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NUMERICAL SIMULATION OF LASER BEAM MACHINING OF POLYMETHYL METHACRYLATE

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Abstract: *Laser beam machining is a thermal based ablation process used for micro milling to create microchannel profiles. In the present work, the single-pass laser cutting process simulation has been investigated in FEM software, considering laser beam as a moving heat source. The main objective of the present investigation is to study the effect of laser parameters on the surface temperature distribution and the nature of gaussian heat source. This paper uses a 2-Dimensional model to analyze the effect of laser beam machining parameters on Polymethyl Methacrylate using COMSOL Multiphysics 5.6. It is also observed that simulated temperature distribution profile follows the same trend as it was analytically developed by previous work for moving heat source. The maximum average temperature attained by the laser beam source is 36435 K. It also noted the temperature degraded rapidly away from the point source of laser beam which leads to bell shaped graph i.e. gaussian distribution at 0.06 time which reduces as the laser beam source moves ahead.*

Key words: *Laser beam machining, Numerical Simulation,* CO_2 *laser machine, Laser power*

1. INTRODUCTION

Laser cutting is a non-conventional manufacturing process which is highly recommended for micro-channeling and drilling operation for its precise and quality cut [1–3]. The usage of laser technology is widespread in the fields of medicine, engineering, the auto sector, and electronic equipment [4,5]. PMMA has been utilizing in application field of Biomedical engineering, due to its biocompatibility, non-toxicity, reliability and processability [6–11]. Laser technology and its application in manufacturing industries generally use CO_2 lasers and Nd: YAG lasers as they are cost-efficient and hence commercially used more over across the world. Thick materials like reinforced metal plates or metal plates were cut with the help of CO_2 lasers. Thickness of cutting material has to be thinner than 20 mm for Nd: YAG lasers. There are a number of advantages claimed for the use of simulation on laser cutting process. Simulation is best suited to analyze complex cutting geometry when it is not possible to solve them through a mathematical method. Many researches have been done on computational analysis of laser cutting simulation. Harish et al. [12] investigated the effect of laser parameters like (pulsed laser energy and cutting speed) on thermal residual stresses induced on tantalum carbide coated graphite substrates during the process of laser ablation. It was studied using micro-Raman spectroscopy and transient thermal analysis was done on COMSOL analysis software. Nath et al. [13] deals with the numerical simulation of laser cutting on Functionally Graded Material, made of nickel and stainless steel (AISI 304), using COMSOL MULTI-PHYSICS software. It is observed that width and depth of cut has increased with the increase in laser power but decrease in parabolic curve with the cutting speed. It is also found that the kerf depth decreases at slower rate compare to the kerf width with increase in speed. Saternus [14] determined the temperature field and

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estimated the shape of cut zone on the basis of numerical simulation by using ABAQUS software in term of comparing criterion-width of cut. The developed numerical model can be an effective tool for technologists to determine the optimal process parameters of the cutting process. Vora et al. [15] used computational modelling for one dimensional laser machining. In the current study, single-pass laser cutting is simulated using FEM software, with the laser beam acted upon as a moving heat source. The primary goal of the current research is to understand how laser parameters affect the distribution of surface temperatures and the characteristics of gaussian heat sources. In this study, using COMSOL Multiphysics 5.6, a 2-Dimensional model is used to examine how laser beam machining factors affect polymethyl methacrylate. Additionally, it is noted that the simulated temperature distribution profile has the same pattern as the analytically established profile for a moving heat source in earlier work.

2. NUMERICAL METHODOLOGY

2.1 Moving Heat Source Approach

In the present work, the laser beam is considered as a moving heat source. Transient heat transfer analysis is done where heat source is moving with respect to time. In many applications such as, laser welding or friction stir welding, the heat source is not stationary. Rather it is moving with respect to time, so such simulations where heat source is moving can be done in FEM software, but the use of subroutine is pre-requisite in some cases for better visualization. To understand the concept, a geometrical representation of moving heat source is shown in the Fig 1. Surface of a three-dimensional substrate is represented in two-dimensional figure here. The red circular portion in Fig. 1 represents the heat source. A laser heat source is applied on surface, which has a diameter equal to the laser spot beam and it is defined by using flux boundary condition.

