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THE TRANSIENT TEMPERATURE FIELD SIMULATION OF LASER CUTTING

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ABSTRACT
Finite element analysis of the transient nonlinear heat and mass transfer was simulated using of the two-dimensional model. The temperature distribution was derived.The analyses were run in the software solver COSMOS/M developed by Company SRAC, USA. The thermal module HSTAR makes possible to realize cases of thermal dependent material properties. Material data can be enter as a function of the temperature. In this case changes of the temperature at intervals 20-300°C are concerned.
Keywords: laser, cutting, simulation

1. THERMAL ANALYSIS
There are three mechanisms of heat transfer. These mechanisms are:
Conduction, Convection, Radiation
In all three mechanisms, heat flows from a higher-temperature medium to a lower-temperature one. Heat transfer by conduction and convection requires the presence of an intervening medium while heat transfer by radiation does not. Laser cutting is characterized by conduction.

1.1. Conduction
Thermal energy transfers from one point to another through the interaction between the atoms or molecules of the matter. Conduction occurs in solids, liquids, and gasses. There is no bulk motion of matter when heat transfers by conduction. The rate of heat conduction through a plane layer of thickness is proportional to the heat transfer area and the temperature gradient, and inversely proportional to the thickness of the layer.

1.2. Types of heat transfer analysis
There are two modes of heat transfer analysis based on whether we are or not interested in the time domain.
Steady State Thermal Analysis
In this type of analysis, we are only interested in the thermal conditions of the body when it reaches thermal equilibrium, but we are not interested in the time it takes to reach this status. The temperature of each point in the model will remain unchanged until a change occurs in the system. At equilibrium, the thermal energy entering the system is equal to the thermal energy leaving it. Generally, the only material property that is needed for steady state analysis is the thermal conductivity.

Transient Thermal Analysis

In this type of analysis, we are interested in knowing the thermal status of the model at different instances of time. A thermos designer, for example, knows that the temperature of the fluid inside will eventually be equal to the room temperature (steady state), but he or she is interested in finding out the temperature of the fluid as a function of time. In addition to the thermal conductivity, we also need to specify density, specific heat, initial temperature profile, and the period of time for which solutions are desired.

1.3. Required input for thermal analysis

To perform thermal analysis, we need the following:

Meshed model - We must mesh the model before running the analysis.

Material properties - We must define the thermal conductivity. Density and Specific Heat may also be required.

Loads and boundary conditions - We may prescribe temperatures at faces, edges, or vertices. Specify thermal energy as heat flux, heat power, or volume heat (heat power per unit volume). Convection and radiation are applied as boundary conditions. When specifying convection, we need to enter the convection coefficient and the ambient temperature of the fluid or gas. Loads and boundary conditions can be associated with time curves. Film coefficients can be associated with time and temperature curves simultaneously. Bulk temperature can be associated with time curves.

Solution Parameters - When creating a thermal study, we must specify whether we want to run steady state or transient analysis. Also, we may choose the FFE or the conventional solver. If we are running transient analysis, we need to specify the period of the analysis, the time increment, and an optional initial temperature.

2. TRANSIENT TEMPERATURE FIELD SIMULATION OF LASER CUTTING

2.1. The thermal and physical characteristic of the thermoplastic material

The PMMA side wall gradually cools after the laser light passing through in the specific cut. At the same time the thermal flow is distributed from the cut plane to the internal dimension of the wall. The thermal process is described by Fourier-Kirchhoff differential equation:

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T\,, \qquad \alpha = \lambda \,/\, \rho c \tag{1}$$

Where λ is thermal conductivity, ρ is density, c is heat capacity.

The thermal conductivity of thermoplastic materials is (100-1000) times less then metals. That fact cause that plastics keep high differences of temperatures between external and internal layers. The parametric analysis of the thermal field was realized by the finite element method. The analysis was run by software COSMOS/M developed by Company SRAC, USA.

