advantage of SLS is that the un-sintered powder on the powder bed remains in its place to support the structure of sintered powder, thus no need to consider a support system, so very complex 3D parts can be achieved by SLS.

SLS is carried out in a controlled atmosphere container with two chambers. One chamber is the feed chamber and the other is the build chamber. The feed piston is raised and the leveling roller transfers the powder to the build chamber. After each scan of the infrared laser, the building piston is lowered and the next layer of powder is transferred. This is done layer by layer until the green part is completed as shown in Fig.1.

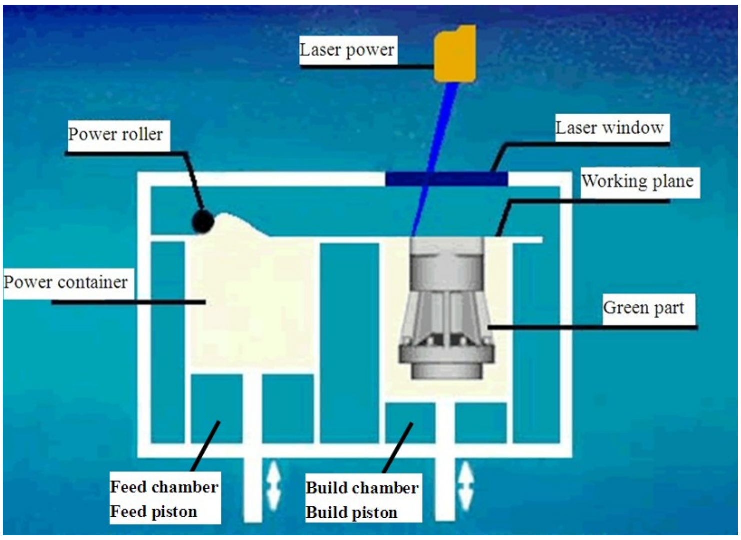


Fig.2 Sketch figure of SLS

In the SLS RP process, CO_2 and the Nd:YAG laser are used as power. The CO_2 laser has high efficiency, launching an invisible laser of 10.6μm wavelength causing no damage to the working medium, therefore it is an ideal laser. The interaction between the laser beam and the RPC materials depends on the laser energy density distribution, as it nearly follows a Gaussian relationship.

2. RPC powder preparation

RPC is mainly composed of rice husk and hot-melt adhesive powder, and the two components accounted for more than 90% of the total mass. There are also other additives in RPC such as a viscosity reducer and light stabilizer, etc.

The rice husk is a natural polymer organic material, with certain toughness, porous, low density and textured. The true density of rice husk is about 720kg/m^3, natural packing density is only 83-160kg/m^3. The rice husk is a fibrous material, its fiber is short, with an average length of only 0.3mm. The surface of the rice husk is burr, very smooth, the particles prone to jam and bypass for its poor mobility. The outer surface of rice husk is covered with smooth horny silica membrane, forming a non-polar surface structure. Such structures can play a certain role of lubrication in the production of wood-plastic composite extrusion process and extrusion products are more dense and tighter than wood flour extrusion product. The rice husk is rich in cellulose, lignin, and silica. Among them, the content of fat and protein is very low. Based on differences in rice varieties, regions and climate, its chemical compositions vary. Under normal circumstances the chemical compositions of rice husk powder are as following: 5-8% moisture, 18-20% ash, 60-63% volatile matter, 17-19% fixed carbon, the lipid content in rice husk powder is about 1%. The major composition of lipid fatty acid is unsaturated fatty acids. The saturated fatty acids, C22 and C24, account for 2% -3%, rather than the mass percentage share of saturated fatty acids is very low. Rice husk powder is covered by one kind of cuticle, playing an effect of waterproof protective, it is a long-chain acid polymer-based shuttle and its content is 22% in rice husk powder. Inorganic constituents in the rice husk powder is silicon dioxide SiO_2, it is arranged in a certain structure from the outer surface to the inner surface of rice husk and its content is gradually decreasing[13]. The SEM photograph is shown in Fig.2.

