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Vapour Smoothening Process to Improve Surface Finish of FDM 3D Printed Ultem Components

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As one of the most popular additive manufacturing techniques, fused deposition modeling (FDM) deposits melted filament material on a build platform layer by layer to construct 3D models. Due to the layered nature of FDM process, the printed components exhibit poor surface quality with a contour-like appearance. To enhance the practicability of FDM 3D printed components, especially to make them comparable to those produced by injection molding in surface finish, post-treatment is necessary. The polyetherimide (PEI) Ultem™ 9085 (Ultem) is an engineering-grade thermoplastic with outstanding chemical and mechanical properties that are suitable for industrial purposes. In particular, owing to its high strength-to-weight ratio, outstanding impact strength, remarkable heat resistance and flame retardant performance, Ultem has been receiving great interest from aerospace industries. As one of the high performance filament materials, the FDM technique further extends the applicability of Ultem in diverse industry fields. In this study, we demonstrated a vapour smoothening based post-treatment technology to improve the surface finish of FDM 3D printed Ultem components. In our self-made vapour smoothening system, treatment on the Ultem components was totally controllable. Through using selected solvent with suitable process parameters, the surface finish of the components could be significantly improved without degrading the mechanical properties. After the vapour smoothening treatment within 30 min, surface roughness (Ra) of the 3D printed Ultem components was reduced from as-printed ~20 µm to less than 0.8 µm. Meanwhile, the environmental barrier performance and appearance aesthetics were also improved. This study highlights the vapour smoothening system design and the optimized process for post-treatment of 3D printed Ultem components.

NOMENCLATURE

AM = Additive Manufacturing
FDM = Fused Deposition Modeling
IPA = Isopropyl Alcohol
PEI = Polyetherimide
Ultem = Ultem™ 9085

1. Introduction

Additive manufacturing (AM) has gained great attention in recent years due to the large possibilities related to the manufacturing technique. Especially, the polyetherimide (PEI) Ultem™ 9085 (Ultem) printed by Fused Deposition Modeling (FDM) technology has been receiving great interest for industrial applications. Nevertheless, compared with components produced by conventional injection molding, the FDM 3D printed components exhibit poor surface quality with a contour-like texture due to the layered nature of FDM process. To enhance the practicability of FDM 3D printed components, post-treatment is necessary to increase surface quality, remove residual stresses, or eliminate possible printing defects on the component surface [1-3].

In this study, FDM 3D printed Ultem components were treated in a self-made vapour smoothening system under controllable conditions. The effects of process time and blower speed on component surface properties, i.e., surface roughness (Ra), appearance and weight change, were studied. The treatment performance of the component surface properties achieved via different treatment conditions were compared and evaluated.

2. Experimental

2.1 Vapour smoothening system

This study was carried out in a self-made vapour smoothening system, which is composed of a vacuum chamber, and two atomizers mounted on the top and bottom of the chamber to evenly and rapidly introduce the solvent into the process chamber and form vapour phase. Pristine solvent vessel is positioned outside the chamber and the solvent can be dosed into the chamber by vacuum pressure with flow control via valves. A blower is installed at chamber bottom to agitate the vapour to ensure its even distribution within the whole chamber. The sample is positioned at the central area of the chamber. After smoothening process, the adsorbed solvent on sample surfaces and the solvent vapour inside the chamber will be pumped out by a vacuum system passing through condenser to allow vapour condensation for recovery and collection of the used solvent (Fig. 1).

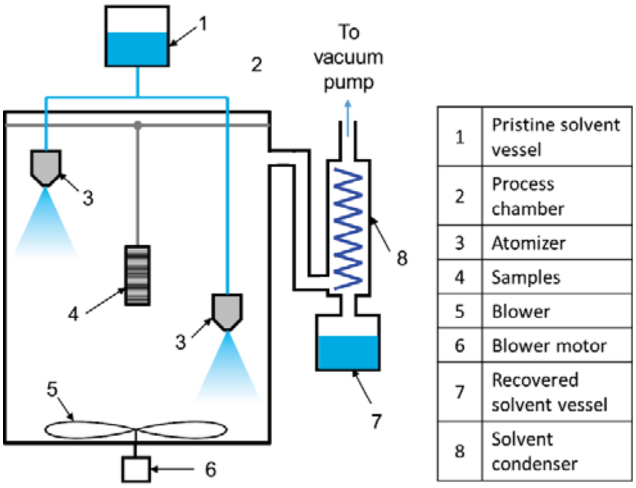

Fig. 1 Illustration of vapour smoothening system configuration

2.2 Vapour smoothening process

The samples used in this study were Ultem coupons printed by FDM technology. The sample size was 38 mm in length × 12 mm in width × 6 mm in thickness. All samples were thoroughly cleaned by ultrasound in IPA bath. Subsequently, the residual IPA was removed by using compressed air gun, then the clean samples were hung dry in oven at 70 °C for > 3 h. Before being loaded in the vapour smoothening chamber, all samples were cooled to room temperature and the sample weight was recorded.

