SIMULATION ON ADDITIVE MANUFACTURING (SELECTIVE LASER SINTERING) OF HIGH SPEED STEEL (M2) – MECHANCICAL BEHAVIOUR AND TEMPERATURE DISTRIBUTION USING COMSOL SOFTWARE

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ABSTRACT

This report is about the introduction to the concept and process of Additive manufacturing. Using the Additive manufacturing techniques, simulation is done on a High Speed Metal (Steel) in this project. In this simulation of metallic powder bed additive manufacturing process we get the major findings like temperature field, residual stresses and melt pool characteristics that occur in a metal. Selective Laser Sintering is a famous metal additive manufacturing process that is used to melt powder metal on a bed and form a metal plate of desired material that is formed layer by layer with the melting of the metal powder.

In this simulation of the laser melting powder bed fusion additive manufacturing process we use a multi-scale approach implemented with the COMSOL Multiphysics® software, Heat Transfer Module, and Structural Mechanics Module. COMSOL Multiphysics is the software which we use in this project for the process of simulation of STEEL.

Index terms: Additive Manufacturing, Melt Pool, Selective Laser Sintering, COMSOL

I.　INTRODUCTION

Additive manufacturing is the official industry standard term (ASTM F2792) for all applications of the technology. It is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms are additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.
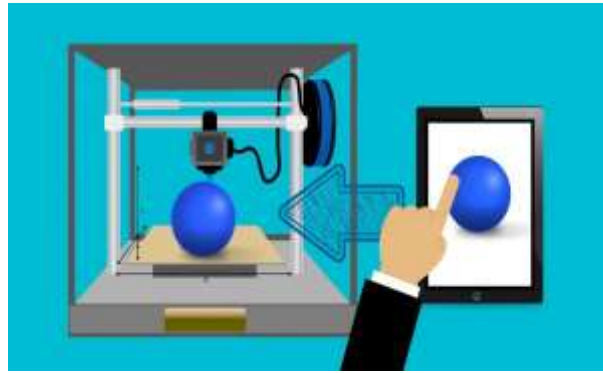
This tool-less manufacturing method can produce fully dense metallic parts in short time, with high precision. Features of additive manufacturing like freedom of part design, part complexity, light weighting, part consolidation and design for function are garnering particular interests in metal additive manufacturing for aerospace, oil & gas, marine and automobile applications.

II. MODELING AND ANALYSIS

1. 3D Geometry Of Block

According to the Selective laser melting process as shown in fig a rectangular high speed steel (M2) metal block should be considered for simulation process.
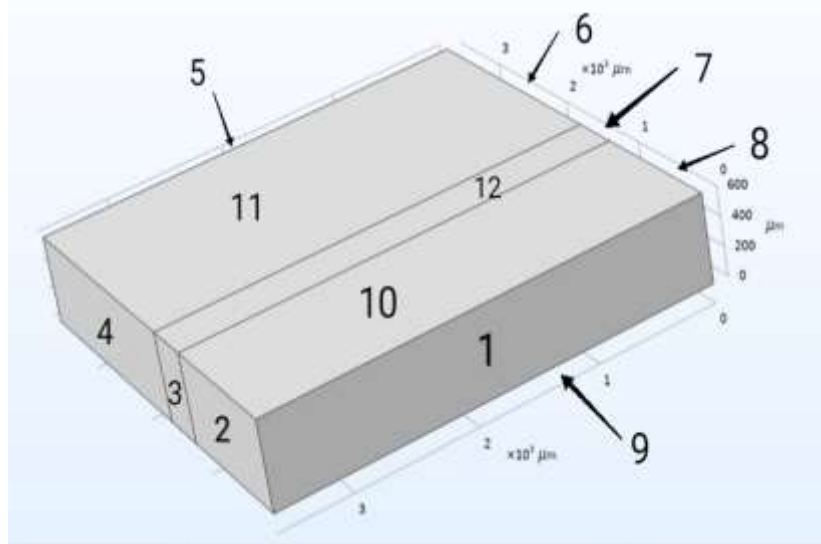
Construction of a block with 3.6(mm) length, 3.6(mm) breadth, 0.6(mm) width. It's divided into 3 layers as shown in this fig. Add HSS (M2) material to the block which is already exist in software. It contains all properties except poission's ratio which should be given in between 0.27 to 0.3 .Laser beam travels on the center layer so the part contains three parts. According to software every surface should have numbers as shown in this fig. according to the process select the surface manually for laser beam, conduction and radiation .

