A CRITICAL REVIEW OF PROCESS PARAMETERS IN LAMINATED OBJECT MANUFACTURING PROCESS

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ABSTRACT

Laminated Object Manufacturing (LOM) is one of the sheet lamination additive manufacturing processes used to manufacture 3D solid object with the help of sheet lamination process. A formerly developed and verified model of LOM was used to study and find out the effects of various process parameters on the temperature profile in the part during the build cycle in this process. The process parameters i.e. roller speed, roller temperature, cutting time of laser, air temperature of the chamber and the base plate temperature were varied independently and their response on the LOM process is noted. This study also presents an analysis of one of the major problems occurred in LOM process i.e. warping and an optimal combination of these process parameters to reduce this warping effect.

Keywords: *Additive manufacturing, LOM, Process Parameters, Warping*

INTRODUCTION

Laminated object manufacturing is an additive manufacturing process developed by California based company Helisys Inc. in which the sheets of material are bonded to form an object. Electric energy, chemical adhesive or ultrasonic energy is used as an energy source in this process. Materials used in this process are Plastic, metal tapes or foils and paper. Interaction between energy source and material becomes possible by means of adhesive, bonding or welding[1]. Laminated objects are commonly utilized for stylish and visual models and are not suitable for auxiliary utilization. The understanding of the thermal behavior of a part build during the LOM process is very important in the part fabrication with better lamination characteristics. The top layer with low temperature may result in the poor adhesion of the individual layer which result into delamination of the completed part while the more temperature result in the structural rigidity loss during the part build which lead to excessive compression or shearing during the pressure application by the heated roller. In order to understand better, the transient behavior (thermal) of the part, a verified mathematical model was developed [1]. So it was decided to study and find out the effects of certain parameters with the help of this model by varying their values. Number of experiments were conducted in a relatively shorter time to study their effects on the part build with the help of this model and this also eliminate the use of high cost actual LOM machine. Also analysis of base plate and chamber air temperature with the help of this model can be done that is not implemented on LOM machine.

BACKGROUND

The full details of the mathematical model have been formerly given by Flach, L., D. Klosterman, R. Chartoff [1] that's why only a brief description of the capabilities of this model will be described here.

A mechanical sub model does not included in this model and thus the coupling of mechanical and thermal behavior cannot be fully simulated. However by adjusting one of the parameters of the model (roller to part heat transfer coefficient), we can get effective results between the actual temperature and the predicted temperature with in a part. Thus, this model is fully able to measure and analyse the thermal behavior of the LOM process.

EXPERIMENTS

The pattern of experiments was designed for a work. This work involved a layup of 260 micrometre thick Silicon carbide ceramic tapes and a twenty-layer 12.20 cm x 5.35 cm block of "green" ceramic material was produced. Data of material property and parameters for this base case is summarized in Table 1[1]. All the parameters were measured experimentally except the roller to part heat transfer coefficient which was used as an adjusting or tuning parameter.

Table1: Machine parameters and material properties for base simulation

Material	Silicon carbide ceramic tapes
Thermal Conductivity	1.25 $Wm^{-1}K^{-1}$
Density	1.98g cm^{-3}
Heat Capacity	1.05 $Jg^{-1}K^{-1}$
Part dimensions	121.9 mm × 53.3 mm
Layer thickness	0.25 mm
Number of layers	20
Heat transfer coefficient (part to air)	18 $Wm^{-2}K^{-1}$
Heat transfer coefficient (part to base)	14 $Wm^{-2}K^{-1}$
Air temperature	22℃
Base plate temperature	22℃
Initial temperature of material	22℃
Roller velocity	25.4 mm sec^{-1}
Roller contact strip width	9 mm
Roller temperature	91℃
Heat transfer coefficient (roller to part)	3300 $Wm^{-2}K^{-1}$
Build cycle time	120 seconds

The parameters selected for analysis were as follows: roller speed, roller temperature, cutting time of laser, chamber air or surrounding temperature and the base plate temperature. The roller temperature and the speed has an impact on the amount of transfer of heat from roller to part while chamber air temperature and base plate temperature has an impact on the rate of loss of heat of the part block. The amount of cooling between the successive layers is affected by the laser cutting time. All of these parameters influence the short term as well as the long term thermal behavior of the part. The values of these parameters used in this experiment and changes made to them are summarized in Table 2 [2]. The complete experiment and its results are given there [3]. In trials 15-18 in order to observe the dynamic response of the process to the variable change, the parameter values were changed.