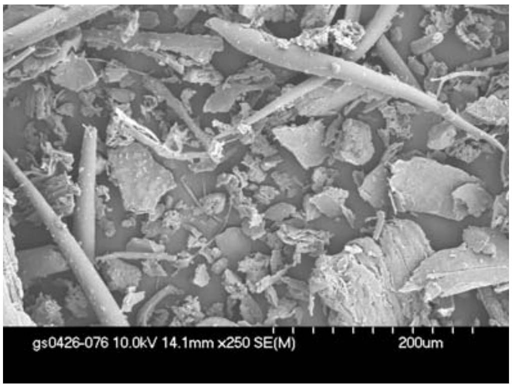


Fig.2 Rice husk powder

The hot-melt adhesive powder used in the experiment is a co-polyester(CO-PES) hot-melt adhesive powder, as Fig.3 shows. It is a kind of plasticity adhesive, and in a certain temperature range its physical state changes with the temperature change while maintaining the same chemical properties. It is a non-toxic, tasteless and environmentally friendly chemical product, and its performance parameters are shown in Table.1.

Table 1 Performance parameters of Co-PES hot-melt adhesive powder

Chemical Composition	Melt Range (°C)	Melting Index g/10min @160 °C	Viscosity Pa.s@ 160 °C	Heat bonding Conditions		
				Temperature (°C)	Pressure (kg/cm^2)	Time (s)
CO-PES	105-115	30	380	125-150	0.5-1.5	5-20

The rice husk powder is basically a wood fiber and has an irregular shape, making it easy to aggregate unlike granular chemical materials such as nylon, spreading the powder uniformly on a bed by a leveling roller is difficult. So it is necessary to add some amount of a viscosity reducer (graphite, white carbon black, calcium carbonate, talcum or glass powder) to improve the powder spreading effect. Wood fiber carbonyls can act as chromophoric groups (aging initiator) which can accelerate the aging of the organic filler and make the surface of the composite fade, forming a thin aging layer and generating large areas of brittle fracture. Adding a light stabilizer can slow aging, increase aesthetics and the lifetime of the parts.

In RPC, rice husk powder and Co-PES hot-melt adhesive powder have a volume ratio of 10:8 ~ 9, they are the main ingredients of WPC. The viscosity reducer accounts for 5%～20% of the total mass of WPC, and the light stabilizer accounts for 0.2%～6% of the total mass of RPC, as Fig.4 shows.

