# Measurement of temperature distribution for "CO2 laser –mild steel processing" By non-Contact methods

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## Abstract

Measurement of temperature distribution by non- contact method ( Digital camera Cyclops 52) are achieved . Outline to non-contact techniques is given Fundamental and basic terms of radiation laws are mentioned. Carbon dioxide laser Everlaser 525 (500w)is employed as a heat source to process mild steel under investigation **at different pressures and powers**.

## خلاصة

تم انجاز هدف البحث وهو قياس توزيع درجة الحرارة عن بعد بواسطة الكاميرا الرقمية ( Cyclops 52) . واعطيت خلاصة عامة لتقنيات القياس عن بعد كما تمت الإشارة الى القوانين الأساسية للاشعاع.
واستخدم ليزر ثاني اوكسيد الكربون ( 500واط ) كمصدر حراري اثناء معالجة الفولاذ **تحت ضغوط وقدرات محتلفة.**

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## Introduction

The Sensation of heat or lack of it is very familiar. The human sensor mechanisms are calibrated by experience and these registered by touch (contact method) or by the Sensation relating to radiated heat (non contact method).

Colour on the other hands to be a guide for the higher temperatures. Colours used to assess the temperature both for the temperature required for the working of the metal and the resulting "temper" of the metal on gradient quenching .

There are means of determining temperature by two different colour method . One relating to the visual range of radiation emitted from hot metal surfaces at temperature above 500c, the other from the physical colour effect related to the passage of hight through an oxide film of varying thickness ( 12,15).

The oxide film "temper" indicator although reliable is only an instantaneous effect during the build up of the oxide film on the hot metal. with the time the oxide film formation continuous and if high temperatures are maintained considerable thermal gradients build up , due to heat transfer considerations, through the oxide film to the metal body underneath CO2 laser is used as a heat of source during the present work to processes mild steel, and digital camera Cyclops 52 was adopted to measure temperature gradient.

## Basic Concepts on thermal emission (2, 9 ,11)

All objects are continually emitting radiation at a rate and with a wavelength distribution that depends upon the temperature of the object and its spectral emissivity ε (λ).

A black body is an object that absorbs all incident radiation and , conversely is a perfect radiator. The energy emitted by a black body is the maximum for a given temperature. The radiated power and its wavelength the distribution are given by the Blanks radiation law (2).

$$W_{(\lambda\lambda,T} = \frac{2\pi hc^2}{\lambda^5} \; [\exp(\frac{hc}{\lambda kT}) - 1]^{-1} \, W cm^{-2} \mu m^{-1}$$

Where ($\lambda$) is the wavelength , (T) is the temperature.

(h) is Planck's constant ( $6.626*10^{-34}$J.s ).

(C) is the velocity of light ( $3 * 10^{8}$ m / s ) .

(K) is Boltzmann's constant ($1.3805*10^{-23}$J/k )

For most thermal radiation sources the total energy is approximately proportional to the fourth power of the temperature

$W= \sigma T^4$ ( watts ) …………… (2)

Where $\sigma$ is Stefan – Boltzmann constant ($5.67*10^{-8}$ $wm^{-2}$ $k^{-4}$ ).

Figure (1) shows the variation in intensity as function of wavelength at various temperatures. The wavelength at which the intensity of radiated output is a maximum is shown by the broken line is given by wines law.

$\lambda_{max}$ T = $2.9*10^{-3}$ m.k (3)

i.e as the temperature increases the wavelength at which the maximum occurs becomes shorter and relatively more energy is radiated in the visible region.

The radiated power output of practical sources is normally less than that for a black body , and they are referred to as non –black bodies .An emission coefficient which varies with the material and its surface condition is used so that the equation for the radiated output becomes:

$W= \varepsilon\sigma T^4$ (watt)…………………………(3)

Where $\varepsilon$ is the coefficient of emissivity and ($\varepsilon \leq 1$)

## Emissivity (15)

In practice , the emissivity of any sample will be affected by a number of factors those having a considerable influence being as follows:

**a-Sighting angle** : pyrometer measure radiation from a surface through a small solid angle . The emissivity of a surface is usually a function of the angle between the line of sight and the normal to the surface . Metals, because the polarization , effect , have a minimum emissivity normal to the surface and these effects become important at angle greater than 60. On the other hand , the emissivity of insulating material is a maximum when viewed normal to the surface . Pyrometers should not , in general , be sighted at more than 45 to the normal of the surface .

