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STUDYING ROUGHNESS OF STEEL CUTTING PROCESS BY LASER

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ABSTRACT: Practical work on laser – Steel cutting Process for thin sheet to gain better informations on cut quality .
Relationship between cutting speed and roughness of the surface at different pressures is shown . It was found that the smoothness of the cut Process is proportional with the cutting speed without any apparent limitation .
Roughest is also Proportional with Pressure of the oxygen gas which is used with CO_2 laser beam.
Keywords: "Roughness , Steel , Cutting , Laser".

1- INTRODUCTION :

Untill the appearance of CO_2 laser in 1965 the prospects for the laser, as a production tool ,were not very promising . By 1967 , CW CO_2 laser of(200 and 300) W output had been built and efficiencies of (15-20)% was reported. CO_2 laser beam alone can only cut very thin metals by melting process . Major step was made towards using the carbon dioxide laser in metal cutting. Particularity with the metals which reacts exothermally with oxygen. Generally , when used for profiling ferrous materials , the CO_2 laser beam is used in conjunction with a coaxial oxygen jet.

The cutting process thus utilizes the laser as an initiator of the exothermic iron oxidation reaction . Even though the energy output of the laser is continuous , this energy acts to periodically initiates a burning – oxidation reaction which propagates a way from the laser created hot spot .

This initiation – propagation event is repeated as a laser beam moves across the material surface resulting in a characteristic cut edge consisting of regularly spaced striations.

Although the edge quality of laser cut steel is generally superior to that achieved by mechanical sawing , the periodic striation place a limit on the applicability of the laser cutting to the production of finished component edges.

However ,a little attention was given to the cut quality by laser until now. The present work concentrated on the roughness which is the main parameter of the cut quality of steel by CO_2 laser. This roughness was correlated with the cutting speed and oxygen gas pressure.

2-HEAT FLOW BY CONDUCTION FOR CUTTING WITH MOVEABLE HEAT SOURCE:

When a steel is cut by means of heat source , heat must be supplied not only to melt the material removed by cut , but also to maintain a temperature gradient in the remainder of the workingpiece , So that the melting temperature may be supported at the edge of the cut , the heat conducted away from the cut may be on appreciable proportion of the total supplied .
Equations predicting the temperature distribution from a heat source travelling with uniform velocity were first set up by Roberts(1) . these equations are widely applied to fusion welding by Rosenthal(2) .

The principle of the quasi – stationary state (i.e; a heat source moves with constant velocity over surface ,the temperature distribution relative to that source becomes constant) was assumed to obtain a solutions for both the temperature distribution and cooling rates in two dimensional case, which he considered to be the case approximating to welding and cutting thin plate of workpiece

Rosenthal(2) assumed that the flow is by conduction in the plate and , by comparison heat losses from plate surface to the surrounding atmosphere may be neglected. And he derived the following expression for temperature distribution in a thin plate.

$$T= \frac{q}{2\pi k}\left[e\chi p\left\{-\left(\frac{\nu\xi}{2\chi}\right)k_o\left(\frac{\nu r}{2\chi}\right)\right\}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

T=Temperature increase at any point.
q= Heat input per unit thickness.
c=specific heat of the plate material.
K=Thermal conductivity of plate material
η=Density of plate material
χ=Thermal diffusivity of plate material , $(\chi=K/\eta c)$
V= (welding), cutting) speed.
K_o= modified Bessel function of the second kind , zero order .
r= Distance of the point from the heat source.
ξ= component distance of the point from the heat source in the direction of molten.

This equation was simplified to give a relation between the width (d) and temperature of any isotherm at the heat point(1).

$$q = 8kT\left(\frac{1}{5}+\frac{vd}{4\chi}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

3- LASER CUT QUALITY (ROUGHNESS PARAMETER):

In engineering design and production, it is important to be able to specify the degree of surface roughness desired. The centre line average (CLA) value of the surface is used and given the symbol R_a. R_a is obtained by measuring the deviation of the peaks from the centre line of trace(3).

The centre line average R_a is:

$$Ra = \frac{h_1 + h_2 + h_3 + \ldots + h_n}{n_h} = \frac{\sum h}{n_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Or $$Ra = \frac{A_1 + A_2 + A_3 + \ ...\ + A_n}{L} = \frac{\sum A}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where $A_{1,2}$ are the areas above and below the mean line in mm^2.