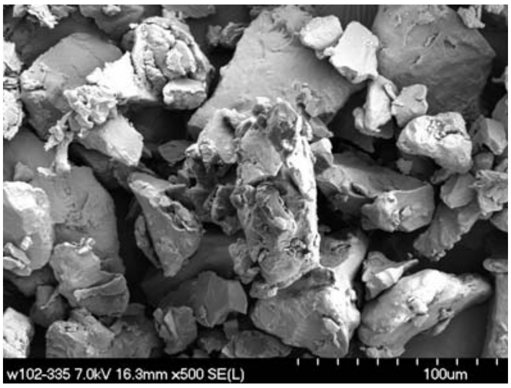


Fig.3 Co-PES hot-melt adhesive powder

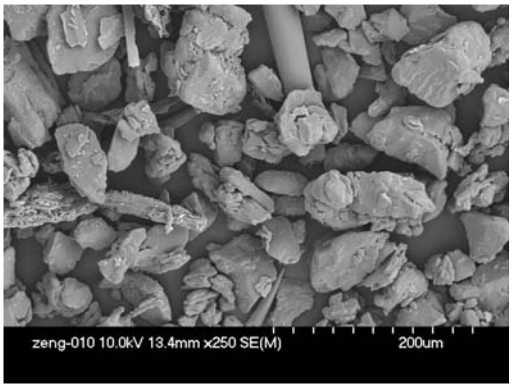


Fig.4 RPC powder

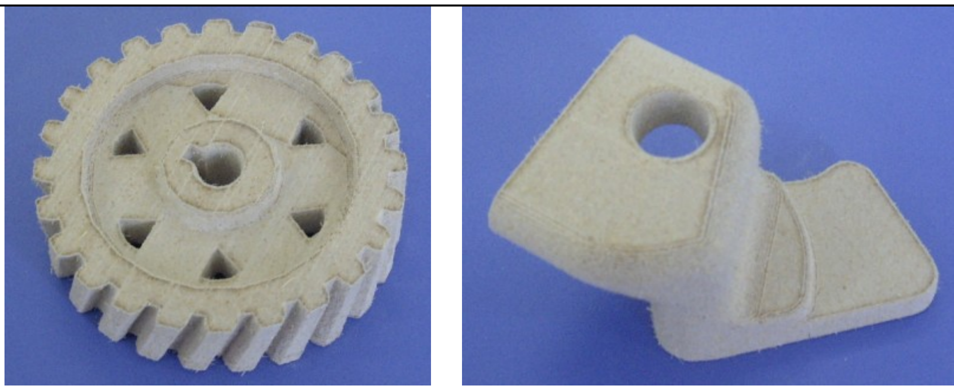
3. Selective laser sintering process

Under laser radiation, the hot-melt adhesive powder melts, the liquid formed by the molten hot-melt adhesive powder binds the wood powder and solidifies when the temperature decreases, leading to consolidation ultimately forming parts.

The rapid prototypes were manufactured using a HRPS-IIIA type SLS machine built at Huazhong University of Science and Technology (HUST) in Wuhan, P.R. China. Experimental parameters are set as following: a CO_2 laser source with a wavelength of 10.6μm, maximum output power is 50W, power consumption is 39%, diameter of the laser spot is 0.3mm, scan space is 0.15mm, layer thickness is 0.2mm and the scanning speed is 2000 mm/s.

Before the laser is scanned, the entire machine bed is preheated to just below the melting point of the material by infra red heaters to minimize thermal distortion and to facilitate fusion to the previous layer. For WPC, the hot-melt adhesive powder has a lower melting point, and in this paper the fusion range of Co-PES hot-melt adhesive powder is between 105-115□, as Table.1 shows, so preheating temperature must below 105^{o}C.

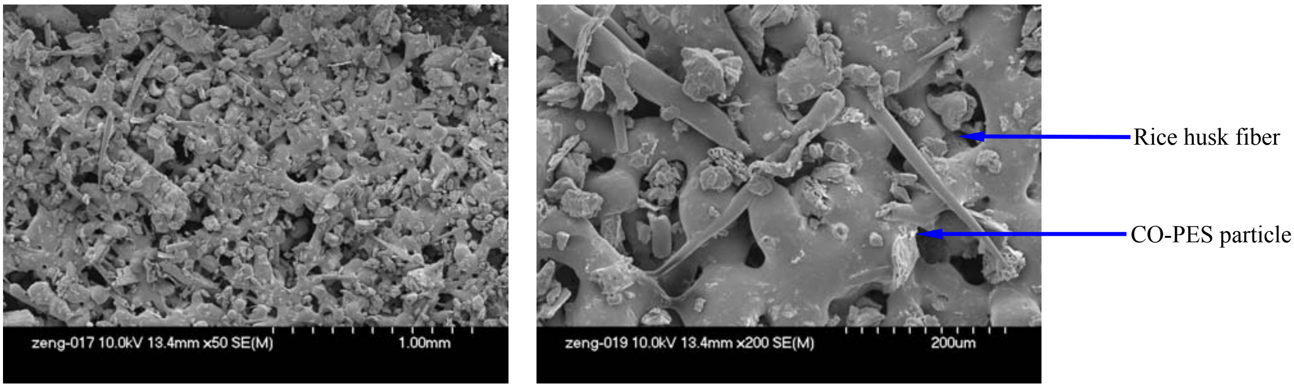
Fig.5 shows the green parts, a gear with 80mm diameter is showed in Fig.5a), a front suspension of automotive engine with 40mm high is shown in Fig.5b). It can be seen the surface of the part is very rough and covered with a powder that can easily be removed.



a) b)

Fig.5 SLS green parts

Fig.6 shows the surface SEM photograph of one green part, from the microscopic point of view, the hot-melt adhesive powder melts and binds the rice husk fiber together under the laser radiation, but there still exists a void fraction. Because of that, the surface of the part is very rough and the mechanical properties are very low, therefore post processing is necessary for RPC Green parts to improve surface quality and mechanical properties.