**b-Wavelength** :when measured over all wavelengths of radiation emitted by a material the property concerned is "total emissivity". when measured over a small wave band, usually at short wavelengths ,the term is "spectral emissivity ".

**c-Temperature** :spectral emissivity doesn't vary greatly with temperature though it is usually wavelength dependent. For metals and alloys , emissivity is higher at short wavelengths than long one so that , as the temperature increases and more energy is emitted at short wavelengths, total emissivity increases.

Non-metal , if they are opaque at all wavelengths generally have spectral emissivity's which are not greatly dependent on wavelength and hence emissivity does not change with a rise in temperature.

**d-Surface conditions** : Surface roughness and oxide layers generally increases the emissivity of a sample.

For metals with smooth , un oxidized surface , emissivity's are usually in range (0.05 to 0.5) and are usually wavelength dependent (5).

Howeever if we ignore the emissivity altogether and infer temperature from the thermometer output ,we shall get a temperature lower than the true temperature by an amount depending on the values of emissivity and the characteristics of the thermometer .

This temperature is known as the "apparent" or "brightness" temperature of the surface if the emissivity is constant this temperature rises and falls in exactly the same way as the true temperature and this may be sufficient for some purposes . To obtain the true surface temperature we must divide the actual output by the emissivity value (ε) before we convert to temperature.

## Interaction between $CO_2$ laser and metals (1 , 2 ,10)

a- CO2 laser work in the infrared radiation at wavelength of (10-6) μm and one powerful enough for metal processing such as ; hardening , welding and cutting .The absorption of

$CO_2$ laser beam in metal is not high enough due to their high reflectivity. Increasing the absorption of the laser leads to change in physical and mechanical properties of the worked material. These changes are largely a function of the thermal properties of the material and can be controlled to some extent by adjustment of the laser power output , spots size and mode (Cw or pulses).figure (2) shoes the vibration energy levels diagram of $CO_2$ and $N_2$.

b- Basic characteristics of the laser metal processing (3 , 5 , 7)

The laser processer is characterized by three main parameters ( figure 3) .

i-The laser beam : The laser include the beam related parameters as power , mode wavelength , divergence , beam diameter , etc……

These parameters are more or less fixed and present by the manufactures of the laser.

ii-The second parameter relates to the optical / nozzle system. Normally a lens fixed in a pressure chamber is used as a beam transmission and gas flow system .The optical system include parameters as focal length, focal spot diameter , depth of focus etc…. , which are parameters related to the quality of the optics and to the mechanical stability of the optical system . The nozzle system include parameters as type of system (coaxial, off-axial ), nozzle shape(convergent, divergent ), nozzle diameter , etc…, parameters which are related to the type gas flow and to the interaction between gas flow, laser beam and material .parameters in this case mainly fixed or preset by manufacturer or fixed for a certain type of system.

iii-The third parameter is related to the material includes optical properties as reflection , absorption depth etc…. , decide whether the material can be processes or not (14)

## Non-Contact techniques for thermal detectors

a-The Videocon , infrared camera , P 8092.

This Camera converts the thermal radiation to an electrical signal .This signal is proportional to the rate of change of the temperature at the target . It operates at room temperatures without cooling , The maximum operating temperature is 40c optimum sensitivity in the range of (8- 14) μm in which there is maximum radiant power from objects at temperature close to ambient.

b-Pyrometers :

i- The optical pyrometers (13): This is used to measure the radiance from the target within narrow band by filtering and is suitable for measuring only above 600 C. This pyrometer is employed to compare the intensity of radiant energy emitting from a target with the intensity of radiation from a body whose temperature in known .The band usually selected is 0.65 μm.

ii- Two colour Pyrometers (6)

The output of the detector is a chain of pulses which is amplified and then separated .The pulses are proportional to the energy transmitted .Determination the temperature from the ratio of the intensities at two wavelets is possible.

iii-Total radiation pyrometer (8) : This pyrometer is designed to take advantage of the dependence of the intensity of thermal radiation upon temperature .It consists an optical system for directing the energy to the detector which converts the radiation energy into an electrical signal .

iv- Band radiation pyrometer (4) .This pyrometer works in a wider band interval than the spectral pyrometer but with smaller range than the total radiation . All other principles are very similar.

c- Infrared cells : The infrared cell detects the near infrared by using suitable filter .This band of radiation needs to be detected because it appears at most temperatures. calibration with infrared emitter is necessary . The infrared cell need convenient amplifier to a void most noise.

d-Photo cells techniques : It is very similar to the infrared cells method .The only difference is that the photo cells detect the visible range as well as the very near infrared .