L is the length of trace in mm.

R_a is the universally recognized and most used international parameter of roughness in mm .

$h_{1,2}$ are the peaks and valleys .

n_h is the number of peaks and valleys.

The qualities of cutting which are desirable to a manufacturer are based on the following essential factors [4, 5, 6, 7]:

a- sharp corners at the entry of the cut;
b- smooth cut surface;
c- parallel sides;
d- narrow cut kerf;
e- non-adherent dross;
f- minimal thermal damage to the material.

The roughness of the cutting edge (h) was useful in estimating the quality of cut. Arata[8] reported that for h < 0.05 mm, the cut was considered as a smooth surface, while with h > 0.05 mm it was considered a rough cut. The assessment of cut quality was based by Thomassen and Olsen[9] on cleanliness and smoothness of cut without any dross or burrs, small HAZ, sharp edges and fine striations.

It was found by[3,4,10] that the smallest value of roughness was at the beam entrance surface, becoming rougher towards the bottom. Powell and King[11] suggested a method for improving surface finish of the edges of laser cut mild steel by modulating the energy input to the material rather than using continuous irradiation.

There are different parameters that influence surface roughness which are outlined below:

3-1- Cutting Speed:

Surface smoothness and stability of the cutting process are dependent upon exceeding a minimum speed. Below this speed the oxygen-steel reaction propagates beyond the laser heated area to the limit of the oxygen boundary. The results are large holes being melted and intermittent operation of the cutting process as was reported by Sullivan a*n*d Houldcroft[12].

As the cutting speed is increased the reaction is inhibited from spreading sideways because the workpiece is moved out of the oxygen stream before this can occur.

An attempt was made by Arata[3] to classify laser gas cuts based upon the shape of the cross-section. At very low speeds, the cuts contain irregularly spaced holes of which the diameters are much larger than the beam spot size and hence are of irregular width. These rough cuts, named group I, are referred to as self-burning cuts . At higher speeds, almost parallel sided cuts, called groups II and III with smooth surfaces and narrow kerf width comparable to the beam size are obtained.

Cut III can be distinguished from cut II by the fact that no dross was attached to the near surface of the workpiece. The increase in cutting speed produces group IV cuts for which the kerf is wider and irregular. For higher cutting speeds, cutting process becomes impossible, as in group V.

The poor cut quality at low speeds was produced because of burning of the region directly adjacent to the cut. As the cutting speed approached the maximum, the cuts produced with oxygen assistance are generally excellent in comparison to those obtained without gas flow.

Relationships between surface roughness and cutting speed for mild steel under different conditions were produced by Kovalenko et al[10] and showed an optimal cutting speed at which the surface roughness is minimum. Also the same relationship was produced by Arata et al[3] as shown in his Figure 1.

3-2- Pressure:

It was found that the quality of cut improved with increasing gas pressure according to[13],since the pressure gradient and shear force are two driving force in melt removal. In some measurement the quality of cut for thicker sheets is maintained by increasing the oxygen pressure, but the quality of cut is still reduced with increasing thickness of material.
Forbes[14] stated that at low pressure (5 psi) burning occurred, at pressures as high as (14-21) psi the surface roughness for mild steel tends to be smaller and more uniform . Thomassen , Olsen and others[9] pointed out that the flow conditions around the nozzle tip and the cutting kerf are of major importance to the quality of the cutting and therefore higher pressure increases the quality of the cut. In the pressure range up to 58 psi, the maximum cutting rates for higher quality cuts increase with increasing pressure.
At pressures higher than 72.5 psi a new phenomena was observed namely
self-burning marks in the kerf cut but small and regular compared to those seen at low speed, while at (72.5-102) psi, the quality was quite unstable.

3-3- Material Thickness:

It was reported by Kovalenko[10] that in cutting thin mild steel (1 mm thick), the surface of the kerf was very smooth and the surface roughness was almost uniform along the entire depth, while for thicker samples, the roughness was not uniform along the thickness. Also cutting of 5 m mild steel was reported by Powell and King[11] as rougher than 2 mm, with burn marks on one side of the kerf.

Powell and Menzies[15] believed that the cut quality of carbon steel tends to be superior to mechanically sawn edges, and at thicknesses less than 3 mm can approach the quality associated with the milling technique. Forbes[14] found that the best result in terms of quality for 3.2 mm thick mild steel was obtained with the laser beam focused on the surface.