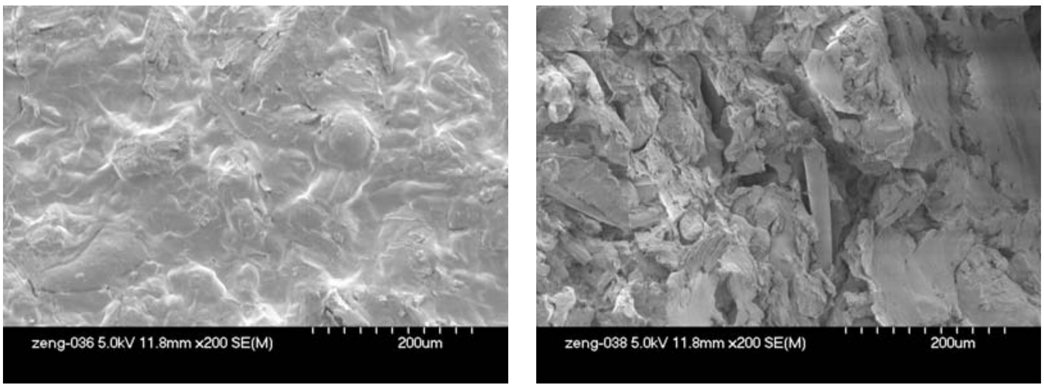


a) b)

Fig.6 Surface SEM photographs of part

4. Post Processing

Post processing – infiltrating with wax – is discussed in this study. When the green parts are immersed in the melting wax, the melting wax would infiltrate the green parts through capillarity action. After post-processing, most of the void is filled with wax, and the voids fraction is decreased significantly. As shown in Fig.7, although there are some voids and naked RPC particles, most of the RPC particles are well wrapped by wax. It indicates that wax shows good bonding with RPC.



a) b)

Fig. 7 Surface SEM photographs of RPC specimen after post-processing

After Post processing – infiltrating with wax, the density of parts is greatly improved, it is 1.4~1.8 times as that before post processing. The mechanical properties are related to density and are significantly improved, The dimensions of Wax-infiltrated parts after post-processing in the X direction, Y direction and Z direction were slightly increased, but the increased value is below 0.1mm, so post-processing makes little impact on the dimensional precision of Wax-infiltrated parts. But after post-processing, surface quality has been greatly improved and surface roughness has been greatly decrease, as shown in Fig. 8.

a) b)

Fig.8 SEM images of WPC specimens after post-processing.

5. Mechanical Properties Testing

Mechanical Properties of parts include tensile strength, bending strength, impact strength and elongation rate, etc. Tests are made to compare the mechanical properties between green parts and Wax-infiltrated parts.

Tensile strength：The dog-bone-shaped tensile specimens having a typical dimension of 165 × 13 × 4 mm, were measured using a Regear computer controlled Universal Testing Machine (Shenzhen Regear Instrument Cooperation, China) according to ASTM D638-2004. A crosshead speed of 5 mm/min and a gage length of 50 mm were used for the test.

Bending：Specimens measuring 80 × 13 × 4 mm were measured under three-point bending using the same Universal Testing Machine in accordance with ASTM D790-2004. A crosshead speed of 1.9 mm/min and a span length of 64 mm were used for the test.

Impact: Specimens measuring 80 × 10 × 4 mm were measured under three-point bending using the Combination Impact Testing Machine in accordance with GB /T 1043 – 1993(China).

Table 2 shows mechanical properties testing results of green parts. Compared with WPC by SLS[12], the tensile strength is 10.7 times and the impact strength is 2.6 times, while the bending strength is decreased by 22%, as Fig.9 shows.