e-Digital Camera Cyclops 52(14) : It is possible to measure up to 3000c with certain very narrow wave band (0.8-1.1) μm temperatures . However , Cyclops 52 facilities can be summarized as follows ( Fig 4 shows measuring distance and forget for Cyclops ):

i-variable focus optical system allowing focusing from (1 m) to infinity.

ii-optional closes up lenses to allow measurements of targets as small as 0.4 mm by using lens no-110 and at maximum focus distance which is 205mm.

iii-precise definition of the target spot together with digital display of the target temperature in the view finder .

iv-Choice of measuring mode, continuous peak or valley hold.

v- Digital output suitable for deriving an optional digital printer.

However , this technique was employed to measure temperature for present work.

f- Temper colour (12) : The temper colour is due to slight oxidation of the surface . As the tempering temperature increases , the oxide film become thicker and a series of colour may be observed .However , temper color is first evident as a pale yellow at a bout 215C and there is a progressive change with rising temperature to blue .

## Experimental work

Everlase 525 model of $CO_2$ laser heat source (500w) was used through out this study to process mild steel of thickness 1.68 mm and 17mm length .The workpiece was oxidized due to air jet which is used throughout this work .However , laser power delivered through nozzle to hit the sample which was exposed as desired to the laser beam by means of the shutter . when the workpiece had completely passed the nozzle the shutter was closed . when the work table returned to its starting point and the shutter re-opened to continue the monitoring the power. However the experiment were carried out to investigate the temperature gradient at different pressures and powers by digital Camera Cyclops 52 as mentioned in previous section.

The sheet (workpiece ) was not perfectly flat due to its being cut from a coil and buckling from previous heating runs which effect the focusing status .

Air is used for marking the sheet . Heating steel to or above 230C and quenching them in air, different colours are seen. It is assumed that there is a direct relationship between these colour and the maximum temperatures attained.

## Results and Discussions

a- Temperature variation along marking at different pressures:

Figure (5) shows the temperature variation along the marking path for two pressures , 5 and 20 psi , at a power of 170w , marking speed 5% of maximum speed( 25mm/s) and material of 1.68mm thick .

Although the energy available at 20 psi is expected to be higher than that at 5 psi due to differences in rate reaction between mild steel and oxygen gas (exothermic reaction), the average temperature recorded along the marking path at a pressure of 5 psi is higher than that at 20 psi . lower temperature at higher pressure may be due to better efficiency in ejecting the molten metal from the irradiated path . In other words more energy is taken a way at high pressure leaving the cut path cooler .

A second explanation to the pressure role is that as the pressure increases and other parameters ( power and speed ) are constant , a wider path is melted and more heat is dissipated through the material bulk . Again lower temperature is expected .

Widening the mark kerf and increasing the molten material reduces the efficiency of the clearing mark or cut path . The efficiency of ejecting the molten product can be related to the cut quality . It was found at a lower pressure the edge surfaces smoother .

b-Temperature distribution along marking path for different laser power.

The different temperature between the maximum and minimum points is proportional to the power( Fig 6 ).

Because the temperature fluctuation is large at higher laser power the condition of the edge cut should be worse . In other words the roughness is greater.

The average temperature along the marking path is also proportional to the laser power when all the other parameters are constant. The 5 psi may not be enough to remove the melted material from the path particularly when the power increases . Building up melted material with better efficiency in absorbing energy may be responsible for the higher temperature recorded as shown in figure (7) .

## Conclusion

mild steel was processed by carbon dioxide laser. An attempt to measure temperature distribution by non-contact method was achieved .Relateships between temperature and marking path at different power and pressures are given.

It was found that the average temperature along the marking path increases as the power is increasing due to higher energy consumed during processing operation , while it decreases as the pressure is increasing which may attributes to cooling effect in spite of presence of exothermic reaction between oxygen and mild steel.