3-4- Gap between nozzle and metal surface (stand off distance):

The gap between the outlet nozzle and the workpiece surface plays an important role in achieving good quality. Babenko and Tychinskii[13] reported satisfactory results at gaps smaller than 1 mm with dross occuring at the bottom side usually easily removable. However, if the gap is too small then high pressure is generated in the nozzle and the lens may be damaged because of excessive back pressure, while with too large
Gap, the gas velocity is too low and the quality of the cut is reduced, which is according to the Forbes statement[14].

3-5- Nozzle:

Nozzle design and hole geometry is important for cut quality. Forbes[14] used different designs of nozzle and found best results with convergent jets used at sonic velocity. A very high quality cut was produced with good stability and highest practical kinetic energy with less slag and the splatter on the bottom edge of the cut was eliminated.

3-6- Power:

Russell[16] pointed out that higher power is necessary when good surface quality is important, but even with high power the quality of cuts, in terms of surface ripple, deteriorates with increasing thickness because of the need to use lower travel speeds .

4-EXPERIMENTAL EQUIPMENTS, MATERIALS AND PROCEDURES :

4-1-Equipments:

The equipments used in this work are:

a- 525 Everlase model of 500W CO_2 laser system which is typical of equipment used for steel processing .

b- Talysurface instrument was used to measure the roughness.

4-2- Materials and procedures :

a-Thin sheets of mild steel was processed by CO_2 laser.

b- Oxugen gas was employed coaxially with the CO_2 laser beam with range of pressure (10-40)psi.

c- Maximum cutting speed was 33.334 mm/sec. which is expressed as a percentage such as 10%, 25%......., u% (100%=33.334mm /sce).

5- RESULTS AND DISCUSSION:

5-1- Relationship between Roughness and Cutting Speed:

A correlation has been established between cut quality or surface roughness of the cut edge with speed during cutting 0.5 mm mild steel.Figure 3 shows the variation of the roughness against cutting speed at different pressures (20, 30 and 40 psi); the laser power employed was 50W.From the figure the roughness can be seen to be inversely proportional to the cutting speed. At very low speed, the cut edge is rougher than that shown at higher speed. This may be due to overheating caused by the oxygen-metal reaction when the reaction rate is faster than the laser traverse speed. In other words, the energy released by the reaction may propagate beyond the area which is already heated by the laser beam to the limit of the oxygen jet boundary. Such low cutting speeds are normally accompanied by a wider kerf, as molten or evaporated material is removed by the gas jet, in comparison to that achieved with higher cutting speeds. Although the interaction time is quite long for very low cutting speeds, there was no evidence of intermittent cutting, with holes through the material spaced along the cut. The lack of intermittent cutting can be explained as follows:

Because the samples are quite thin (0.5 mm), the temperature gradient is very low through the thickness. The low temperature gradient will produce similar temperatures at all points in the heated area.Therefore the burning rate should be constant and no clear holes occur unless the metal properties differ from point to point. Inhomogeneity of the metal's properties is the probable cause of any fine holes that may appear.

In general, it was found that the cut was very smooth and the roughness uniform along the sample depth of 0.5 mm thickness.

Comparing results of the present work with the published literature is very difficult since the parameters which are produced during this work are not directly comparable with previous results due to the differences which occur in experimental settings such as pressure, power, speed, beam spot size, nozzle configuration etc. Nevertheless a general comparison is drawn as much as possible.

Kovalenko[10] stated that the cutting speed influences the cut quality in the way that surface roughness decreases as the cutting speed increases until a certain speed, called by the author an optimal speed. Beyond the optimal speed the roughness increases. The present work agrees partly with the work published by[10] and the only difference is that there is not an optimal speed but continuous decrease in the roughness as the cutting speed increases.

Arata[3] also confirmed that the cut edge is significantly affected by the cutting speed and the author noticed at very low speed that the cut contains irregularly spaced holes due to self burning. At higher speeds the most parallel sided cuts have smooth surfaces. The main conclusion which can be drawn from the same work is that the roughness of the upper portion tended to decrease with increasing the cutting speed until it became constant value at speeds higher than 33.34 mm/s. The above conclusion agrees with the present results up to the maximum cutting speed used in the present work of 33.34 mm/s (100%). The statement by Romanenko[18] that cut roughness decreases as the cutting speed increases is also valid for the present work.

