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Development of automatic smoothing station based on solvent vapour attack for low cost 3D Printers

Prof. Marlon Wesley Machado Cunico, Ph.D. , marloncunico@yahoo.com.br
Universidade de São Paulo campus São Carlos
Concep3d Pesquisas Científicas

Patrick Medeiros Cavalheiro
Concep3d Pesquisas Científicas

Prof. Jonas de Carvalho, Ph.D.
Universidade de São Paulo campus São Carlos

Abstract:
Along the last years, 3d printing has been playing a new and important role in several market segments. As consequence, finishing methods have been developed and applied in order to improve surface roughness and mechanical strength. One of these methods is the solvent vapour attack. Nonetheless, this process is still manual and might lead to object deformation or structural damages. For that reason, the main goal of this work is to present a new approach that was implemented in automatic smoothing station. In this new approach, a close-looping control system identifies the vapour attack level in addition to controlling drying time and number of times that cycle is repeated. By the end, this proposal was identified to advances in 3d printing field, being a next step for domestic and distribuited manufacturing.

Key words: *Additive manufacturing, Smoothing process, dimensional evaluation*

1. INTRODUCTION

Additive manufacturing technologies have remarkably grown along the last years. Additionally, fused filament fabrication or low cost fused deposition modelling has also achieved an extraordinary advance with respect to precision and finishing [1]. Nevertheless, objects which are obtained by such methods use to result in anisotropic mechanical behaviour besides poor surface roughness. For that reason, low cost equipment is mostly restricted to hobby and prototypes applications.

In order to solve or reduce these issues, Priedeman and Smith [2] introduced the surface post-process based on vapour solvent attack, whose patent owner is Stratasys. This post-process is also known as smoothing process. In general, the surface finishing of the object is provided by a vaporised solvent treatment. Other works studied different kinds of smoothing techniques, so that we can classify these processes in: a) liquid immersion [3, 4], b) cold vapour [4, 5]; c) cold atomizer vapour [6]; d) hot vapour [1, 7, 8].

In spite of that, these kind of processes are still hand craft and might imply in object geometrical distortion in addition to object damage[1]. In addition, different object shapes make the process control harder. Therefore, the main goal of this work is to introduce a new method that controls the vapour attack process in an automatic way.

In this new method, we developed and fabricated an automatic smoothing station that controls the severity of hot vapour attack, level of drying, temperature, pressure and solvent absorption rate in a close-loop system. The simplified schematic of this concept is presented in Figure 1, where the basic diagram block of the close-loop control system is also exposed.

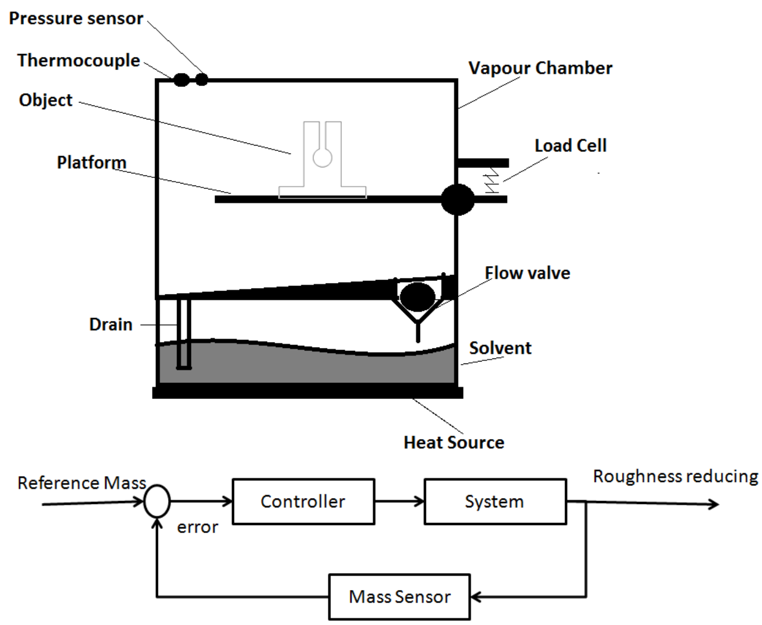

Figure 1 –Schematic of automatic smoothing station and block diagram of close-loop control system

In order to evaluate this proposal, we analysed the object roughness as a function of solvent absorption ratio, drying ratio and number of cycles. In this analysis, besides identifying the transfer function of system, we evaluated the efficiency of On-Off control system with target and minimum threshold.

It is important to note that the load cell is placed outside of smoothing chamber, and the condensated liquid on the platform was measured and removed from the threshold, compensating the effect of liquid on surface during the evaporation and drying stages.

By the end, we identified the main implications and potential application of this new method for small and medium business and specialised market segments.

