Measurement of temperature distribution during mild steel processing by "CO_2 Laser- oxygen jet system" At low pressure

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قياس انتشار درجة الحرارة خلال معالجة الفولاذ واطئ الكربنة بمنظومة ليزر ثاني اوكسيد الكاربون ودفق من غاز الاوكسجين

جاسم حسن رشيد

Abstract

The aim of this research is to measure temperature distribution during cutting of mild steel process. Carbon dioxide laser is employed as a point heat source. Oxygen gas jet with low pressure is also used Coaxially with the laser beam to produce more energy in order to reduce the laser power consumed for this process.

Relationship between temperature and distance beyond the cut edge (marking path) was found Non contact technique is adopted to achieve the target.

Keywords: temperature, Co_2 Laser, Oxygen gas, processing

خلاصة البحث

الهدف من هذا البحث قياس انتشار درجة الحرارة خلال عملية قطع الفولاذ باستخدام ليزر ثاني اوكسيد الكاربون كمصدر حراري نقطي وأستخدام دفق محوري لغاز الاوكسجين مع شعاع الليزر لغرض زيادة الطاقة من اجل تقليل القدرة الليزرية المصروفة خلال هذه العملية . العلاقة بين درجة الحرارة والمسافة المتباعدة عن خط القطع قد اوجدت بتبني تقنية القياس عن بعد لانجاز هذا الهدف.

الكلمات المفتاحية: درجة الحرارة , ليزر ثاني اوكسيد الكاربون , غاز الاوكسجين , المعالجة

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Introduction

The rapid development of techniques for generating beams of high power radiation , related to the development of powerful optical quantum generators , has made the problem of the interaction of intensive radiation with the material quite pressing .Many investigations have appeared in this area earlier (1 , 2), allowing researcher to draw conclusions concerning the primary physical processes resulting from the effects of high power radiation and in many cases to calculate certain characteristics of these processes .The results of these investigations are of great practical significance , since they provide a basis for many applications of lasers in science and technology.

The classical analytical solution for the heat conduction problem with a point heat source is well established . The analytical solution for the moving heat source is unidirectional was first presented by Rosenthal(3) and the equivalent finite element approximation was published by Ascough (4) .The problem becomes far more demanding and complicated when heat laser are taken into account due to radiation and convection from the outer surface of the object and when included in the governing differential equation.

The Mathematical basis for considering heat transfer due to conduction only

The governing differential equation for heat conduction in a three dimensional media can be explained by referring to figure (1) . The energy balance in the body shown can be expressed as :

Heat flow During time (dt)	+ heat generated by internal source during time (dt) .	= heat out flow during time (dt) + change in internal energy during time (dt).

The rate of heat flow in all three directions can also be shown as:

$$\left.\begin{aligned} q_x &=- k_x\ A \frac{\partial T}{\partial x} = - k_x \left(\frac{\partial T}{\partial x}\right) dy\,dz \\ q_x &=- k_y\ A \frac{\partial T}{\partial y} = - k_y \left(\frac{\partial T}{\partial y}\right) dx\,dz \\ q_z &=- k_z\ A \frac{\partial T}{\partial z} = - k_z \left(\frac{\partial T}{\partial z}\right) dx\,dy \end{aligned}\right\} \quad \text{..................(1)}$$

Similarly , the heat outflow in the x-direction at the face x+ dx is :

$$q_{x+dx} = q_x + \left(\frac{\partial q_x}{\partial x}\right) dx$$

By considering all three faces the governing differential equation for heat conduction for the problem in figure (1)can be expressed as:

$$\left.\begin{aligned} &\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + q = c\frac{\partial T}{\partial t} \\ &\text{or} \\ &k_x \frac{\partial^2 T}{\partial x^2} + k_y \frac{\partial^2 T}{\partial y^2} + k_z \frac{\partial^2 T}{\partial z^2} + q = c\frac{\partial T}{\partial t} \end{aligned}\right\} \quad \text{..........................(2)}$$

Where:

q is the strength of the heat source defined as that generated per unit volume per unit time.