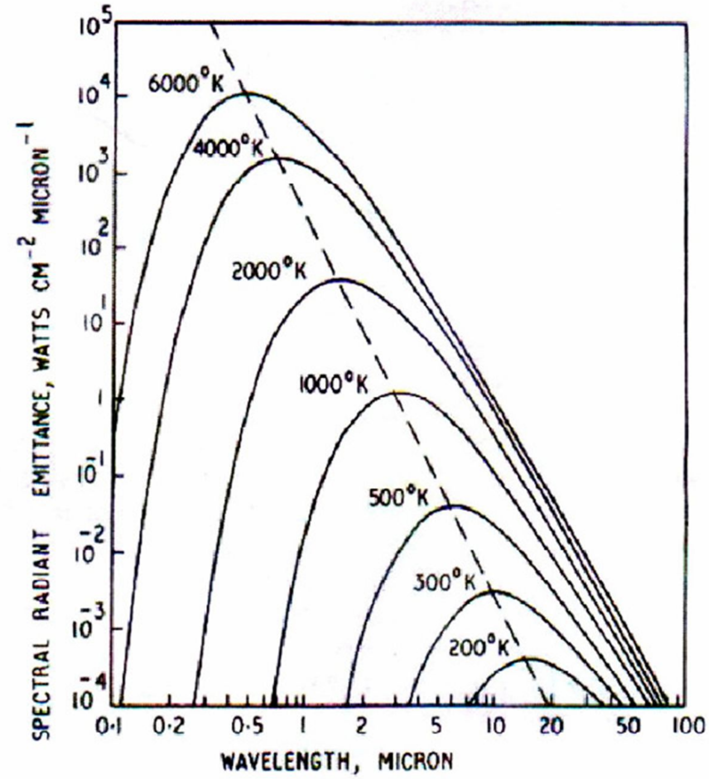


**Fig** 1 The spectral radiant emittance of an ideal blackbody at various temperatures, as a function of wavelength in micron

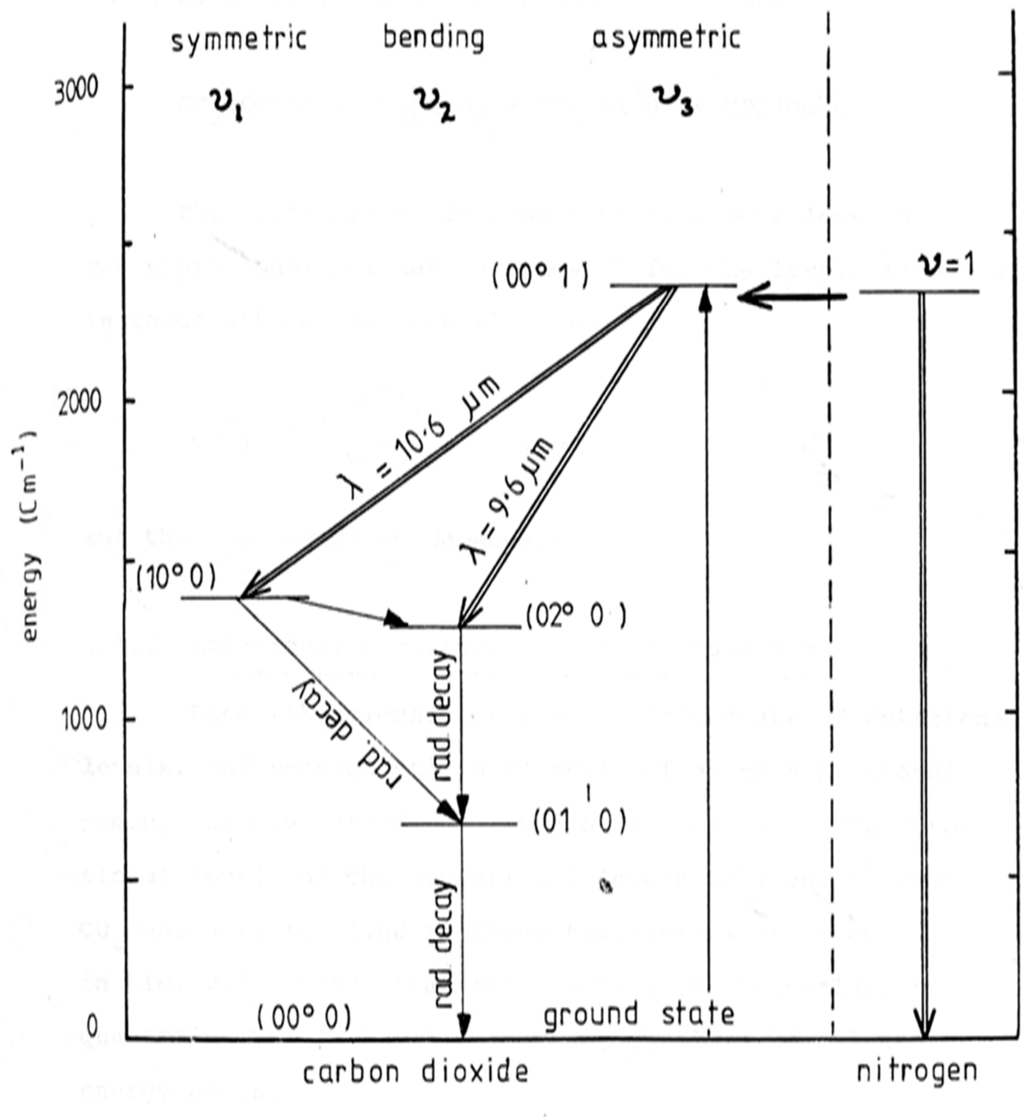


FIG. 2.2: Energy level diagram of lower vibrational levels of $CO_2$ and $N_2$.