Table 2: Schedule of LOM parameters

Trial	Roller temperature(°C)	Roller speed (cm/sec)	Base Plate Temperature(°C)	Chamber Air Temperature(°C)	Laser Cutting Time (sec)
1	91	2.54	22	22	77
2	150	2.54	22	22	77
3	200	2.54	22	22	77
4	250	2.54	22	22	77
3	200	2.54	22	22	77
5	200	2.54	50	22	77
6	200	2.54	75	22	77
7	200	2.54	100	22	77
3	200	2.54	22	22	77
8	200	2.54	50	50	77
9	200	2.54	75	75	77
3	200	2.54	22	22	77
10	200	3.81	22	22	77
11	200	5.08	22	22	77
12	200	2.54	22	22	57
3	200	2.54	22	22	77
13	200	2.54	22	22	97
14		2.54	22	22	117
15	91	2.54	22/50*	22	77
16	91	2.54	22/100*	22	77
17	91/150*	2.54	22	22	77
18	91/200*	2.54	22	22	77

RESULTS AND DISCUSSION

The temperature below the bottom most (First) layer was indicative of the part body temperature. So, in order to compare the response of the part when undergone through different parameters, it was determined to notice the first layer temperature only.

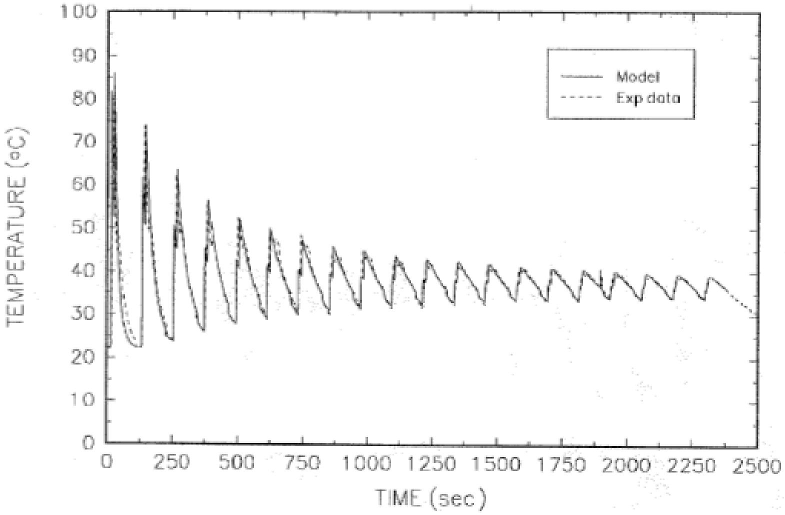

Figure 1: Base simulation and experimentally measured temperature profile for a 20-layer, SiC LOM part, as measured by a thermocouple just above the 0th layer (foam tape base) during the build process The cycle time is 120 seconds per layer. The experimental conditions are given in Table 1 and Table 2 (trial #1).

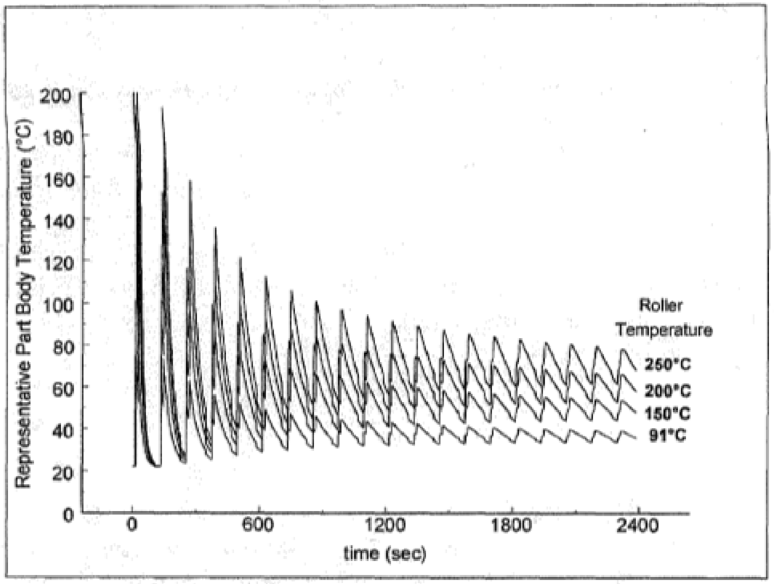

Figure 2: Parametric variation of roller temperature: simulated, dynamic temperature profiles inside a 20-layer SiC LOM part during the building process (120 seconds per layer) using the parameters given in Table 2 (trials 1-4).