The thermal modulus HSTAR makes possible to realize cases of the thermal dependent material properties. Material data can be entered as a function of the temperature. In this case changes of the temperature at intervals 20-300°C are concerned. The physical characteristics of the thermoplastic materials are changed very expressively in this temperature interval. Values λ,ρ,c were entered as the function of the temperature through medium of the thermal curves.

The heat flow values were entered as the variable parameters. Progressive ignition and extinction of the heat flow simulates the ray laser movement. The maximal temperature was regulated on the already alluded cracking temperature by the repeated change of the heat field value and following thermal field calculation.

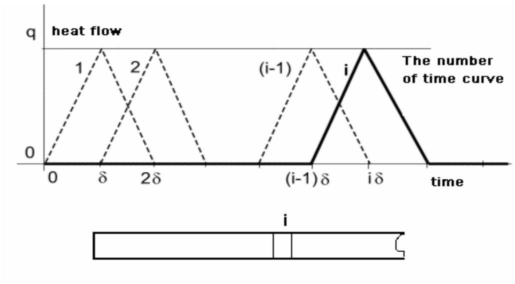
The time variable heat flow was entered into the particular flat elements (constituent the model half of cut) by time curves i=1,2,3. (fig. 1a).

2.2. Model

The dimension of the select specimen is showed in the figure 1b.

The thermal field was taken for two values of the cutting speed, namely $1{,}6\cdot10^{-3}\mathrm{ms}^{-1}$ and $0{,}05\ \mathrm{ms}^{-1.}$

Due to space limit presented results are only for cutting speed $0{,}05\ \mathrm{ms}^{-1}$ in the following figures.