To perform the vapour smoothening process, the process chamber was first pumped down to around −0.9 bar and kept for > 15 min to further remove any residual IPA that might be adsorbed on sample surfaces and/or trapped in open pores. Thereafter, the chamber was vented to around −0.6 bar. Totally 20 ml solvent was then introduced into the chamber and vapourized by the atomizers. The samples were kept under the solvent vapour atmosphere for certain process time to allow surface smoothening treatment. The blower at chamber bottom was controlled at different speeds. After completion of treatment process, the chamber was pumped down again to remove the solvent vapour and the solvent adsorbed on sample surfaces. After > 1 h pumping down time, most of the solvent could be recovered by the condenser and collected in the recovered solvent vessel. The chamber was then vented to atmospheric pressure, and the samples were unloaded and hung in a fully venting environment overnight for further evaporation of any residual solvent. After the whole process, the samples were weighted again.

Sample surface roughness was measured by using a Taylor-Hobson Form Talysurf Series 2 stylus profilemeter following ISO 4288 standard.

3. Results and Discussion

3.1 Effect of process time

To evaluate the effect of vapour smoothening process time on sample surface properties, one piece of Ultem sample printed by FDM was hung at the centre of process chamber. All the other conditions were remained the same as those described in the Experimental section, except that the process time was controlled to be 15 min, 30 min, 60 min. For the 15 min sample, the introduced solvent amount was 17 ml instead of 20 ml. The blower speed was controlled at 1260 rpm. The surface roughness of untreated Ultem samples printed by FDM is commonly around 20 µm. After 15 min treatment (Table 1), the surface roughness (Ra) significantly decreased to less than 3 µm. When the process time was further increased to 30 min, the Ra value further dropped to 0.24 µm. When the process time was further extended to 60 min, there was only very slight decrease of the Ra value (Fig. 2b). Thus, at current treatment condition, satisfactory results could be obtained within 30 min process time. Furthermore, with the increase in treatment time, the sample weight change (before and after the vapour smoothening process) increased as well (Table 1). This weight increase should be due to the residual solvent in the sample structure, hence more solvent was trapped for longer process time.

The sample appearance achieved by different process time also clearly demonstrated the effect of treatment time on sample surface properties. The sample surface became shining, and the contour-like texture turned almost undistinguishable after 30 min treatment time (Fig. 2a). Nevertheless, increasing process time to 60 min did not contribute much difference to sample appearance, which is in good accordance with the results of surface roughness measurement.

Table 1 Surface roughness (Ra) and weight change of 3D printed Ultem samples after different vapour smoothening conditions

		Ra / µm	Weight change
	15 min	2.78	+0.73%
Process time	30 min	0.24	+1.52%
	60 min	0.19	+3.26%
	840 rpm	0.47	+1.74%
Blower speed	1260 rpm	0.22	+2.26%
	~2700 rpm	0.24	+2.39%

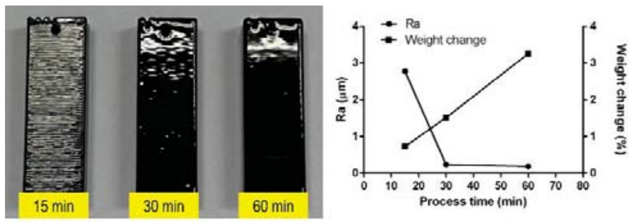

Fig. 2 (a) Photos of the samples treated under different process time;

(b) sample surface roughness (Ra) and weight change vs. different process time.

3.2 Effect of blower speed

The effect of the blower speed on vapour smoothening results was also investigated under three different blower rotation speeds, i.e., 840 rpm, 1260 rpm, and ~2700 rpm. For the third speed setting, the measured speed value continuously fluctuated between 2550 rpm and 2850 rpm under high rotation speed. Process time was set at 30 min for all three tests. Other conditions remained the same as those described in the Experimental section. As shown in Table 1, when blower speed was increased from 840 rpm to 1260 rpm, the surface roughness (Ra) slightly decreased. However, when blower speed was further increased to ~2700 rpm, Ra value did not decrease anymore (Fig. 3b). This result indicates that the effect of blower speed was not very significant when the speed was higher than certain value (e.g. 800 rpm in this study). Meanwhile, sample weight change after treatment also showed a trend of increase with process time, as shown in Table 1.

The appearance of the samples treated under different blower speeds was similar (Fig. 3a). This is in good accordance with the results of surface roughness measurement, since there was no significant difference in the Ra values of these samples.

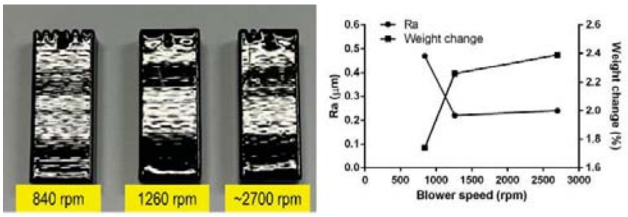

Fig. 3 (a) Photo of the samples treated under different blower speeds; (b) sample surface roughness (Ra) and weight change vs. different blower speeds.

3. Conclusions

In this study, a self-made vapour smoothening system was successfully set up and used for vapour smoothening treatment of FDM 3D printed Ultem components. The surface roughness (Ra) of the Ultem samples could be significantly reduced from as-printed ~20 μm to less than 0.8 μm in 30 min treatment time. Meanwhile, the shining and sealed surface of the components after vapour smoothing treatment were expected to improve the environmental barrier performance and aesthetics appearance. Studies on further optimization of the vapour smoothening process is in progress.

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