Feasibility study on developing productivity and quality improved three dimensional printing process

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Abstract: Solid freeform fabrication (SFF) technology plays a major role in industry and represents a reasonable percentage of industrial rapid prototyping/tooling/manufacturing (RP/RPT/RM) development applications. However, SFF technology still has long way to progress to achieve satisfactory process speed, surface finish and overall quality improvement of its application. Today, three dimensional printing (3DP) technique that is one of SFF technology is receiving many interests, and is applied by various fields. It can fabricate three dimensional objects of solid freeform with high speed and low cost using ink jet printing technology. However, need long curing time after manufacture completion. And it must do post-processing process necessarily to heighten strength of objects because strength of fabricated objects is very weak. Therefore, in this study, we proposed an improved 3DP process that can solve problems of conventional 3DP process. The general 3DP process is method to spout binder simply through printer head on powder, but proposed process is method to cure jetted UV resin by UV lamp after jet UV resin using printhead on powder. The hardening of resin is achieved strongly at early time by UV lamp in proposed method. So, the proposed process can fabricate three dimensional objects with high speed without any post-processing.

Keywords: SFF(solid freeform fabrication), 3DP(three dimensional printing), RP(rapid prototyping), UV-resin, Optical hardening

1. INTRODUCTION

Detail investigation of time compression technologies evolution show the concept of “Time to Market” motivated the evolution of solid freeform fabrication (SFF) technology up to the present level. Recently SFF processes have extended the application areas to RT and RM. Most of SFF processes are based on layered manufacturing technology (LMT), processes such as fused deposition modeling (FDM), stereolithography (SL), selective laser sintering (SLS), three dimensional printing (3DP), laminated object manufacturing (LOM)[1]. The present SFF process cannot compete with conventional manufacturing process[2] such as injection molding for mass production. In today, 3DP technique that is one of SFF technology is receiving many interests, and is applied by various fields. It can fabricate three dimensional objects of solid freeform with high speed and low cost using ink jet printing technology. However, need long curing time after manufacture completion. And it must do post-processing process necessarily to heighten strength of objects because strength of fabricated objects is very weak. So, the conventional 3DP process can’t say that is high speed if compare the total fabrication time including dry time and post-processing time with other process[3-5].

In this study, we proposed an optical hardening process that can reduce the fabrication time of conventional 3DP process. The general 3DP process is method to spout binder simply through printer head on powder, but proposed process is method to cure jetted UV resin by UV lamp after jet UV resin using printhead on powder. The hardening of resin is achieved strongly at early time by UV lamp in proposed method. Therefore, is process that can fabricate three dimensional objects with high speed without any post-processing.

2. BASIC TEST OF 3DP PROCESS

2.1 Design and printing

For this test, we used the ZPrinter 310 in Z corp. This printing test's main issue is to evaluate most of these limitations by printing a rather complex part.

The first issue considered was the surface finish behavior depending on the slope of the surface. So it was necessary to design a part on which it could be possible to find surfaces of any slope. Layer-by-layer RP systems - and in the present case 3DP - are also known to give the possibility to build parts without geometry limitations. But one of the known limitations of 3DP parts is part fragility:

![Fig. 1 CAD model of the part to print](image)

Then it could be interesting to print a complex part that is not very stable and that has quite fragile sections. With these considerations, the shape of the part for the printing test has been designed as figure 1. The shape of this part is maybe not the most appropriate for the present study, but it will anyway reveal some interesting features concerning the 3DP process.

![Fig. 2 Results of the coil-shaped part printing](image)

The estimated printing time was approximately 2h. After the first printing, the part has been left for about 1h30min in
the powder bed in order to let it dry (the printer user's manual recommends to leave it for 15 to 30 min). The problem occurred at this stage was to remove the part from the powder bed without breaking it. This operation must be conducted with as much care as possible. The printed part has indeed a very bad balance (it is very badly equilibrated) and it has numerous weak sections: it is then difficult to remove it without putting to much pressure on it (pressure put by the operator or by the powder). The first printing resulted in a total failure: the printed part broke inside the powder bed and some fragments were even lost during the removing process (it has been impossible to completely fix it after). After this first failure an idea has been considered that maybe the part was too big to support its own weight at its weakest sections. It has then been decided to lower the reduction factor and to set it at 25%.

The second printing had a printing time of 1h30 and it has been left for about 2h in the powder bed. But here again the part broke during the removing and post-processing steps. This time it was less serious and the part has been fixed afterwards. Still a complete unbroken part was necessary. So a third printing has been made, using the original reduction factor of 30% and letting the part in the powder bed for about 4h this time. Then removing and cleaning were conducted with extreme care and the final unbroken printed part was finally obtained.

Table 1 Printing results

<table>
<thead>
<tr>
<th></th>
<th>Printing n°1</th>
<th>Printing n°2</th>
<th>Printing n°3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction factor</td>
<td>30%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Printing time</td>
<td>2h</td>
<td>1h30</td>
<td>2h</td>
</tr>
<tr>
<td>Resting time</td>
<td>1h</td>
<td>2h</td>
<td>4h</td>
</tr>
<tr>
<td>Post-processing time</td>
<td>1h</td>
<td>1h</td>
<td>1h30</td>
</tr>
<tr>
<td>Total needed time</td>
<td>4h</td>
<td>4h30</td>
<td>7h30</td>
</tr>
<tr>
<td>Remarks</td>
<td>failure</td>
<td>Partial failure</td>
<td>Success</td>
</tr>
</tbody>
</table>

2.2 Test results

1) Fragility: Three tries have been necessary to obtain a complete unbroken part. For the first two failures the parts broke by themselves, unable to support their own weight and the weight of surrounding powder. They broke at especially weak sections. For the third printing, the obtained part was a success but it has been necessary to let it in the powder bed during 4h to dry and to strengthen its structure. Extreme care also needed to be taken during removal and cleaning steps. The fragility of the printed part is then a real problem: if the printing process itself is quite fast (several hours), this speed becomes of no use if it is too difficult and it takes too much time to remove the part without breaking it.

