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"Mathematical Modeling And Numerical Simulation Of Selective Laser Sintering By Considering Heat Transfer Process"

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Abstract - Selective Laser Sintering (SLS) is an important branch of Additive manufacturing ("3D printing") technologies. It is also know as leading process for developing rapid prototype objects by selectively fusing layers of powder according to numerically defined cross sectional geometry. This process was initially developed to produce polymer-based components, but due to the advancement this process is now capable of producing structurally perfect parts directly from metal powders. In this manufacturing technique a pre-heated layer of material powder undergoes a laser radiation in a selective way so that three dimensional metallic or polymeric solid parts can be produced.

In the present paper we use three dimensional steady and transient finite element model developed in abaqus to study the heat distribution taking place during sls process applied to polycarbonate powder.

Key Words: **SLS , Abaqus, Polycarbonate powder.**

1. INTRODUCTION

The ever increasing competition in the world market for manufactured products , development of new frontiers demanding highly customized products in shortest possible time has ultimately lead to the development of new methods of manufacturing which have ability to challenge the position of conventional manufacturing.

Layered Manufacturing (LM), Additive Manufacturing (AM) or Solid Freeform Fabrication (SFF) is a class of manufacturing methods that has seen a rapid growth over the years since in late 80's. It enables quick production of complex three-dimensional parts of designed macro and microstructure directly from CAD data, completely eliminating the intermediate tooling steps, therefore shortening production time and reducing associated costs. The invention of layered manufacturing has brought a breakthrough in manufacturing technology because of immense benefits associated with it. Additive manufacturing processes take the information from a computer-aided design (CAD) file that is later converted to a stereolithography (STL) file. In this process, the drawing which are made in the CAD software is approximated by triangles and sliced containing the information of each layer that is going to be printed. Studies are reviewed which were about the strength of products made in additive manufacturing processes. However, there is still a lot of work and research to be accomplished before additive manufacturing technologies become standard in the manufacturing industry because not every commonly used manufacturing material can be handled. The accuracy needs improvement to eliminate the necessity of a finishing process. The continuous and increasing growth experienced since the early days and the successful results up to the present time allow for optimism that additive manufacturing has a significant place in the future of manufacturing.

The proposed work deals with sintering of polycarbonate powder in which the mathematical modeling of different sub model such as optical, thermal and sintering have been carried out. A transient three dimensional finite element model is developed to simulate the phase transformation during the selective laser sintering process. Owing to the continuous movement of the laser beam the model takes also into account the transient nature of the problem. Results for heat flux distribution using polycarbonate powder for steady and transient condition, will be presented.

2. MODELING

The physical processes which are mainly associated with the SLS process are heat transfer and sintering of powder. The modelling and numerical simulation of the SLS process includes optical, thermal and rheological(sintering) processes.

1.1 Sintering model :

The sintering behaviour commonly referred to the phase transformation of the material from the powder state to the solid state by the sintering process.

$$\frac{\partial \rho}{\partial t} = \left(\rho^{\max} - \rho^{t+\Delta t}\right) A \exp\left(-\frac{E}{RT}\right)$$

where ρ is the powder density, ρ max is the density of the totally sintered (solidified) material, *E* is the activity energy set at a correct value to obtain a good kinetics of the sintering with reference to standard process parameters and with *A* the pre-exponential factor been fixed at 8.84×1016 s−1.

1.2 Optical model :

The optical behavior is commonly referred to the interactions between the laser beam and the powder bed surface. Phenomena considered in the optical model are reflection, transmissions, absorption, etc.

$$I(t,w)=(1\text{-}R)I_0\exp\left(-\frac{2r^2}{w^2}\right)$$

Where R is the reflectivity of the surface of the material, the reflectivity of the CO2 laser in polycarbonate powder is approximately 4% . I0 is the maximum beam intensity, calculated from the laser power P and the characteristic radius of the laser intensity profile w given as

$$I_0=\frac{2P}{\pi w^2}$$

where *w* is the characteristic radius, a function of the laser radius, and *P* the laser power.

1.3 Thermal model :

The thermal behavior refers to the heat transfer mechanisms that occur due to the laser light penetrating the powder bed. Phenomena considered in the thermal model are conduction, convection and radiation.

$$\rho\times c_p\frac{\partial T}{\partial t}=\nabla\cdot(k_e\times\nabla T)+r$$

is the heat equation with temperature- and sintering dependent heat conduction properties (*cp* been the specific heat and *r* the internal, volume, heat source term).

Heat conductivity:

The local effective heat conductivity, ke , relates not only to the local temperature of the powdered bed, but also to the heat conductivity of solid material ks , the heat conductivity of air kg and the porosity Ɛ . A model to calculate the heat conductivity is separately proposed by two conditions, low-temperature and high-temperature. At low-temperature, only the phenomenon of convection affects the heat conductivity. While at high-temperature, the heat transfer by radiation is evidently enhanced that can also affect the heat conductivity:

$$k_e=\begin{cases} k_s(1-\varepsilon)/(1+\varphi k_s/k_g) & T\le 673°K \\ (1-\varepsilon)/\left[1/k_s+\varphi/(k_g+\varphi D_p h_{rs})\right]+\varepsilon D_p h_{rv} & T>673°K \end{cases}\quad (\mathrm{W/m°K})$$

Where Φ is a model parameter function of the material porosity Ɛ , and Dp is the average diameter of powder grain. The model parameters hrs and hrv are the radiation heat transfer coefficients between solid surface of the powder grain, and between voids respectively.