ρ is density of the material .

C is specific heat of the material.

T is temperature of the body.

V is volume of the body.

Since the differential equation in (2) is second order with respect to x , y and z two boundary conditions need to be specified. The possible boundary conditions are:

$$T(x, y, z, t) = T_o \quad \text{for} \quad t > o \quad \text{on} \quad S_1 \; \ldots\ldots\ldots\ldots \; (3)$$

$$K_x \left(\frac{\partial T}{\partial x}\right) I_x + k_y \left(\frac{\partial T}{\partial y}\right) I_y + k_z \left(\frac{\partial T}{\partial z}\right) I_z + q = 0 \; \ldots\ldots\ldots\ldots (4)$$

For t > 0 on S_2

Where :

q boundary heat flux.

I_x ,I_y , I_z, are the directional Cosines of the outward normal to the boundary.

S_1 is boundary on which the value of temperature specified as To (t).

S_2 is boundary on which the heat flux q is specified.

The differential equation in (2) can be simplified if transient conditions are ignored (i .e, the problem is quasi – stationary and no change of temperature with time can occur).

So far the differential equation shown in equation(2)is only valid fer a stationary heat source . following reference (1) , equation (2) can be modified to the condition of a moving heat source as shown below. If we assume that the source has the freedom to move in all three direction x , y, and z with constant velocities v_x , v_y and v_z then with respect to moving coordinate system ξ , η , ζ the problem is still quasi – stationary (i.e to a person travelling with the coordinate axis system there is no change of temperature with time) . thus:

$$\left.\begin{aligned} \xi &= x - v_x\, t. \\ \eta &= y - v_y\, t. \\ \zeta &= z - v_z\, t. \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

And equation (2) becomes:

$$K_x \frac{\partial^2 T}{\partial \xi^2} + k_y \frac{\partial^2 T}{\partial \eta^2} + k_z \frac{\partial^2 T}{\partial \zeta^2} + q + C\rho V_x \frac{\partial T}{\partial \xi} + C\rho V_y \frac{\partial T}{\partial \eta} + C\rho V_z \frac{\partial T}{\partial \zeta} = 0 \quad \text{......... ....(6)}$$

Gaussian Heat Sources

Figure(2) illustrates a typical coherent laser beam as it enters the focusing lens. By referring to figure(3) , it can be seen that for most applications the heat intensity distribution at the focused spot is Gaussian as shown in figure (3). Thus the heat intensity at any radius (r) is (5):

$$I_r = I_{max} \exp \left[2\left(\frac{-r}{W_2} \right)^2 \right] \quad \text{........................(7)}$$

with $2w_z = \frac{4\lambda f}{\pi W_1}$

Thus $I_r = I_{max} \exp \left[2\left(-\frac{r\pi w_1}{2\lambda f} \right)^2 \right]$ ....(8)

The Role of oxygen gas during mild steel processing

Attempts to process mild steel by CO2 laser were done by many researchers (4, 6, 7, 8) Little success was made until the advent of the gas nozzle by Houldcraft (2) when he used oxygen coaxially with the laser beam during processing mild steel. Laser beam is responsible for igniting and stabilizing a burning process and the assist oxygen gas produces an additional heat input by an exothermic reaction between the oxygen and mild steel , also to blow out the molten material and protects the laser optics as well as to blow the material vapor out of the processed zone to avoid precipitation of the hot gaseous emission on the workpiece and to prevent them from condensation. When oxygen directed toward the surface of the workpiece only a fraction of the jet is absorbed by the workpiece since part is lost at the surface of the workpiece and another part is reflected by the molten layer. Consequently , in the molten layer three kinds of particles are present; Pure gas atoms , Pure metal atoms and the reaction products .The molten layer gains pure oxygen atoms from the reactive gas flow and from the decomposition of the reaction product . In addition , reactive gas particles are lost by chemical reaction , evaporation and by ejection of molten materal. The temperature of the molten zone depends on the amount of heat lost by different cooling processes , such as heat conduction and heat convection by ejection of liquid material (9)or by evaporation from the surface of the molten layer as considered by Shuocker (10) and by the melting of solid material due to the movement of the molten layer.