LASER CUTTING PROCESS PARAMETERS.

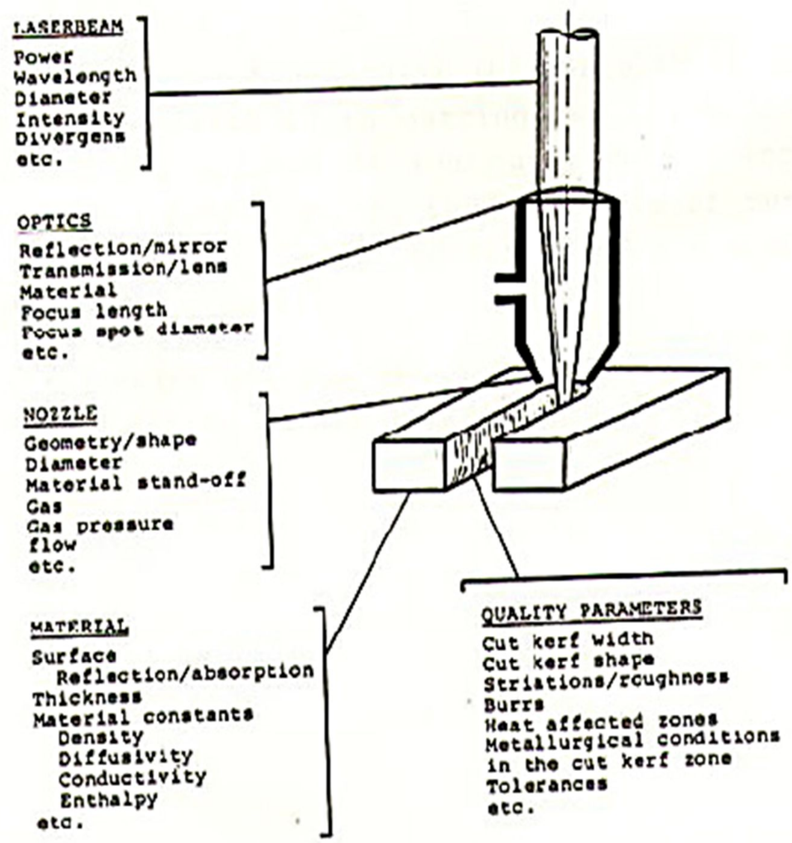


Figure 3-1: Main parameters in the laser cutting process

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