2. MATERIAL AND METHODS

For the experimental analysis, we applied an multivariable method (2^{3-1}) with no central nor face point, where the number of cycles (repetitions), and solvent absorption were the main variables. On one hand, for the On-Off control method, we also evaluated the solvent absorption target and drying threshold . This study's responses were roughness, geometrical distortion and total spent time. The experiment Design is presented in Table 1, where the main control factors and influence levels were presented.

All the experiments was done in triplicate in order to statistically supported and the analysis of variance can indicate the confidence level for each variable effect.

Table 1 – Design of experiment

Variables	Control Factor -1 lv	Control Factor 1 lv
Passes	2	3
Target Solvent Absorption ratio	4%	6%
Threshold of Drying ratio	2%	4%

On example of total controlled process monitoring is exposed in Figure 2. In this figure, the target mass absorption, drying threshold and cycles are expressed in function of time.

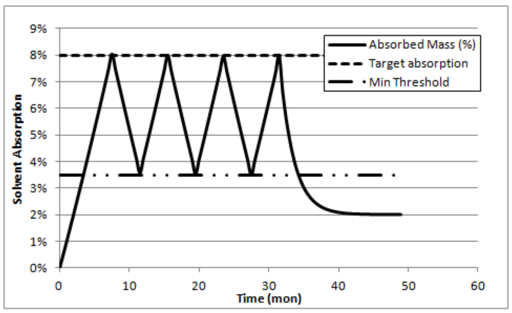

Figure 2 – Schematic of Solvent absorption, minimum threshold, target absorption and number of cycle repetition

For that process, we have also established a constant evaporation temperature (70°C), while acetone was used as solvent. In this case, the boiling temperature of acetone is 56°C so that we ensure that the vapour generation is kept constant along the exposure time. In addition, the general temperature ramp is presented in Figure 3.

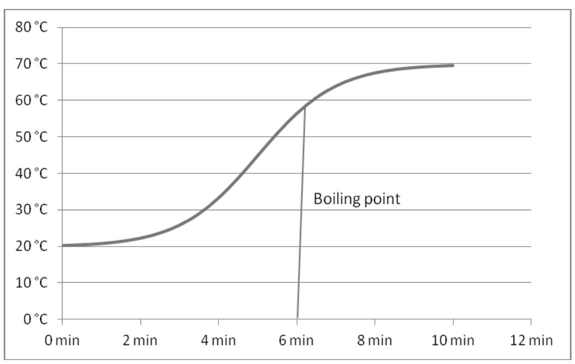

Figure 3 – Increasing temperature ramp curve

We have also established that the fabrication parameters were also constants, where: nozzle diameter is 0.4mm, layer height is 0.15mm, object density is 90% and 3 lines of contour shell. The material used was natural ABS GP35

For the analysis of surface roughness, we used an optical microscope and image processing in order to obtain the roughness of surface profile. The image processing was performed in MATLAB, while the image acquisition have been done by the optic microscope Digital Avangard Optics AN-

E500 [9], which provides until 500x of amplification magnitude. The geometrical distortion was analysed by a image processing through MATLAB, where the total deviation and local distortions were identified in a resolution of 0.001mm.

With respect to the equipment measurement system, the analogue load cell provides an error of 0.001g, while the data acquisition was defined to be 100 samples/s and 12bits resolution .

In order to ensure the experiment repeatability we established a procedure that consists in 5 steps, exposure, drying, , stabilization, dimensional analysis, surface roughness analysis, as it is possible to see in Figure 4. In this figure, the equipment working flow chart is also presented, indicating the operational dynamics of applied ON-OFF control.

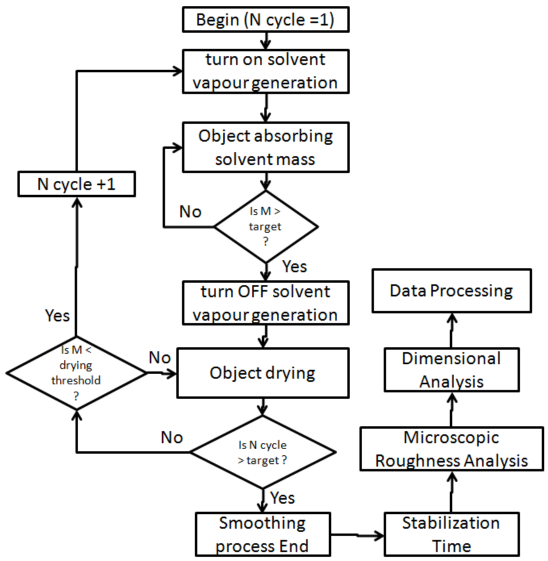

Figure 4 – Experiment flow chart

In this procedure, we included a stabilisation step before performing the tests after smoothing. This step was included to dry the solvent which impregnated the part surface. Otherwise, the properties of specimens would be jeopardised.

It is also important to note that all the specimens that suffered vapour treatment were submitted to microscopic analysis in addition to one specimens which were not exposed to vapour. In this case, these specimens were used as reference to analyze the effects of vapour treatment on the object.