2. Assigning the Parameters

After selecting the material as HSS(M2) to the block, check all the parameters of the material.

Property	Nomenclature	Value(units)
Material properties		
Melting temperature	T_m	1700 (K)
Vaporization temperature	T_v	3,273.15 (K)
Latent heat of melting	L_m	1,067.43 (J/g)
Latent heat of evaporation	L_v	1,066.5 (J/g)
Mass of vapour molecule	M_v	1.693e−25 (kg/atm)
Thermal expansion coefficient	α	8.4e−6 (1/K)
Temperature derivative of the surface tension	γ	−8e−5 (N/(m K)) Dynamic viscosity

μ   (T<2,1900K)

Laser machining parameters   Number of laser pulses

f   10, 20, 30, 40, 50 pulses   Pulse energy

(E_p)   0.2,0.4,0.6,0.8,1 (J)   & corresponding average laser energy density

(E_d)=E_p/((D^2π)/4)*f   -------   0,7, 1.4, 2.1,

2.8, 3.5×10^7 (J/m^2) respectively   Pulse width

P_w 0.5 (ms)   Beam diameter

D   0.6 (mm)   Emissivity   ε

0.7   Heat transfer coefficient   h   10 (W/m^2 K)

Absorptivity   A   0.25

Half-width of the curve   ΔT   30 (K)

Reference point to represents the center

of the laser beam X_r 1,000 (μm) Standard deviation of the

Gaussian laser beam   φ   100 (μm)   Ambient temperature

T_a 293.15 (K)   Initial temperature

T_i 293.15 (K)   Stefan−Boltzmann constant

σ   5.67×10^{-8} (W/m^2 K^4)   Universal gas constant   R

8.314 (J/mol K)   Gravitational acceleration   g

9.81 (m/s^2)

3. Declaring The Variables

Variables are used to simplify the Gaussian distribution for laser heat source.


4. Giving The Laser Heat Source

Adding the Laser Heat source to the 12th layer on the solid makes the laser move in that path where the heat travels in that direction . The principle of the Laser Heat Source is the Gaussian Distribution .

Laser beam is travels using Gaussian distribution is denoted by **P_g.** The function expressed in variables. Laser beam travels in center layer as show in the above fig.   In simulation, the laser is defined as energy source term and described by radiation source with a Gaussian distribution function.
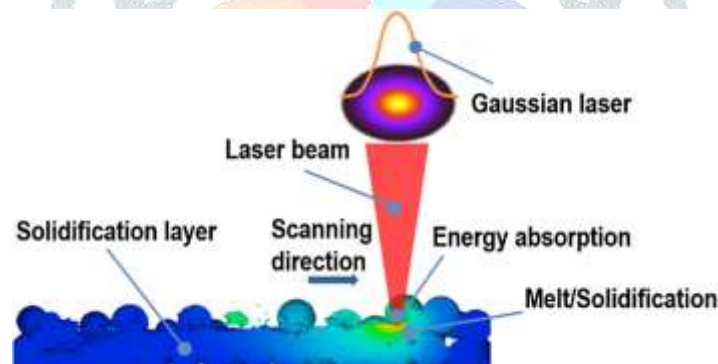

$$P_g = A \left[E_p/(P_w(\pi/4) D^2) \right] \exp \left[((x-x_r) /2\times r_0^2)^2 \right]$$