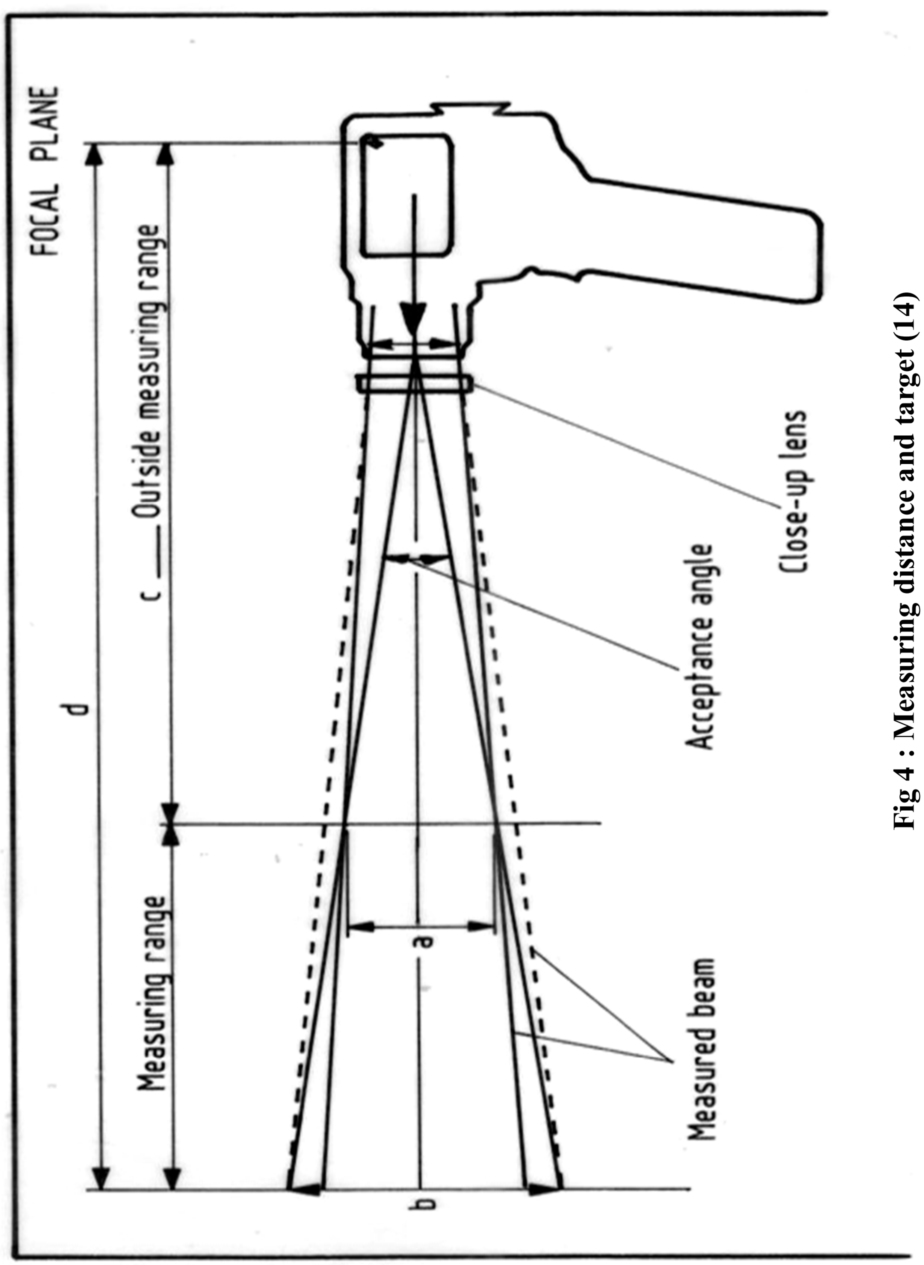


**Fig 4 : Measuring distance and target (14)**

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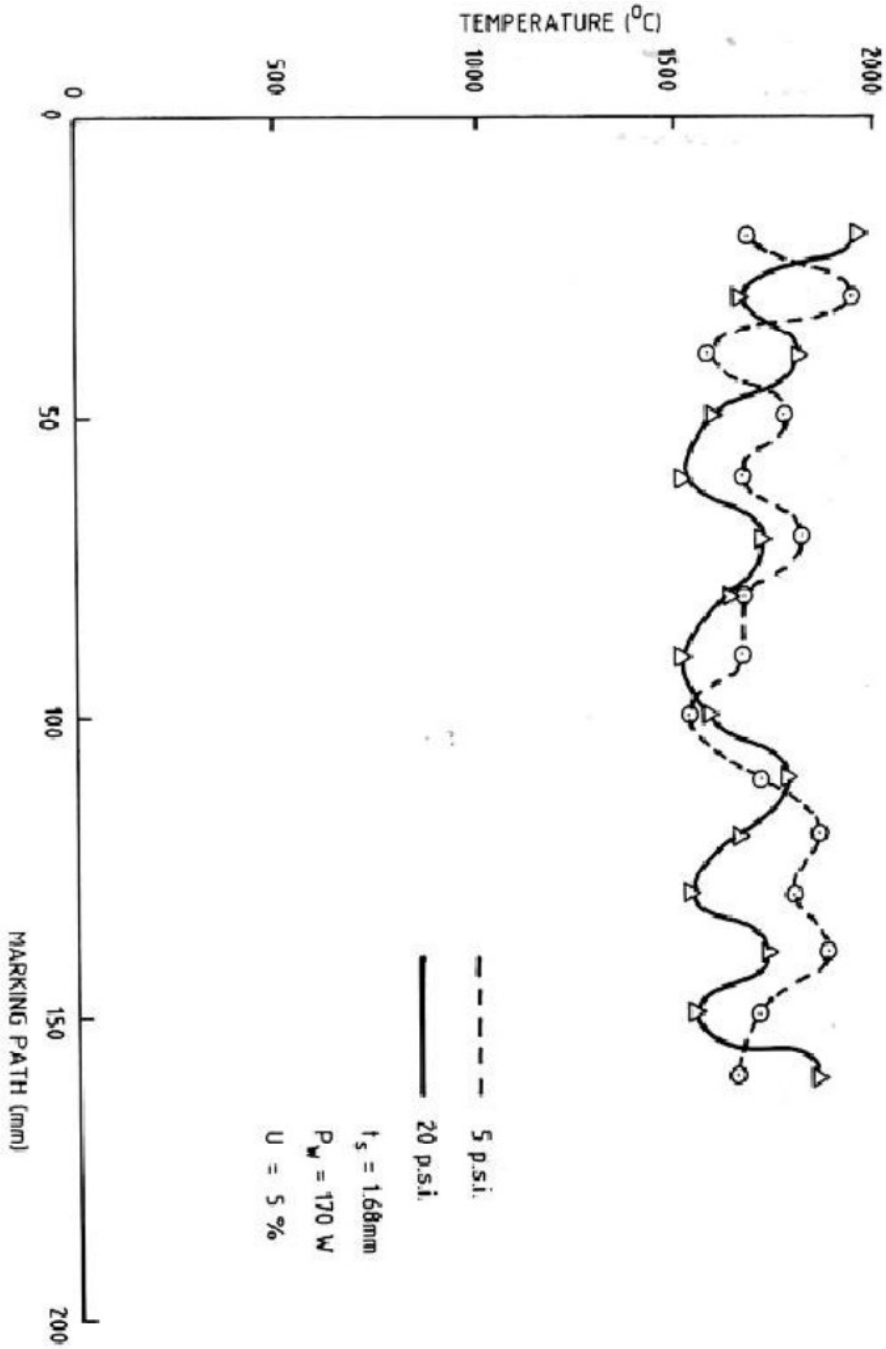