2) Deformation: It is actually considered that deformations stay quite negligible in 3DP process. But for this printing test the part is not common and its balance is quite unstable. Some weak sections must support the weight of the whole part. Then it is logical to think that significant deformations could occur. These deformations have indeed only been observed on the second printing (reduction rate of 25%). For the first printing, since it broke at many locations, deformations resulting from too much stress put on weak sections could not be observed. For the third printing, the part has been left in the powder bed for quite a long time. So the part has had time to get stronger in its weakest sections. The second printing can be considered at the middle of these two extreme cases. The second part was strong enough not to get broken in too many locations, but it still was too weak and some cracks appeared. These cracks were fixed with dedicated glue, and the part was then kept in a single piece. But after several hours it has been noticeable that the part was a little squished in the vertical direction. This may be caused by the fact that it was not strong enough after the printing process and it kept drying after (fixing its structure in the same time). Pressure caused by its own weight was too important and the part shrank in the vertical direction.

Another interesting remark can be done concerning deformation. The deformation that occurred to the second part could also have been a consequence of the part’s shape. This part has indeed the shape of a coil, so it is supposed to be easily deformed. It is also supposed to be able to restore its original state after deformation. Based on this principle, a simple test has been made on the third printing. Pressure has been put on it and deformation appeared. But this deformation stayed elastic and the part restored its original state after releasing pressure.

3) Printing speed / Post-processing: quality/time effectiveness: After this printing test, it appeared that post-processing is very important to obtain a good printed part. It also appeared that depending on the shape of the part to be printed, the time of rest in the powder bed might be quite important. For instance, considering our successful try, printing time was quite short (about 2h) but the part had to rest in the powder bed during 4h and the post-processing required about 1h30: in total 7h30 were required to get a finished part. So the question of effectiveness can be raised. If 7h30 are required to get a printed part like this (its shape is not too complex and its size is not too important, the only difficulty is its unstable balance), is 3DP still a competitive RP system? Yes, it can still be said that this is a quite competitive solution: these 7h30 are actually a large approximate time of what is needed (since the resting time is not well known and the post-processing time can be quite reduced depending on the ability of the operator). The problem is to form someone to use this system to its best efficiency.

Most of the remarks done here are based on qualitative observations. To get a more precise analysis of the 3DP process, it is necessary to run tests that will provide numerical results. The present qualitative test will help to set up a guideline on which parameters will have to be varied and which properties will have to be measured. It will lead to a quantitative printing test presented in the following section.

3. PROPOSED 3DP PROCESS

3.1 The schematic of proposed process

In this study, we having advantage of conventional 3DP process, wish to propose new process that can improve disadvantage. The proposed process is very similar with conventional 3DP process. Only, spout UV resin instead of binding solution to powder bed, and cure it by UV-lamp. This process can reduce fabrication time more than conventional 3DP process. In conventional process, when jetted resin of low viscosity on powder bed does not become hardening perfectly, new layer is accumulated continually.

So, after fabrication was completed, the long time (at least build time) was required before do post-processing process. But, in case use proposed process, jetted UV resin is hardened perfectly by UV-lamp in each layer. Therefore, the special delay time is no necessity after fabrication, and it can reduce
3.2 Printing test

We achieved an experiment to verify proposed process. In the test, used each a powder, polyamide and polystyrene for powder or polymer bed formation, and used Fullure720 model in Objet Geometries Ltd. as resin. Also, we used a dispenser in Mushi corp. which was attached heater for resin jetting. The nozzle diameter of dispenser for test was 170μm and 300μm, supply pressure was 3bar, jetting temperature was 95 degree and UV-lamp used MHL 250 model.

We used three materials in an experiment, and firstly Zb102 powder in Z corp. But, because the compatibility of powder and UV-resin was bad unfortunately, we failed to fabricate the green part. Because the compatibility of two materials was bad, deposited resin was not impressed to the powder bed. And it formed a drop to the surface on powder bed.

We used a polyamide in 3D systems at second experiment. At hardening process, deformation of green part happened by the heat. Figure 6(a) is as result that spouts the resin on polymer bed. After build two to three layers, deformation happened in built part by heat such as figure 6(b).

At third experiment, we used polystyrene that have dull special quality in temperature than polyamide material. It is satisfied two problems that compatibility and deformation. As experiment result, we could get clean surface of part by optical hardening process. And after manufacture was completed, remove polymers that was not ossified without any post-processing and confirmed strength of about 150–200N that may use justly. But, we confirmed in case deposited volume of resin is many more than necessity or UV curing time is long, that heat deformations happen. Figure 7 is experiment result that use polystyrene.

4. CONCLUSION

Dimensional analysis was processed and it appeared that printed parts were always bigger than wanted. This observation has been explained by two phenomena: bleeding and anisotropy. Main result obtained from mechanical strength tests is that green parts (no post-process) are way too fragile to be used for practical purpose: they are just strong enough to be handled for post-processing. So post-processing is always required before printed parts can be used. It can also be noticed that glue post-processing gives a good mechanical strength to printed parts and one can consider that all post-processed parts get the same mechanical behaviour.

And we proposed a novel 3DP process that can reduce the fabrication time of conventional 3DP process. The hardening of resin is achieved strongly at early time by UV lamp in proposed method. Therefore, it can fabricate three dimensional objects with high speed without any post-processing. In the future, we plan to verify reliability of proposed process through more various experiments.

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