The concept of heat transfer due to a moving point source was experienced by Rosenthal [16]. Through the mathematical formulation, the temperature distribution in the plane through the point source is found as shown in the Fig. 2. The practical application of laser such as laser cutting, welding, shaping, etc. require the laser beam to move with respect to the workpiece. So, laser beam is considered as point moving heat source.

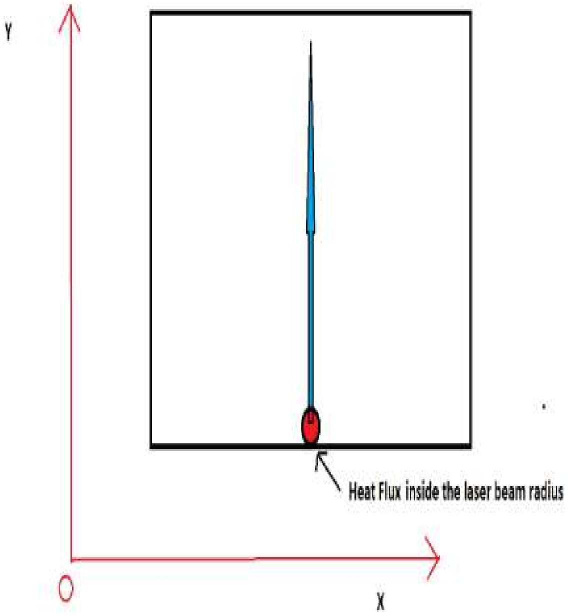

Fig. 1 An example of Moving heat source

In terms of simulation of the laser cutting due to moving heat source, FEM based software is used to predict the temperature profile. From the contour plot of the simulation of temperature distribution, it is found that the distribution follows the same trend as the theoretical pattern of moving heat source. By comparing Fig. 2 and Fig. 3. it can be visualized that the simulated laser cutting process matches with the concept of moving heat source used by Rosenthal [16].

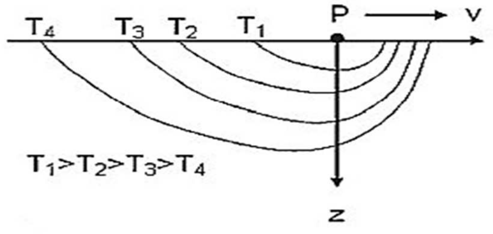

Fig. 2 Theoretical Isothermal pattern of moving heat source by Rosenthal [16]