**Fig.(5)** Variation of temperature along marking path

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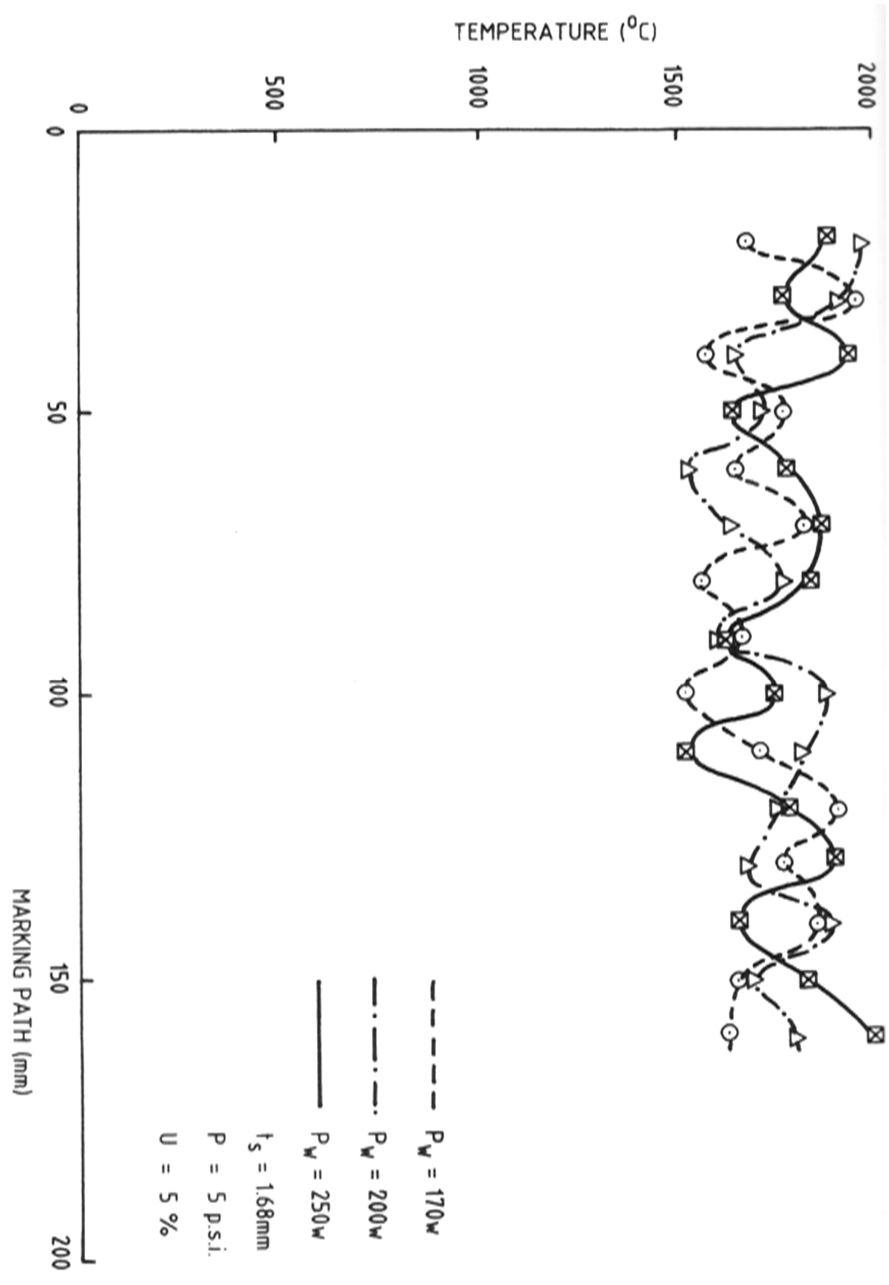