5-2-- Relationship between roughness and pressures:

Figure 3 shows that when the pressure increases from (20 to 40) psi, the roughness increases also, i.e there is a direct relationship between roughness and gas jet pressure during cutting of 1.68 mm mild steel at a cutting speed of 5% (1.67 mm/s) and power of 125W. The roughness is decreased up to (10-15) psi. Above this range and up to the highest used pressure which is 40 psi the cut quality becomes poorer. It can be seen from a comparison of Figures 2 and 3 that the thinner sample has a smoother cut edge. However, it is considered that the increase in roughness with pressure can be attributed to the excessive energy supplied by the exothermic reaction between the oxygen jet and mild steel, as more oxygen is supplied and to the fact that a laser power greater than threshold was used for low pressure cutting.

The present work partly disagrees with the previous work reported by Thomassen and Olsen[9] in which the author pointed out that cutting mild steel with high pressure up to a certain level, produces an increase in the rates of high cut quality. At pressures above this level some small burning marks appear in the kerf. The appearance of burning marks is a sign of cut quality deterioriation and the surface edge becomes rougher to some extent which depends on the mark size. However, deterioration of cut quality gives a similar conclusion to that found in the present work for pressures beyond 20 psi.

Kovalenko[10] pointed out that it was difficult to find a distinct influence of oxygen pressure on the surface roughness of mild steel, but in general there was a slight tendency for roughness to become more uniform and smoother for gas pressures in the range (14-21) psi. Olsen[19] reported that cutting with a pressure of 72.5 psi and speed 11.6 mm/s gave better results than the cut made at 29 psi and speed of 8.3 mm/s.

However, it was noticed that better cut quality always occurs at the top surface .Striation lines are more regular in the upper portion than in the lower part of the workpiece as shown in figure (4) .It means that the cut quality at the upper part is better due to little oxygen pressure reaches the bottom though the narrow cut kerf in comparison with upper cut edge.

6- CONCLUSIONS:

When reviewing the subject , It was found that study of the present objective is still slim and deeper study was needed to fill the gaps . Cut quality in particular receives little attention from research workers . Thus ,the present work may be considered another step to fill the gap and to understand the roughness which is considered the main parameter of the cut quality . However it was found that the cut quality in terms of roughness can be excellent to that previously published . This work shows that the roughness decreases as the cutting speed increases without any apparent limitation , Also it is proportional to the pressure particularly above 15 psi . It seems that the optimum pressure less than 15 psi is.

The suggestion for future work is to findout the optimum speed (maximum speed for minimum roughness) for cut quality in terms of roughness .

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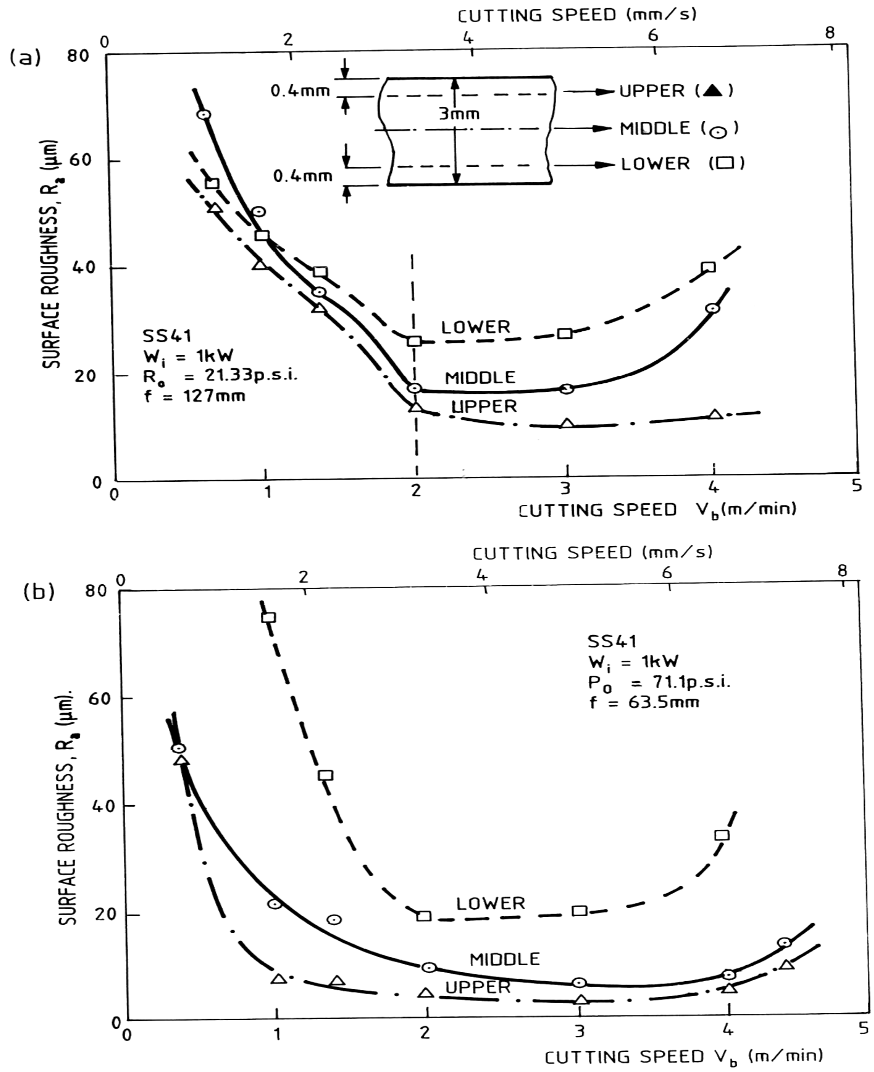