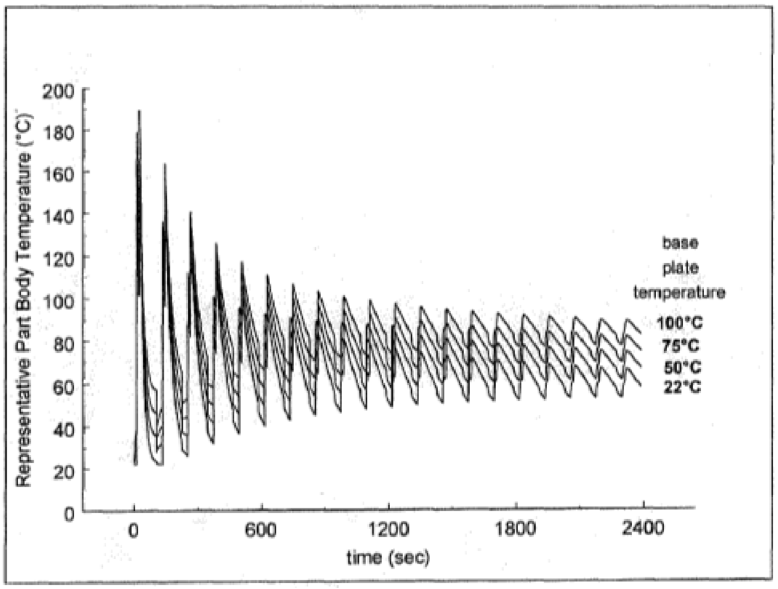

Figure 3: Parametric variation of base plate temperature: simulated, dynamic temperature profiles inside a 20-layer SiC LOM part during the building process (120 seconds per layer) using the parameters given in Table 2 (trial 3, 5, 6, 7).

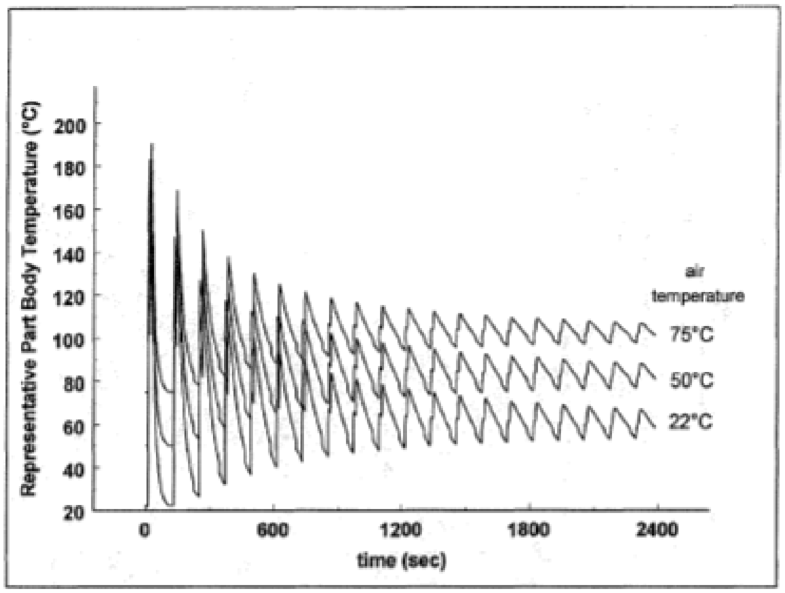

Figure 4: Parametric variation of chamber air temperature: simulated, dynamic temperature profiles inside a 20-layer SiC LOM part during the building process (120 seconds per layer) using the parameters given in Table 2 (trials 3, 8, 9).