All values are expressed in parameters using variables this expression simplified and apply in heat source.
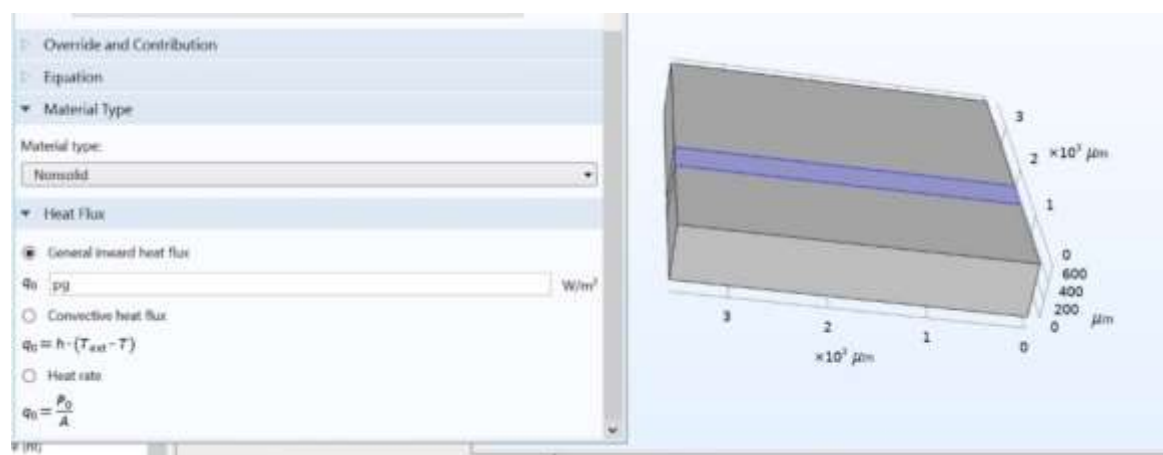
5.　Determining the Conditions for Cooling

Laser beam gives high temperature to the body for bond between the particles .So after that solidification purpose two types cooling are there in nature for creating the real atmosphere around the body. So, the total surface of 3D body react with this except the lower surface, it consider as insulator.　　　　　　　　　Heat loss = convection + radiation
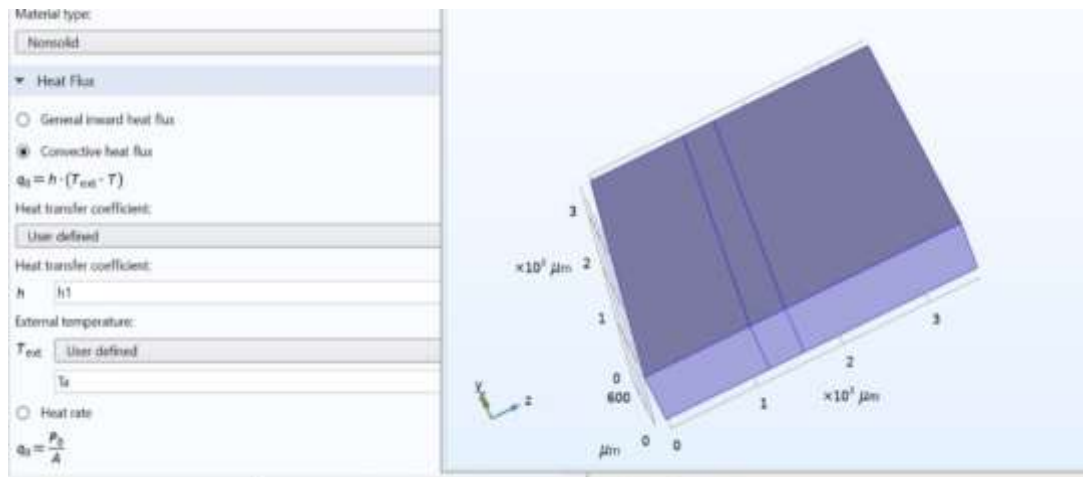
Convection:　　Cooling is the process of convection in metals. Where h1 is heat transfer coefficient . h_1 value is expressed in parameters it's a free convection process, so h1 have small value. Function used in cooling ,

$$\text{Heat transfer} = h_1(T - T_{atm})$$

where,　$h_1 = 10$ W/m^2.k,　$T_{atm} = 293k$, and T is depends on laser heat

6.　Determining the Conditions for Radiation

Radiation is one of the heat loss process . It's used to create actual conditions around the block (body).