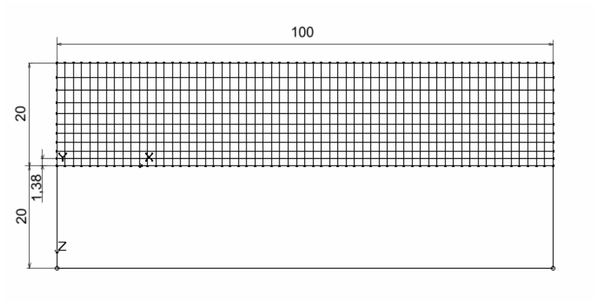


Figure 1a. Schema of boundary conditions of the movement ray laser

Figure 1b. The dimension of the specimen (mm) and finite element mesh

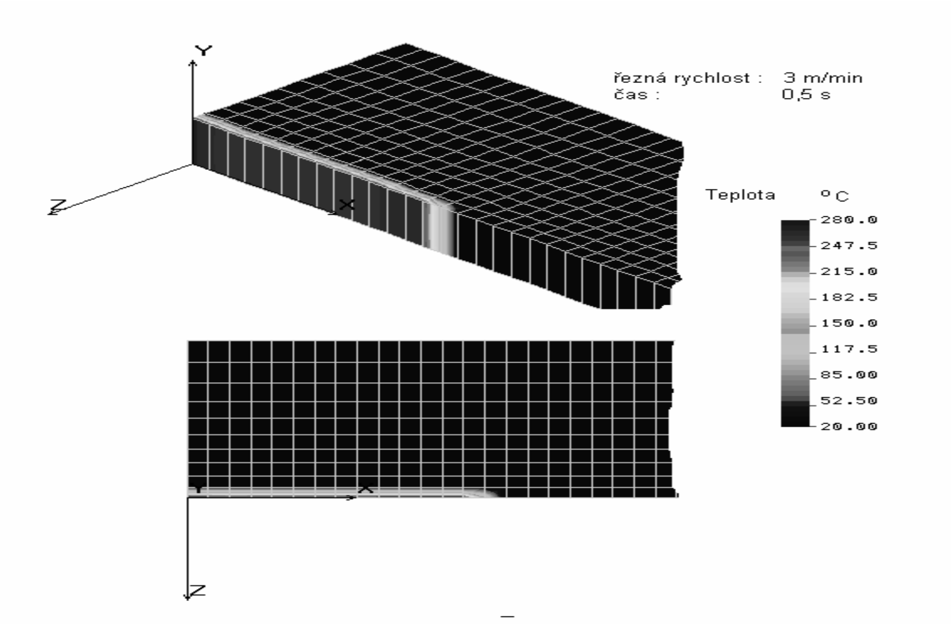


Figure 2. The thermal field for cutting speed 0,05 ms^{-1}. in time t=0.5 second

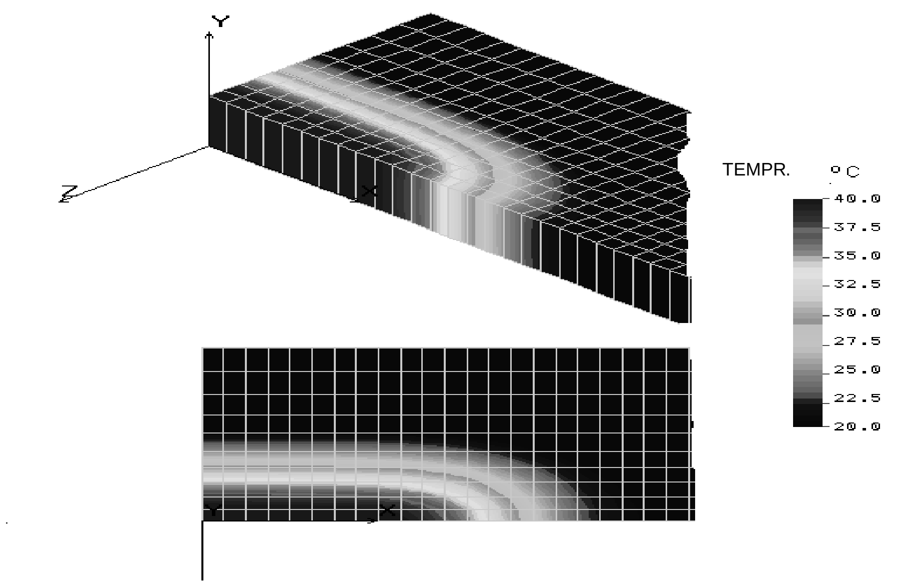


Figure 3. Simulation of the heat distribute at surrounds after 3 min. (speed 0,05 ms^{-1})

3. CONCLUSION

Simulation of the laser beam is showed in the figure 1a and dimensions of the specimen and finite element mesh are showed in the figure 1b. The heat distribution is showed in figure 2. Figure 3 presents the thermal flow expanding from the cut plane to the internal dimension of the wall after 3min.

The model LASER interaction with thermoplastic material is possible. The influenced area high temperature gradient is narrow after passing of through the LASER ray. The area width is only a minim dependent on the cutting speed. At the near proximity the high temperature gradients induce as high short time value of transient thermal stress so as residual tension.

Providing that linear-elastic behaviour of specimen, the thermal tension responds thermal state in the time „t“. Level of these tensions is proportional to the temperature gradient. The linear-elastic tensile relaxes after equalization temperature in the specimen.

With regard to complicated mechanical behaviour of polymers, if you like to temperature and time dependence of this behaviour, "freezing" residual tension, which partially relaxed at the time, persist generally in product after ending of technological process.

Laser beam is the tool of the future. It can cut without affecting the surrounding material. Its energy is clean, reliable and docile it's ready to be tamed and handled to give an unequalled quality to the process. Quality of cut depends from working parameters of laser cutting process (laser power, feed rate, material thickness.)

Resulting structures can be very exact and with high quality of surface in dependence on laser parameters and on type of machining materials. The biggest problem is the transformation of unremoved material again into solid state. This phenomenon causes deterioration of both accuracy of dimension and quality of surface.

If technological conditions (moving speed of the laser head, the beam output, mode parameters of the optics) are optimized, a good quality of the cut can be reached for wide spectrum of materials.

At the conclusion, it is possible to state that it is necessary to know output parameters combination of concrete laser system and properties of machined polymer materials for obtaining good results of machining by laser. It is possible to obtain high accuracy of machined texture with respect to these conditions. The result machining is different at the use of various kind of laser.

4. LITERATURE

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5. ACKNOWLEDGEMENT

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