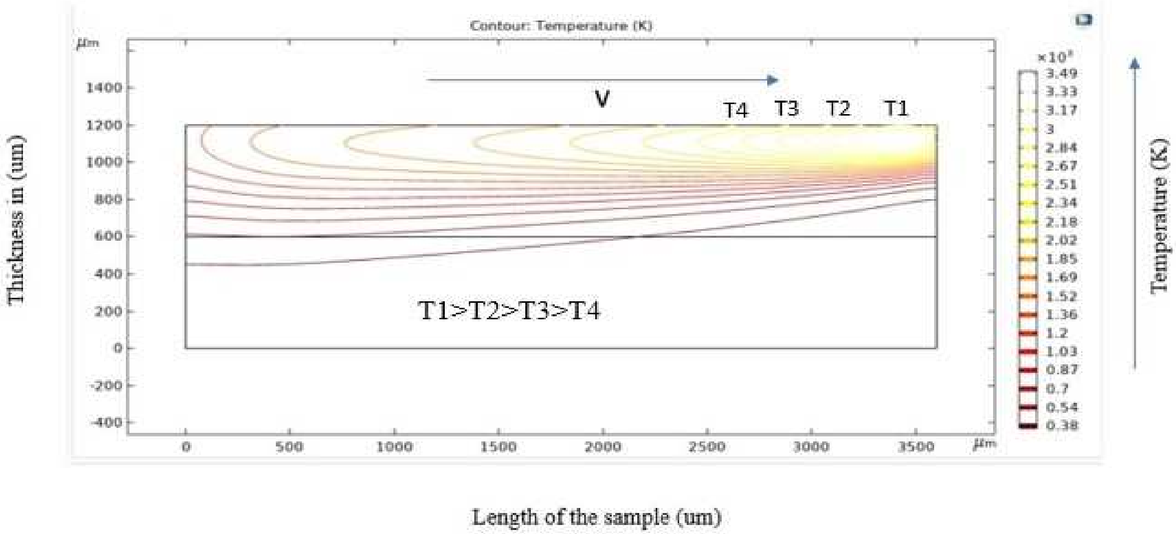

Fig. 3 Isothermal pattern of moving heat source (Simulation)

. Table 1

Parameters used for simulation [15]

S. N o	Name	Description	Expressions	Values
1	Ep	Laser Energy	1[J]	1 J
2	D	Beam diameter	0.6[mm]	6E-4 m
3	emi	Emissivity	0.91	0.91
4	h1	Heat transfer coefficient	10W/ [m^2 /K]	10W/ (m^2·K)
5	A1	Absorptivity	0.91	0.91
6	DT	Half width of the curve	30[K]	30 K
7	x0	Reference point to represents the center of the laser beam	(-D)	-6E-4 m
8	xd	Standard deviation of the Gaussian laser beam	100[um]	1E-4 m
9	Ta	Ambient temperature	293.15 [K]	293.15K
10	H1	Height of the sample	D*2	0.0012 m
11	W1	Width of the sample	D*6	0.0036 m
12	Vin	Laser scanning speed	10 [mm/s]	0.01 m/s
13	t_stop	Single pass duration/stop computation	(2*D+W 1)/Vin	0.48 s

T1 is temperature closest to the point heat source, T2 is far and T4 is farthest from moving heat source point. As visualize from the above figures, it is found that T1>T2>T3>T4. The laser cutting simulation has been successfully achieved and the results were demonstrated through graphical representation in results and discussion.

2.2 Numerical Simulation

The study of the simulation of temperature distribution of single pass laser cutting process, considering laser beam as moving heat source is done with the use of a FEM-based software. The parameters and variables used in the modelling process of simulation is referred to in Table 1 and Table 2.

Table 2

Variables

S . No	Name	Description	Expressions
1	Ed	laser Energy density	$Ep/(pi * 0.25 * D^{\wedge}2)$
2	G_space	Gaussian distribution	$exp\ (-(((x - xr)\ ^{\wedge}2)/(2 * xd^{\wedge}2)))$
3	Pg	Laser heat source	$A1 * Ed * G\_space$

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4	xr	Laser beam transient position	$x0 + Vin * t\_stop$

The thermo-physical properties of the PMMA material, which is used for the modelling purpose is considered as listed in Table 3.

Moving heat source is going from left to right, length of the material is 3.6 mm and velocity is 10 mm/sec. Laser beam having diameter 0.6 mm, initiated with clearance of 0.6 mm from the initial point of the material, so the total length is considered to be 4.8 mm. The time taken for the simulation is distance divided by velocity which gives simulation time as 0.48 second. The simulation can visualize in Fig. 4. The moving source is reaching at the last point of the material. The region of bright yellowish light indicates highest temperature achieved in the simulation more than $3.5 * 10^3$ K. The dark red region indicates lower temperature region with minimum range of temperature.