Radiation formula Surface to ambient radiation $= \mathbf{e} \times A \times (T_{body}^4 - T_{atm}^4)$
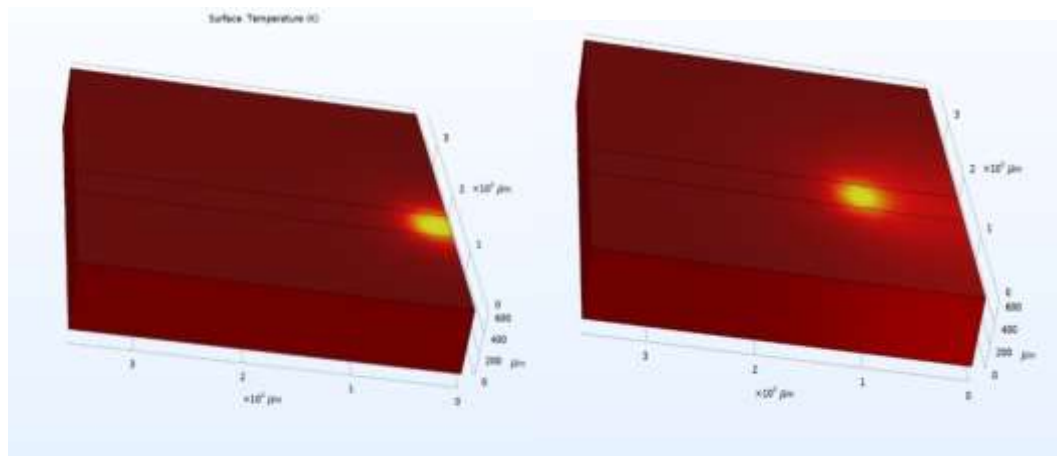
Where $\mathbf{e}$ is Stefan-Boltzmann constant , temperatures are given in the parameters. Radiation effects total body as Show in this fig.
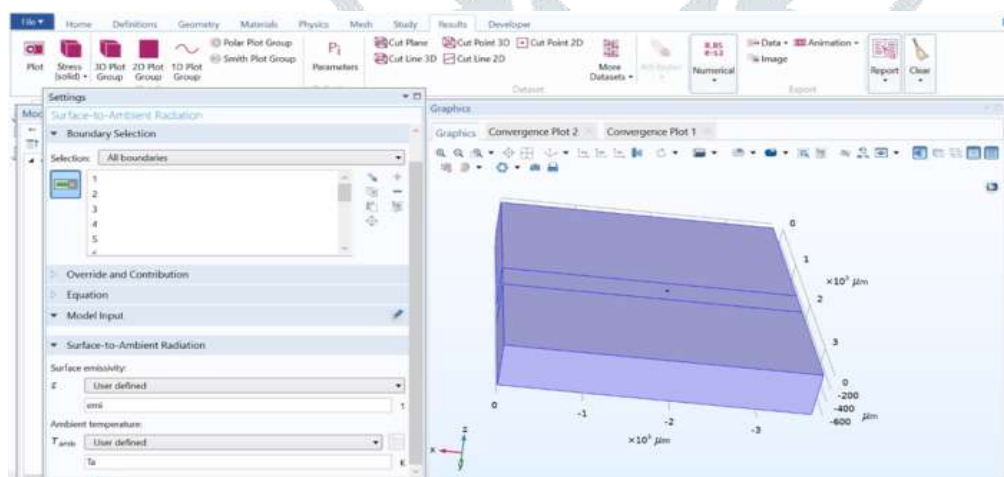
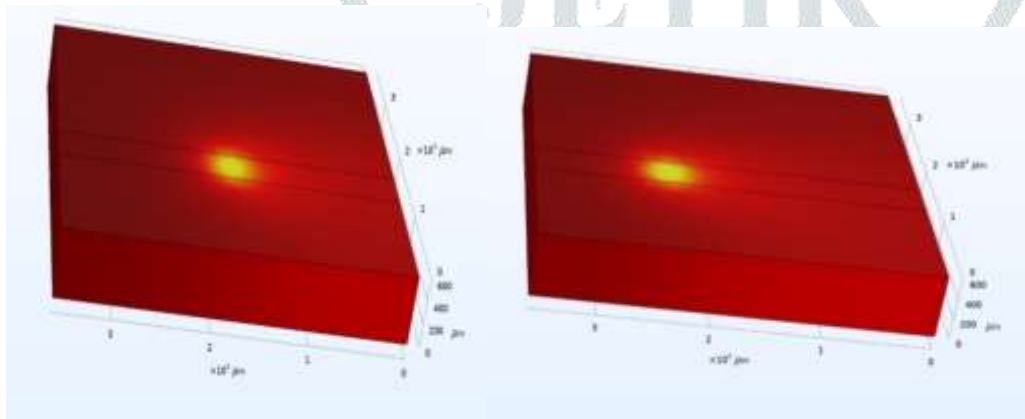## III.   RESULTS AND DISCUSSION

1.   Temperature Distribution

The block consist traveling laser beam and cooling, radiation beat losses. Traveling laser beam according to time as show in the fig .