(3.)

Fig.(1): Roughness variation against cutting speed (64)

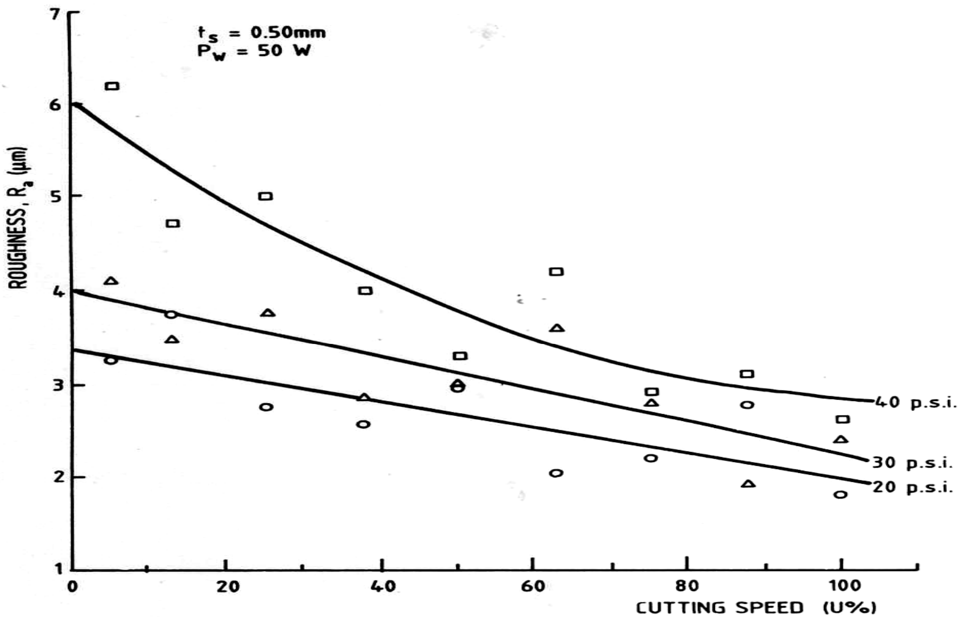


Fig.(2) Variation of roughness with cutting speed

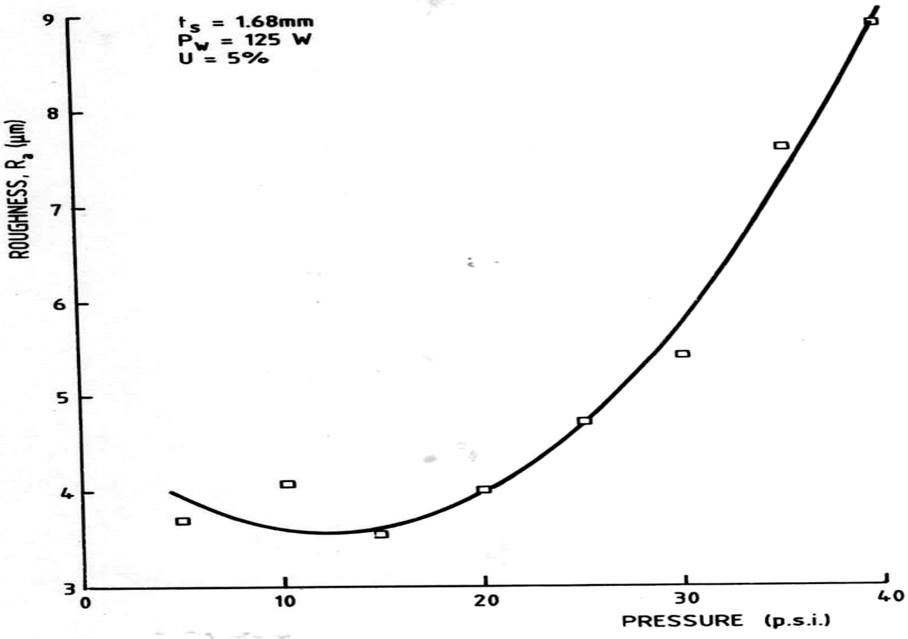
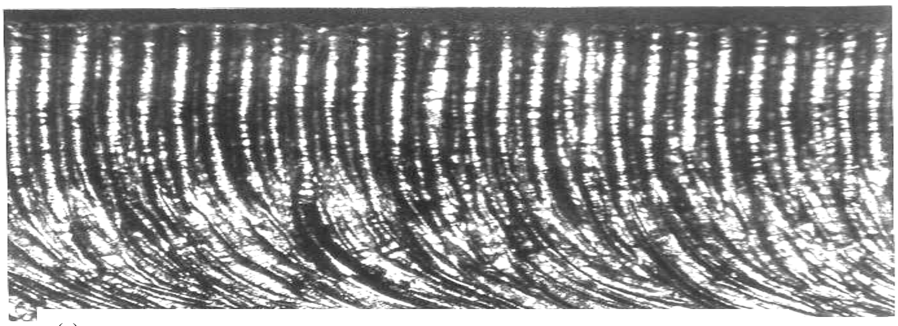
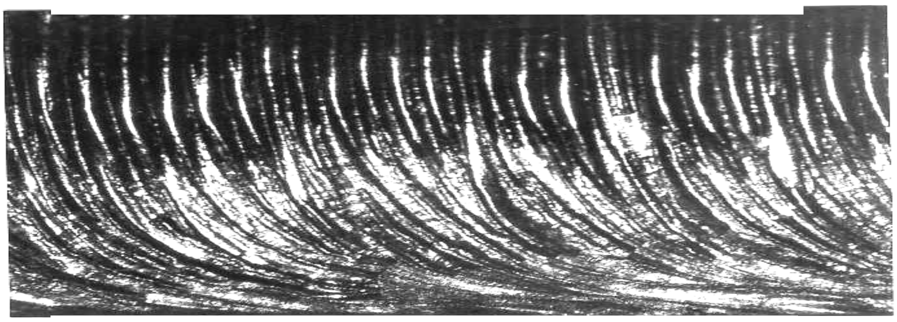


Fig.(3) Relationship between roughness and assisting gas pressure (oxygen)



(a)

ts=1.68mm
p_w=125 w
u=5%
p=20 ps



(b)

ts=1.68mm
p_w=125 w
u=5%
p=40 ps

Fig. (4):striations of cut edges for mild steel.

دراسة خشونة قطع الفولاذ بالليزر

م. جاسم حسن رشيد

قسم الفيزياء / كلية العلوم / جامعة ديالى

الخلاصة

اجراء عملي لقطع شريحة فولاذ رقيقة قد تم انجازه لغرض الحصول على معلومات افضل بخصوص نوعية القطع . كذلك تم تبيان الصلة بين سرعة القطع وخشونة السطح المقطوع عند ضغوط مختلفة حيث وجد ان نعومة السطح تتناسب طرديا مع سرعة القطع دون ظهور تحديد لهذا التناسب .

كما لوحظ ان خشونة السطح المقطوع هي الاخرى تتناسب طرديا مع زيادة ضغط غاز الاوكسجين المستخدم مع ليزر ثاني اوكسيد الكاربون .