Experimental equipments

The experiments were carried out on CNC-cutting table with a CO_2 laser (conherent Everlase 525) delivering 500 w (cw) at the point of processing .Experiments were achieved with a piece of sheet mild steel of 1.68 mm thickness .A laser beam is focused by an optical system on the surface of the material being processed .

Oxygen supplied to the heated zone through a nozzle which is coaxial with the laser beam .Figure(4) shows the diagram of the nozzle used in the present work. The diameter of the nozzle should be in general large enough to let the laser beam through.

Infrared thermometer (Cyclops 52) was used for non-contact temperature measurement (11). According to the supplier , it operates in a narrow band (0-8-1.1 μm) specially selected to ensure maximum freedom from errors due to emissivity and atmospheric absorption.

Results and discussion

Relationship between temperature distribution and distance from the marking path (cutting line) is shown in figure (5) It is clear that the average temperature decreases as the distance from the marking path increases which is expected. Also the average beyond the cut edge is higher for lower cutting speed at the same distance from the marking path(cutting line). This is due to expose the metal for longer time . Metal exposure for longer time gives higher opportunity for oxygen gas to react exothermally with mild steel releasing additional energy which absorbed by metal.

This leads to increase the temperature and conducting the heat for wider zone beyond the cut edge. This zone is called heat affected zone (HAZ) which is one of the cut quality parameters . Therefore, the cut quality is expected to be improved as the cutting speed increases due to minimize the HAZ.

Figure (6) shows the temperature fluctuation from point to point along the marking path and at different distances (y).The fluctuation at the center is very obvious which depends on the conditions applied during marking or even cutting.The fluctuation becomes smoother as the distance of the thermometer increases away from the marking zone until a straight line is produced at a particular distance, at which point the temperature is simply room temperature. The shape of the curves in Figure (6) is similar to the sand waves on a beach near the sea line. These sand waves reflect the roughness of the coast in the same way that the temperature fluctuation reflects the roughness of the cut edge. The results of figure (6) could be used to explain cut quality particularly if more results are produced under many different conditions.

Conclusions

An attempts to measure temperature distribution in mild steel which processed by CO2 laser is achieved .

non-contact method (Cyclops 52) proved that it is suitable technique in this field.

variation of the temperature from point to point along marking path and in heat affected zone gives the answer for cut edge is not completely smooth and how the heat is conducted through metal. Higher temperature during metal processing increases probability of evaporation and may improve the cut edge in particular. This improvement is due to the fact that the gas momentum can push the vapor a way more easily than the liquid phase.