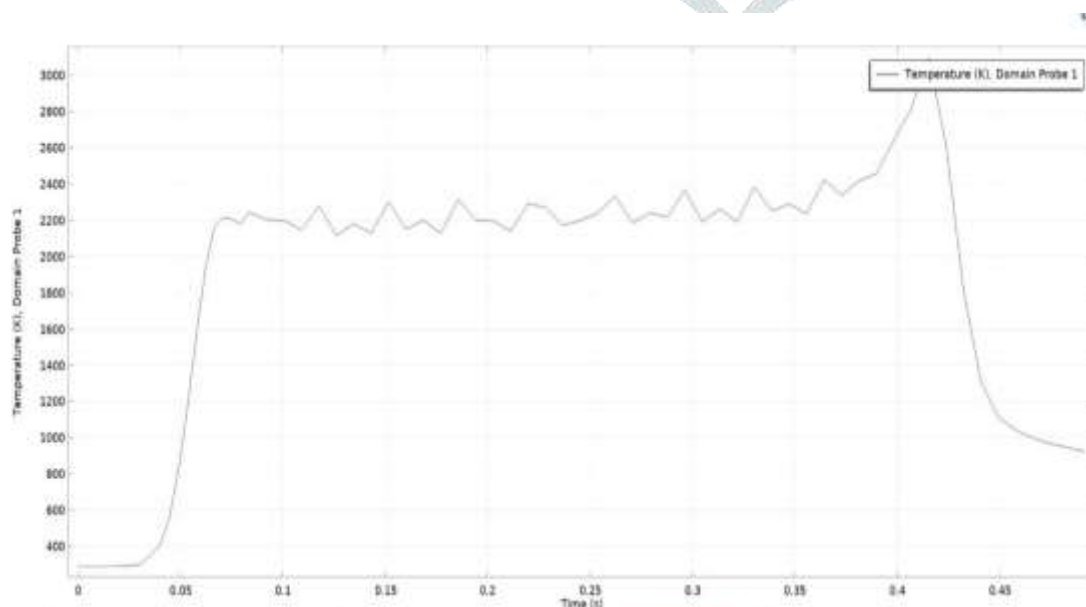(a) 0.08 sec   (b) 0.16 sec

(c) 0.24 sec   (d) 0.30 sec

The time depends on laser speed and length of block.

Graph plot between time vs. temperature.

Maximum temperatures of the body is depends on the input heat given in joules. Temperature Distribution depends on three parameters

    i.   Speed (V_{in})

   ii.   Diameter of Laser Beam (D)

  iii.   Input Energy (E_p)

The Temperature Distribution on the following parameters, and now let's see how the temperature distribution changes with different values of this three parameters.

Firstly let's keep the speed and Diameter be constant and the values of Input Energy changes. The Values of Temperature are taken in the form of Table.

Taking the Values of Speed (V_{in}) =10mm/s and Diameter (D) = 0.6mm

Input Energy	Max. Temperature(k)	Working Temperature(k)
$0.7 \times 10^7 J/m^2$	3000K	2100 to 2400K
$1.4 \times 10^7 J/m^2$	5500K	3800 to 4500K
$2.1 \times 10^7 J/m^2$	8500K	5500 to 6000K
$2.8 \times 10^7 J/m^2$	10800K	7400 to 8000K
$3.5 \times 10^7 J/m^2$	13000K	9000 to 10100K

Speed	Max. Temperature(K)	Working Temperature (K)
5 mm/s	3400 K	2300 to 2600 K
10 mm/s	3000 K	2100 to 2400 K
15 mm/s	2800 K	2000 to 2200 K
20 mm/s	2600 K	1900 to 2100 K
25 mm/s	2500 K	1800 to 2000 K

Now keeping the values of Input Energy (Ep) = 0.7×10^7 J/m2 and Diameter (D)=0.6mm and varying the values of Speed (Vin). We got the Following values :