Table 3

Thermo-physical properties of PMMA material [3,17]

S. No	Characteristic	Units	Value
1	Thermal conductivity	Wm-1K-1	0.19
2	Specific heat	JkgK-1	1466
3	Density	Kg/m3	1180
4	Emissivity	-	0.91

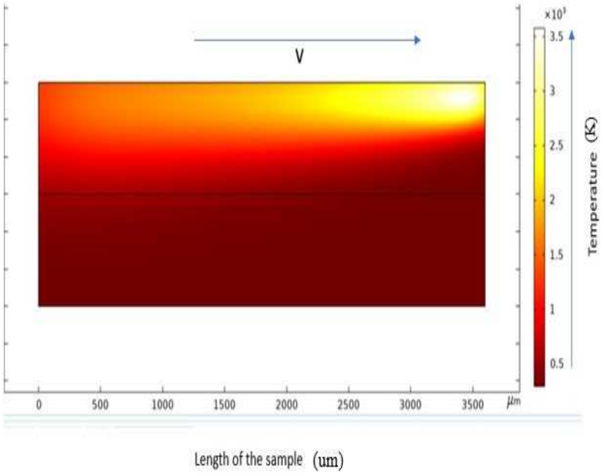
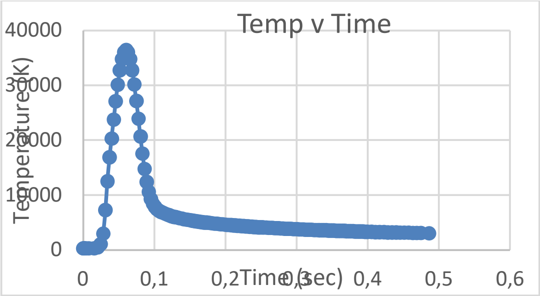


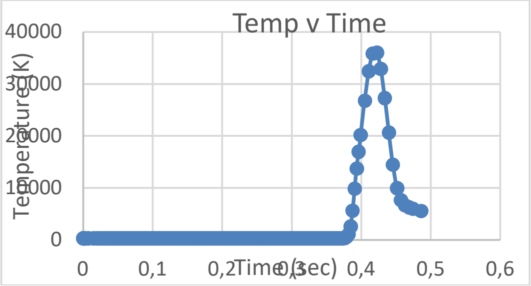
Fig. 4 Simulation of moving heat source in single pass laser cutting process.

3. RESULT AND DISCUSSION

The temperature distribution is shown in the graph plotted between temperature and time at a distance when laser beam crosses initial point as shown in Fig. 5 (a), and another graph is obtained at end point of the material shown in Fig. 5 (b). In both the cases gaussian shape is formed. Fig. 5 (a) interprets that the temperature falls down after the beam radius moving heat source point because of heat losses due to convection and radiation. The maximum temperature attained is 36435 K at 0.06 time and it degrades afterward as shown.



(a)



(b)

Fig 5. Temp v Time graph, when moving heat source is at, (a) start point (b) end point, of the material

The behavior of the contour and graphs plotted follow the same trend as those were investigated in the previous work done [15]. Fig. 6. shows the temperature distribution at every instant of laser as moving heat source. The trend at every point follows gaussian or normal distribution. The maximum average temperature attained is 36435 K which is maintained at every point as laser passes. It also shows the the temperature degraded rapidly away from the point source of laser beam which leads to bell shaped graph i.e gaussian distribution. at 0.06 time which reduces as the laser beam source moves ahead.