Specific heat:

The specific heat of polycarbonate material is assumed linear function of temperature in both the solid and the melt phases. The temperature dependence of the specific heat, Cp , is given by the following equation

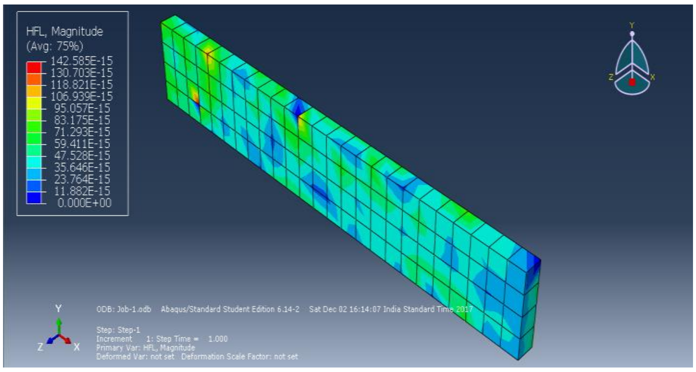
$$C_p=\begin{cases} -20.56+4.103\times T & T\le 418°K \\ 935.34+2.284\times T & T>418°K \end{cases}\quad (\mathrm{J/kg.°K})$$

The current FE approach relies on the geometrical approximation of the powder bed by a 3D rectangular parallelepiped mesh of 5mm x 0.8mm x 0.2mm for the polycarbonate model. These mesh size are adapted to the modeled laser trajectory so that it contain "DC3D8" in the thermal FE analysis undertaken within the ABAQUS code.

Table -1: Material properties and process parameters for the polycarbonate SLS

Property or process parameter	Full name	Value	Unit
$T_{initial}$	Pre-heating temperature	373	K
ρ_o	Initial density of powder	600	Kg/m³
ρ	Full dense solid material density	1200	Kg/m³
h	Film coefficient	25	W/m²k
Ɛ	Emissivity	0.8	-
E	Activation energy	149.7	kJ/mol
K	Conductivity	0.22	W/mk
C_p	Specific heat capacity	1200	J/kgk

3. RESULT



ODB: Job-1.odb Abaqus/Standard Student Edition 6.14-2 Sat Dec 02 16:14:07 India Standard Time 2017

Step: Step-1
Increment 1: Step Time = 1.000
Primary Var: HFL, Magnitude
Deformed Var: not set Deformation Scale Factor: not set

Fig.1. Steady state condition

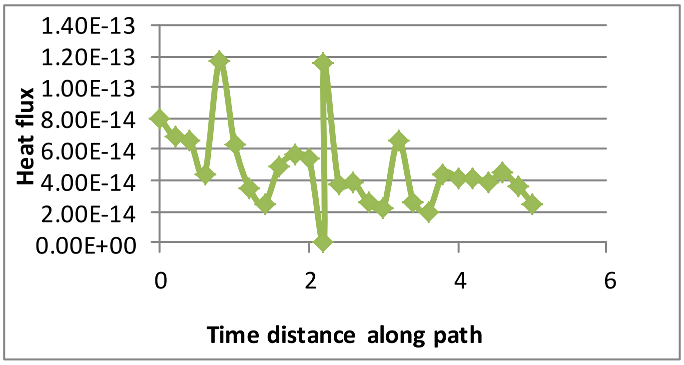


Fig. 2 Time distance along path

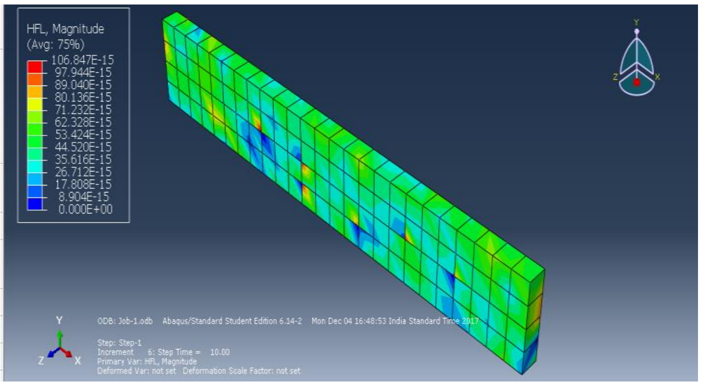


Fig.3 Transient state condition

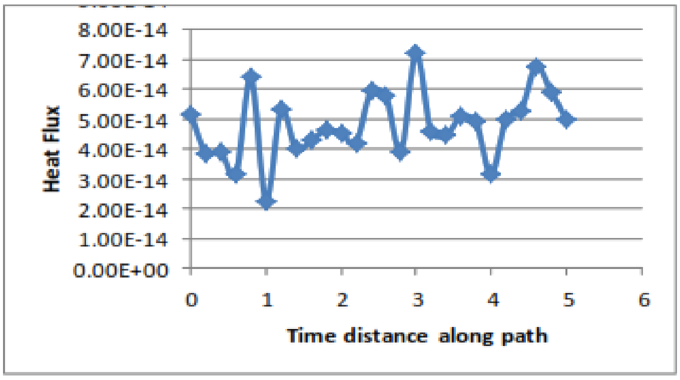


Fig. 4 Time distance along path

4. CONCLUSIONS

In this paper, we present the thermal modeling by finite element method of a Selective Laser Sintering (SLS) process. We model the behavior of the materials under this process using three different sub-models: a sintering sub-model, an optical sub-model, and the thermal sub-model. Interpretation of the results both in terms of steady and transient condition shows that the distribution of heat flux fluctuate more in steady condition than in transient condition.

Two cases of SLS processes are reported here: steady and transient state, In the case of transient SLS, the modeling approach was compared to experiments and showed a good correspondence between the two.

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