3. RESULTS AND DISCUSSIONS

With respect to the gravimetric control, we could see that absorption and drying stages imply on cyclic behaviour . In this case, further studies are still needed to identify the effect of absorption rates in chemical structure in addition with the correlation with penetration depth and filaments fusing.

In the roughness analysis, we identified that the proposed controlled process works in accordance with the expected. Figure 5 shows that the roughness profile reduces the maximum and minimum peaks in addition to reducing Rz and Ra coefficients.

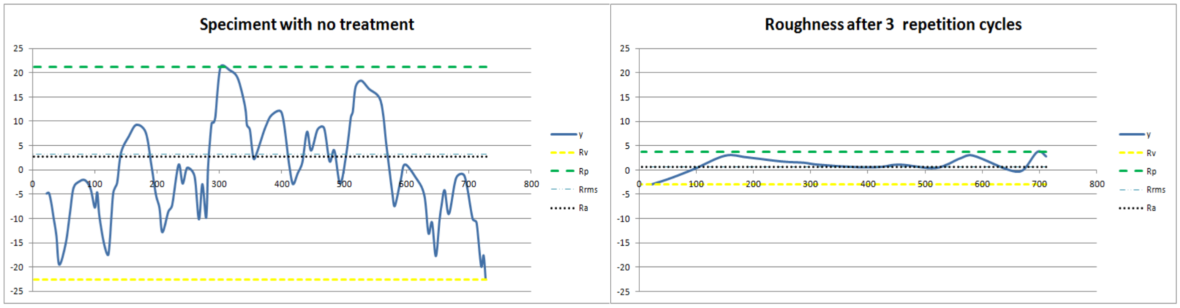

Figure 5 – Roughness profile analysis in μm dimensions

With regards to the main effects of control factors on roughness, Figure 6 presents that mass absorption target causes more effect on roughness. On the other hand, the combination of number of cycles and mass absorption target results in the minimal studied roughness.

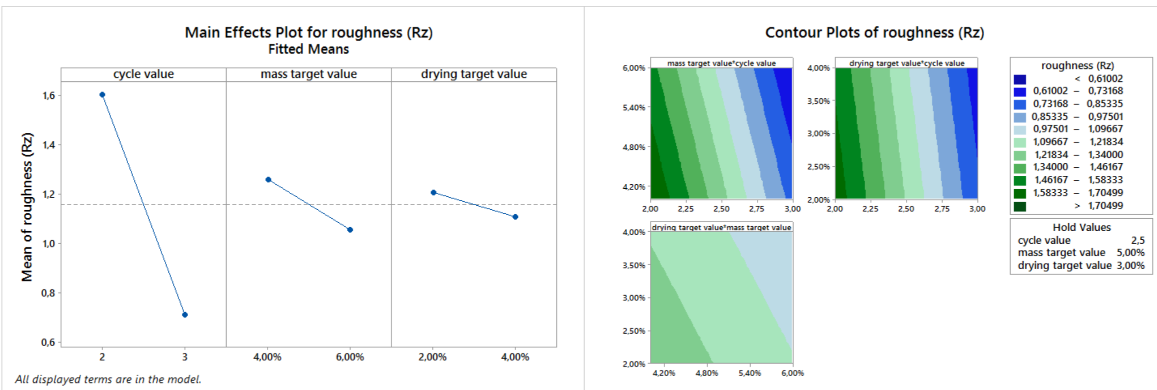

Figure 6 – Main and secondary effects of control factors on roughness

We can see that the geometrical distortion was also low in all studied cases, as presented in Figure 7. In this case, the equipment setup that caused minor effect on distortion was below 10μm. It might be explained by the fact that short vapour attack penetrates only superficially and does not significantly alter internal structure of object, as presented in previous studies [1].

On the other hand, the polishing appearance also increase as a function of number of passes, as it is possible to be seen in Figure 7

Figure 7 – Polishing effect as a function of number of repetition cycles

In spite of this study did not evidenced object damages further studies are still needed to identify the process limits. On the other hand, it was noted that this automatic method reduced human interference and reduces risks of objects damages.

4. CONCLUSIONS

In this work, the proposed method was identified to work, in addition not to producing severe geometrical distortions nor internal disruption, as hand craft methods.

It was possible to determine that this method might reduce the surface roughness in 5 times, besides the geometrical distortion does not exceed 1% even after 3 cycles. We could also identify that higher number of cycle implies on better finishing and automatic mass control tends to avoid potential part jeopardizing, as such long exposure time does.

By the end, we can indicate that this sort of process might be included in domestic or small business manufacturing cells, increasing the flexibility, productivity and quality of parts. This might push industry strategy to change in a short term future and migrate from a centre manufacturing to a distributed manufacturing system.

Although this process concept is shown to work, there are still further studies to be done in order to better understand the impact of different smoothing techniques and their control parameter on object properties.

5. ACKNOWLEDGMENTS

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