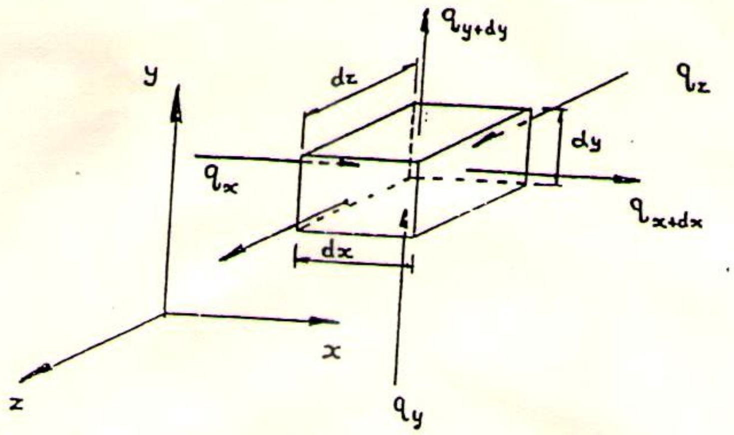


Fig. 1. Heat conduction in a 3D medium

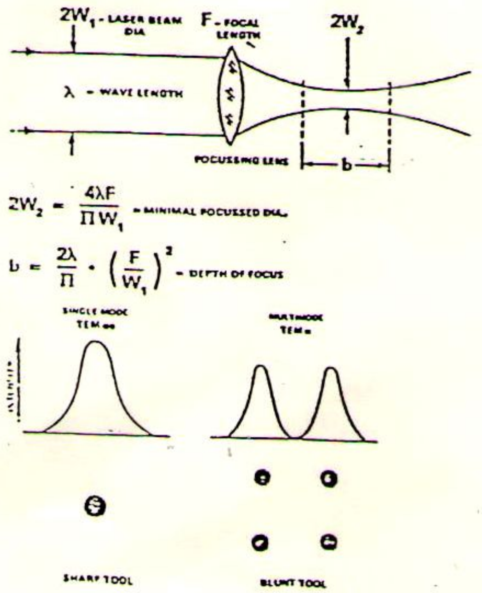


Fig. 5. Typical Gaussian beam structure

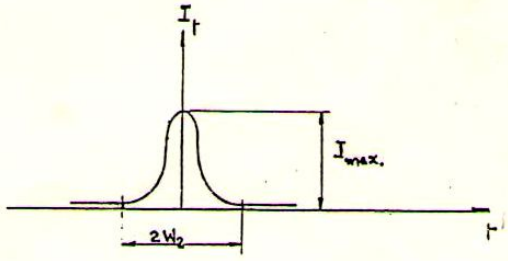
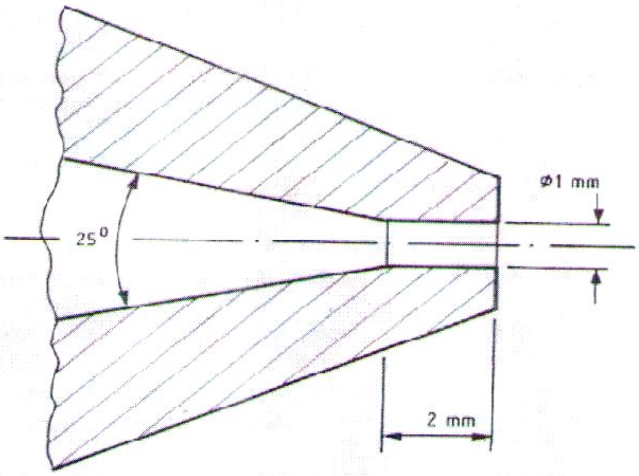
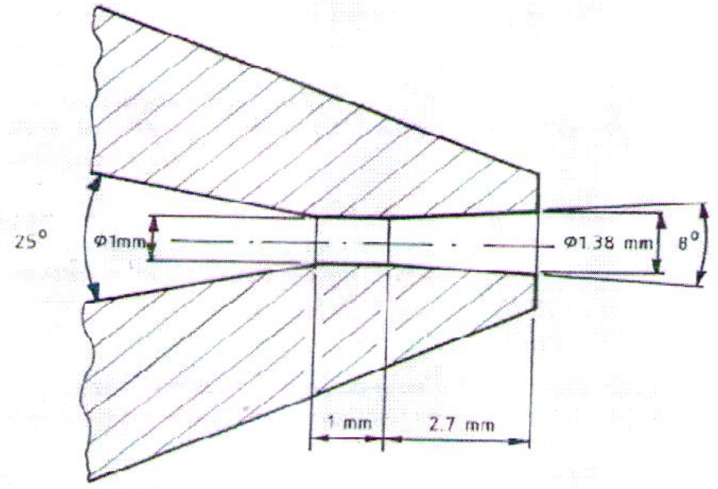


Fig. 6. Gaussian energy distribution in a laser beam



(a) STRAIGHT EXIT NOZZLE



(b) CONICAL EXIT NOZZLE

Fig. 4. Design of different nozzles.