Now keeping the values of Input Energy (Ep) = 0.7×10^7 J/m2 and Speed (Vin) = 10mm/s and now keeping the value of Diameter constant. We got the following values :

| Diameter mm	Max. Temperature (K)	Working Temperature(K)
0.5 mm	4300 K	2900 to 3200 K
0.6mm	3000 K	2100 to 2400 K
0.7mm	2200 K	1600 to 1800 K
0.8mm	1800 K	1300 to 1500 K
0.9mm	1600 K	1100 to 1300 K

Maximum temperature(k)	Minimum temperature(k)	Maximum thermal stress (M pa)	Average thermal stress (M pa)
1800	293	90	50
2800	293	140	80
340	293	160	110
4000	293	200	160
5500	293	250	190
8500	293	350	220

2. Thermal Stresses

Laser beam contains very high temperature, so this temperature distributes to total body. Stress is the force acting per unit area. The force can be of any form. When the applied force is in the form of temperature the resultant stress is called Thermal stress. It is observed when an object expands or contracts due to a change in temperature. Thus, we can define Thermal stress. According to above diagram each colour have certain value of thermal stress in N/m$^{2.}$

The scale (right side of the diagram) have different colours according to the colour thermal stress acting on the body as show in the fig . Comsol multi-physics software gives von-misses stress.
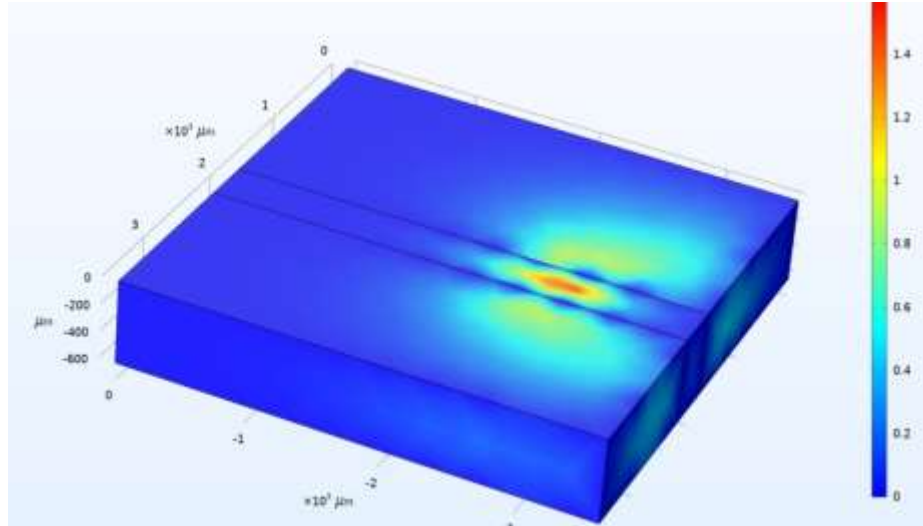
Von-mises stresses:

Von Mises is credited with coming up with what is arguably the most accepted yield criterion (way of resolving these stresses). He designed an equation that takes in each shear and principal stress value, and in turn spits out a single "von Mises stress value", which can be compared to a yield strength of the material. If the value is greater than the yield strength, the part is failing according to his criteria. If it is less, then the part is said to be within the yield criteria and is not failing (for yield failure only). The equation for Von Mises stress is shown below.

$$\sigma = \sqrt{0.5\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2\right]} + \sqrt{+3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)}$$

Note the sigma's (σ) correspond to normal stress values, and the taus (τ) are the shear stress values.   According to the all consideration thermal stresses depends on temperature difference.

IV.   CONCLUSION

In this paper temperature and thermal stress distribution of high speed steel is presented. While modeling the simulation of SLS process, the maximum and working temperature and thermal stresses of powder bed were analyzed .The following observations were found in the selective laser sintering process. Temperatures depend on input heat energy, laser beam velocity and diameter. Thermal stresses depend on the temperature difference. So the below values gives good results in laser sintering process according to model and considerations for high speed steel (M2).

Laser beam diameter (mm)	Input energy (J/m^2)	Laser velocity (mm/sec)
0.6	0.7×10^7	10

At this condition we get 3000k maximum temperature and 2100 to 2400 working temperature. This temperatures are in between melting temperature (1700k) and boiling point (3273.15k), so its gives good bonding between particles and this condition we get less thermal stress (140 M pa) with compare to maximum thermal stress (1000 M pa) of high speed steel (M2).

V.   REFERENCES

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