**Fig(6)** Variation of temperature along marking path

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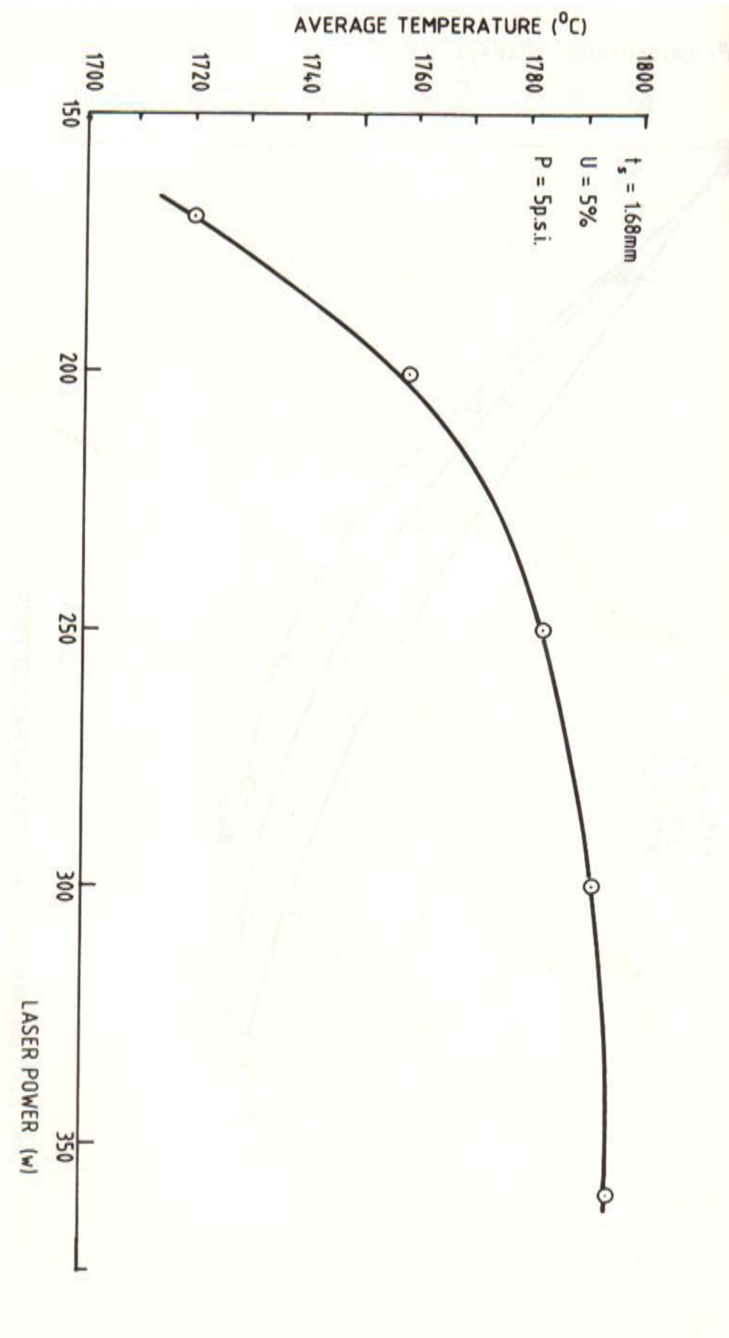


**Fig(7)** Variation of average temperature against laser power.

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