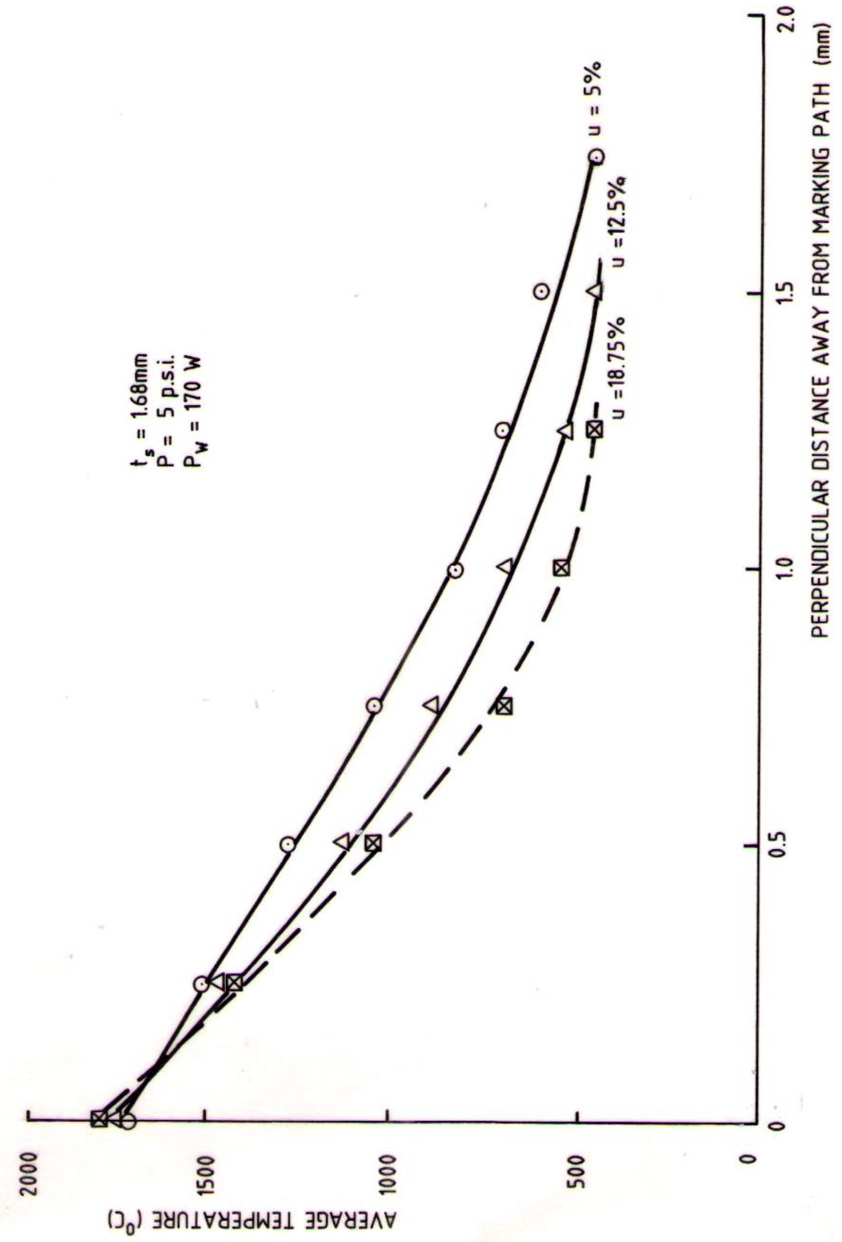


Fig. 5. 45. Variation of the average temperature along marking path and in heat affected zone.