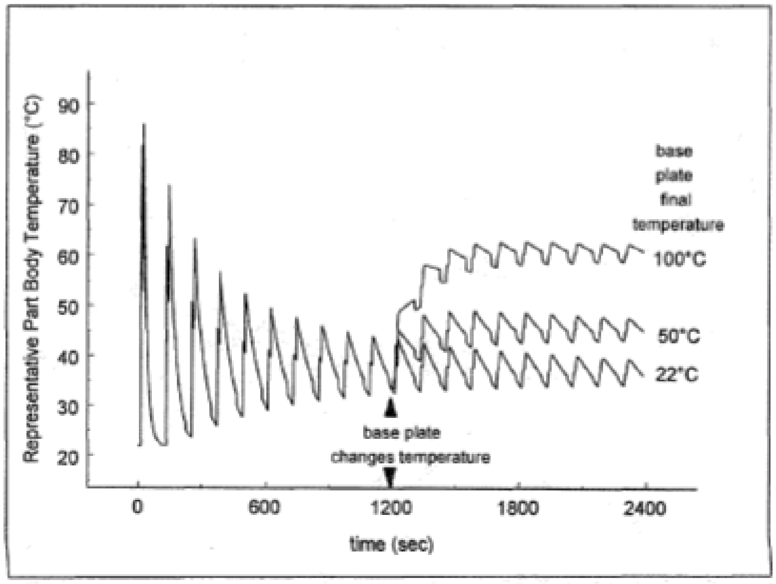

Figure 5: Effect of changing base plate temperature halfway through a run: simulated, dynamic temperature profiles inside a 20-layer SiC LOM part during the building process (120 seconds per layer) using the parameters given in Table 2 (trials 15, 16).

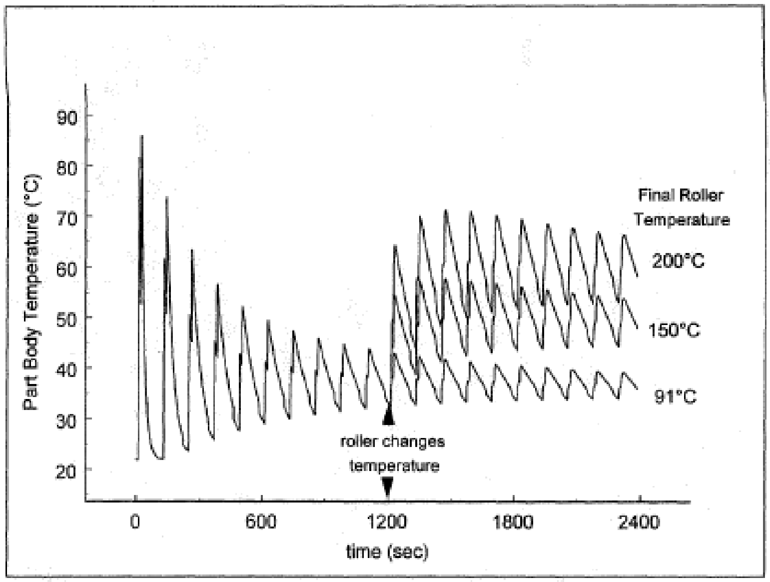

Figure 6: Effect of changing the roller temperature (from 91°C) halfway through a run: simulated, dynamic temperature profiles inside a 20-layer SiC LOM part during the building process (120 seconds per layer) using the parameters given in Table 2 (trials 17, 18).

The first parameter studied was roller temperature. The roller temperature was deviated in the range between 91°C to 150°C and all the other parameters were kept constant and same as in the base trial (trial 1). The temperature of the surface layer (in contact with the roller) is most significantly affected. From the figure 2, Mean part body temperature increased about 10°C for every 50°C rise in the temperature of the roller.

The roller speed was studied next because the time of the contact of the roller with the part surface also influences the amount of heat transferred to the part. So, the overall build time of the part can be changed and affected by changing the roller speed. It was observed that for a 50% increase in the roller speed, the mean part body temperature decreased by about 7°C and by about 23°C for a 100% increase [3]. Again the top surface or layer in direct contact with the roller was the most affected one.

The next study involved the difference of the base plate temperature only. Increasing the base plate temperature gives the higher temperature to the work part being built. The mean part body temperature rises to 9°C for 25°C increase in base plate temperature. The results for the variation in this parameter are shown in the figure 3. The impact of the variation in this process parameter on the process was taken as more efficient than the impact of roller temperature.

The next study involved the effect of changes in the chamber air temperature. The transient variation of the part body temperature with the varying base plate and chamber air temperature is shown in figure 4. The mean part body temperature rises 20°C approx for 25°C rise in the chamber air and the base plate temperature. So, this effect was considered as the most efficient upto now.

The value for laser cutting time is taken as 77 seconds for the experiment. Since the cycle time varies throughout the part build because of the changes in the cutting by laser from layer to layer, that’s why this effect is need to be investigated. Varying the cutting time of laser applied between the layers successive to each other of build material affect the temperature of the part because of the reason that, rising this time allows the extra time for the part to cool by heat transfer to the surroundings and the base plate. Though this effect was rather little, in most of the cases, for a 20 second increase in the laser cutting time, about 3°C fall in the body temperature of the part occurred [3].