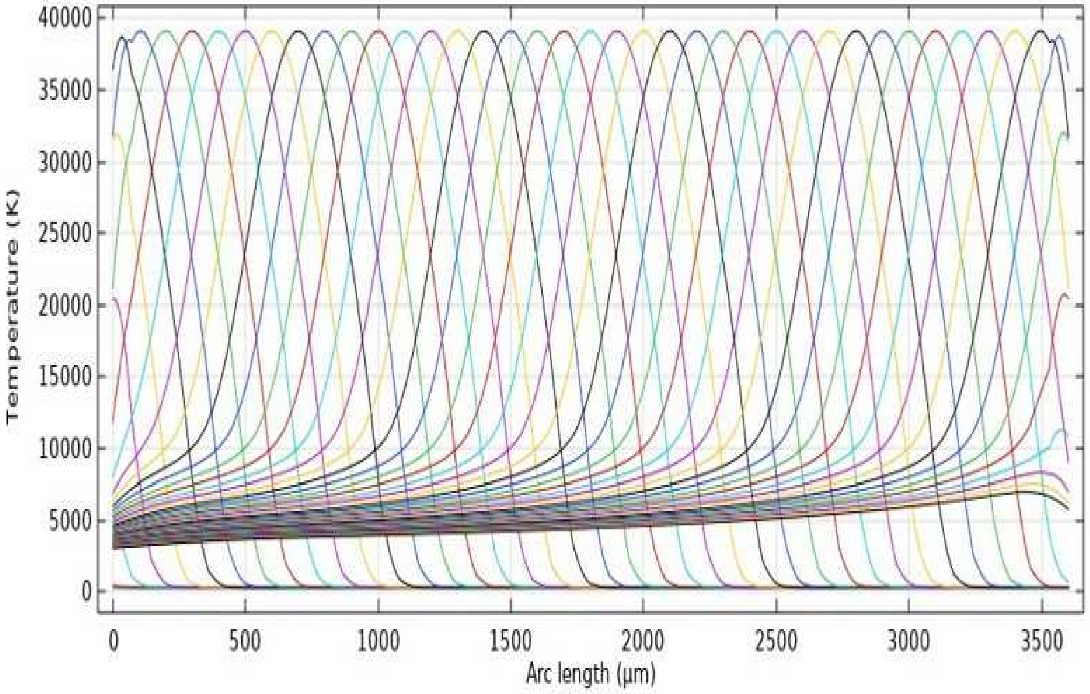


Fig. 6. Temp v Arc length, at every instant of moving heat source

4. CONCLUSION

COMSOL™ Multiphysics was used as a finite element method software to develop a computational model for understanding the impact of CO_2 laser beam machining process on the PMMA substrate by considering laser parameters like laser energy density and applying essential boundary conditions.
From the above thermal analysis following conclusions are to be carried out-

- The surface temperature distribution was analysed considering the laser beam as a moving heat source.
- The results matches with previous analytical models and displayed normal distribution due to a gaussian heat source.
- The temperature decreases after the beam radius moving heat source point due to heat losses from convection and radiation.
- Increased laser power and decreased speed leads to a rise in heat input energy.
- The maximum temperature attained was 36435 K at 0.06 time, then temperature degraded as the laser beam source moved.
- It was also found that as the laser beam source moved forward, the temperature rapidly decreased away from the laser's point source, resulting in a bell-shaped graph (or gaussian distribution) at 0.06 time.
- The present study can further be extended to determine the material removal rate and predict ablation depth through element deletion techniques.

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Simularea numerică a prelucrării cu fascicul laser a polimetilmetacrilatului

Rezumat: Prelucrarea cu fascicul laser este un proces de ablație termic utilizat pentru microfrezare pentru a crea profile microcanale. În lucrarea de față, simularea procesului de tăiere cu laser cu o singură trecere a fost investigată în software-ul FEM, considerând fasciculul laser ca o sursă de

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căldură în mişcare. Obiectivul principal al prezentei investigaţii este de a studia efectul parametrilor laser asupra distribuției temperaturii la suprafață și a naturii sursei de căldură gaussiene. Această lucrare utilizează un model 2-Dimensional pentru a analiza efectul parametrilor de prelucrare cu fascicul laser asupra metacrilatului de polimetil folosind COMSOL Multiphysics 5.6. Se observă, de asemenea, că profilul de distribuție a temperaturii simulat urmează aceeaşi tendință așa cum a fost dezvoltat analitic de lucrările anterioare pentru mutarea sursei de căldură. Temperatura medie maximă atinsă de sursa fasciculului laser este de 36435 K. De asemenea, a observat că temperatura s-a degradat rapid departe de sursa punctiformă a fasciculului laser, ceea ce duce la un grafic în formă de clopot, adică distribuția gaussiană la 0,06 timp, care se reduce pe măsură ce sursa fasciculului laser se deplasează înainte.

Cuvinte cheie: *Prelucrarea cu fascicul Laser, Simulare Numerica, Masine CO_2 laser, Puterea Laserului*

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