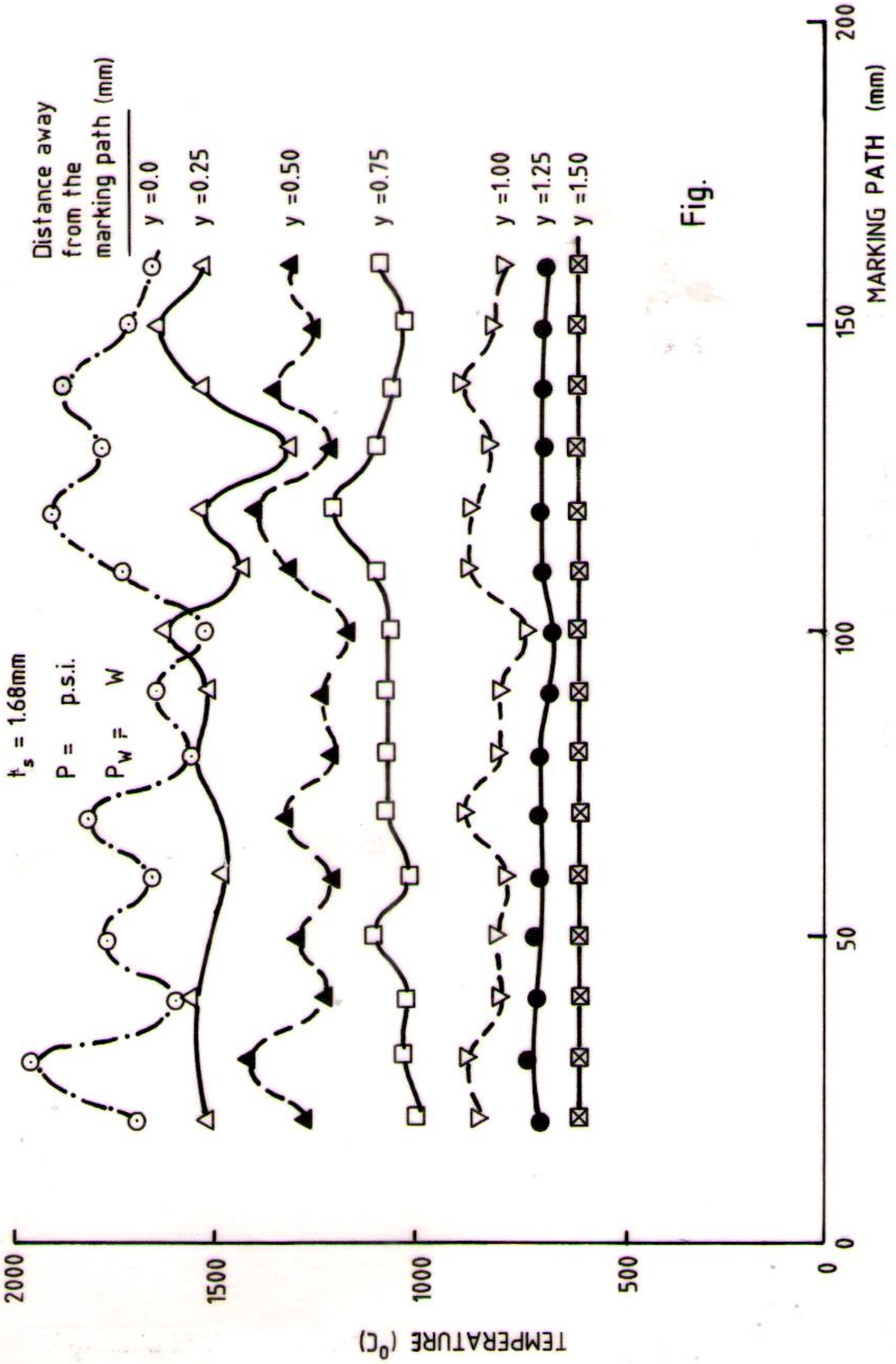


Fig. 5. 46. Variation of the temperature along marking path and in heat affected zone.

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