Some active tests were also performed where the base plate and roller temperature were varied through the build process to find out how many layers (or cycles) were needed for the workpart to answer to the variation in these values. From figure 5, it can be concluded that the part body temperature consistently reaches its new mean temperature within 3 to 4 cycles. Also we got similar results for the variation in the temperature of the roller.

WARPING

Warping is the important type of problem in the laminated object manufacturing process. It frequently happens at the starting of the fabrication of part in the process, specially when the laminated part is cold, temperature of the heating is low, or the size of the prototype is large.

Warping generally begins at the end corners and curves the part upward as shown in the figure 7 [4].

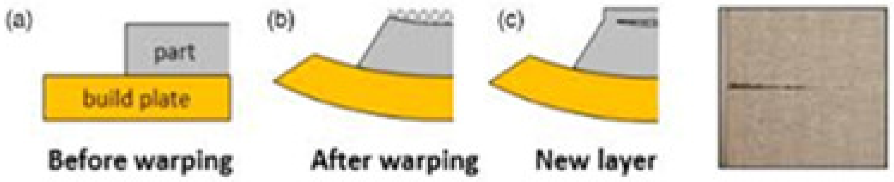

Figure 7: Schematic of build plate warping effect during processing (a-c) and resultant damage

Intra-laminar thermal forces produced by the non-uniform distribution of temperature at the interfaces of layer of the part, also plays a major role in causing the warping. When the hot roller is pressed onto the laminated layer of the part, the temperature at that layer rises and falls when it is removed during the laser cutting. During this process, the laminated layer extend or contract with the variation of temperature during the operation resulting in the deformation between the layers due to the thermal force. This thermal force is considered as one of the most significant factors for warping. So, the analysis and simulation of this intra-laminar thermal force was conducted [5].

CONCLUSION

The analysis has shown that the process parameter studied above has an influence over the performance of the process. mainly, the combination of base plate and chamber air temperature would appeared to be the most sensitive for control of the overall part temperature but practically using the base plate temperature could also be done to achieve the finite control. The roller temperature found to be the most effective parameter in influencing the temperature of the layer of the surface of the part. Thus if we require the high range of temperature at the surface of layers and lower temperature range all through the rest of the part, the control of this parameter would assign a mean to achieve this.

While the main cause of warping is found to be intralaminar thermal forces of compressive nature produced by the uneven thermal deformation between the layer interfaces. The process parameter like roller or flat speed, roller heating temperature and the contact pressure applied between the layers will affect the workability and warping of the part laminated. If the roller or flat is hotter and moves slower, the predicted intralaminar thermal force will be smaller and the prototype will not appear to warp. So an optimum combination of the process parameter may be used to reduce the unwanted warping effect.

REFERENCES

[1] Flach, L., D. Klosterman, R. Chartoff, "A Thermal Model for Laminated Object Manufacturing Process" Proceedings of the Solid Freeform Fabrication Symposium, Austin, TX, August, 1997, pp. 677-688.

[2] Lawrance Flach and Jacobs, Klosterman, and P. Chartoff, “Simulation Of Laminated Object Manufacturing (LOM) With Variation Of Process Parameters”, Department of Chemical and Materials Engineering and Rapid Prototype Development Laboratory and Ohio Rapid Prototype Process Development Consortium, University of Dayton, U.S.A, pp. 407-416.

[3] Jacobs, M.A., “Thermal Modeling and Control of the LOM Process”, Undergraduate Honors Thesis, Chemical Engineering, University of Dayton, April, 1998.

[4] W. J. Sames, F. A. List, S. Pannala, R. R. Dehoff & S. S. Babu (2016): The metallurgy and processing science of metal additive manufacturing, International Materials Reviews.

[5] Lin, Feng & Sun, Wei. (2001). “Warping Analysis in Laminated Object Manufacturing Process”. Journal of Manufacturing Science and Engineering-transactions of The Asme - J MANUF SCI ENG. 123. 10.1115/1.1403447.

[6] Md Ashiqur Rahman and Hridoy Biswas,” A Brief Review of Additive Manufacturing With Applications”, Proceedings of 14th Global Engineering and Technology Conference 29-30 December 2017, BIAM Foundation, 63 Eskaton, Dhaka, Bangladesh.

[7]Klosterman, D., R. Chartoff, N. Osborne, G. Graves, A. Lightman, G. Han, A. Bezeredi, S. Rodrigues, S. Pak, G. Ialmanovich, L.Dodin, S. Tu, "Curved Layer LOM of Ceramics and Composites," Prototyping Technology International '98, (Annual Review Book), ed.Jonathan Lawson, UK & International Press, Surrey, UK, April, 1998, pp.145-149.