Table 2 Average mechanical properties testing results of green part

Green parts	Tensile strength (MPa)	Bending strength (MPa)	Impact strength (kJ/m^2)
RPC	0.15	0.37	1.495
WPC	0.014	0.475	0.567

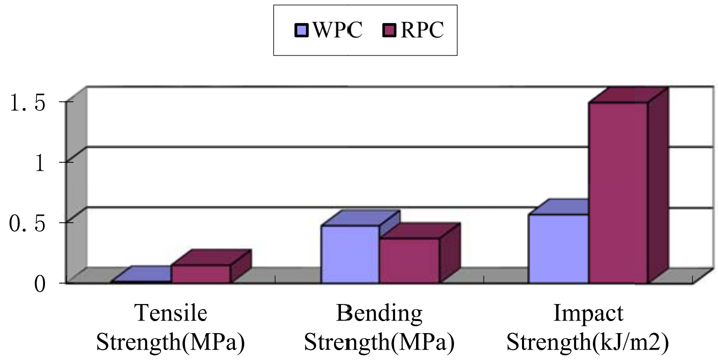


Fig. 9 Average mechanical properties comparison of green parts

Table 3 shows mechanical properties testing results of wax-infiltrated parts. For wax-infiltrated parts, the average tensile strength is 1.47Mpa, the average bending strength is 3.86MPa and average impact strength is 3.74kJ/m^2, as showed in Table 3, compared with those without post processing, the tensile strength is 9.8 times, the bending strength is 10.4 times and impact strength is 2.5 times, respectively. From results it can been known, after post processing–infiltrating with wax, the green parts become compact and the density is improved, so the mechanical properties are significantly improved.

Table 3 Average mechanical properties testing results of wax-infiltrated parts

wax-infiltrated parts	Tensile strength (MPa)	Bending strength (MPa)	Impact strength (kJ/m^2)
RPC	1.47	3.86	3.74
WPC	1.21	2.73	1.41

Compared with those of WPC, the tensile strength is increased by 21% and the bending strength is increased by 41%, while the impact strength is 2.65 times, as Fig.10 shows.

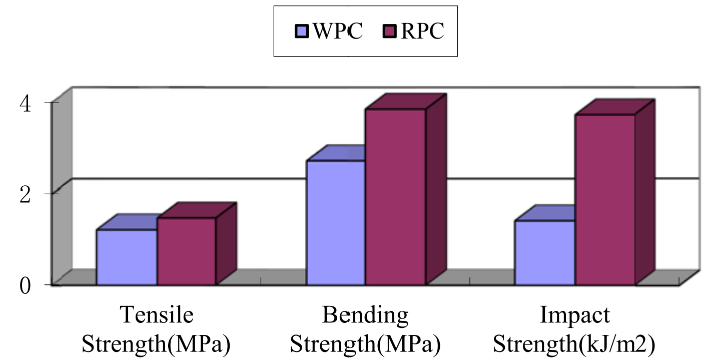


Fig. 10 Average mechanical properties comparison of wax-infiltrated parts

6. Conclusion

In this paper, RPC is successfully developed to make parts by SLS process according to its advantages, such as green biological, good mechanical properties, high hardness, anti-aging, dimensional stability, easy to color, with a wood texture and also recyclable, with its most important advantage being its low-cost. A mixing process was successfully developed to prepare RPC powders. Before mix, the rice husk power is dried for reducing the hydrophilic nature of rice husk fiber and improving the wettability and the adhesion actions of the interface. Green parts were formed from RPC by selective laser sintering (SLS) process, when the applied laser energy density was 283W/mm^2, the SLS green parts had sufficient strengths for features as small as 0.1mm to be built and post-processed, and relatively high dimensional accuracy. In order to further improve the properties of the pattern, the post-processing – infiltration with wax – is applied. Through post-processing, the void fraction is decreased significantly and the mechanical properties are significantly improved, Through post-processing, the void fraction is significantly decreased and the mechanical properties are significantly improved, the average tensile strength, bending strength, and impact strength are 1.47 MPa, 3.86 MPa and 3.74KJ/m^2. Compared with those of WPC, the tensile strength is increased by 21% and the bending strength is increased by 41%, while the impact strength is 2.65 times.

Acknowledgments

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