Studying Parameters of Cutting mild steel By "Carbon dioxide laser – oxygen and air jet" system

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Abstract

The target of the present research is to show the optimum cutting speed and suitable pure oxygen gas pressure for particular thickness of mild steel using carbon dioxide laser as a cut tool. The relationships between basic cutting parameters using pure oxygen and mixed gases (90% oxygen and 10% air) were achieved. It was found that the laser power is proportional with the cutting speed for both pure oxygen and gas mixture, but the used power for cutting particular thickness higher for gas mixture in comparison with the pure oxygen. Presentation the correlations between different parameters gives better understanding for laser cutting process in general . In addition, the results of this work maybe support the common idea about CO_2 laser as desirable cutting tool for modern technology field.

Key words: parameters, cutting, air jet, CO_2 laser

دراسة عوامل قطع الفولاذ واطئ الكربنة بمنظومة ليزر ثاني اوكسيد الكاربون ودفق من الهواء والاوكسجين

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خلاصة البحث

الهدف من البحث الحالي هو اظهار سرعة قطع قصوى بوجود ضغط ملائم لغاز الاوكسجين النقي ولسمك معين من معدن الفولاذ باستخدام ليزر ثاني اوكسيد الكاربون كأداة قطع . العلاقة بين عوامل القطع الاساسية باستخدام اوكسجين نقي ومزيج غازي (90% اوكسجين و 10% هواء) قد تم ايجادها . عند قطع سمك معين قد وجدنا ان قدرة الليزر تتناسب مع سرعة القطع في حالتي استخدام الاوكسجين النقي وخليط الاوكسجين مع الهواء . الا ان القدرة اللازمة لقطع سمك معين اعلى عند استخدام خليط الغاز مقارنة بالأوكسجين النقي ، ان اظهار العلاقات بين مختلف العوامل ستعطي فهما افضل لعملية القطع بالليزر على وجه العموم ، بالاضافة فان نتائج هذا البحث ربما تدعم الفكرة السائدة بان ليزر ثاني اوكسيد الكاربون اداة قطع مرغوب فيها في مجال التكنولوجيا الحديثة .

الكلمات المفتاحية:- العوامل , القطع , دفق هواء, ليزر ثاني اوكسيد الكاربون

Introduction

The rapid development of techniques for generating beams of high power radiation , primarily related to the development of powerful optical quantum generators , has made the problem of the interaction of intensive radiation with material quite interesting .Many investigations have been appeared in this area during past years, allowing 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(1 ,2 , 3 , 4 , 5).

In the early 1970's , laser cutting had limited applications being mostly used in high technology industries such as aerospace and the available commercial equipment could only cut light sheet because of their limited power output (6.7).

With the development of high power laser , material processing by laser is now being used as part of the production , route for many items such that the laser is increasingly used as commercial cutting tool.

Cutting steel sheet is one of the primary requirements in the fabrication of the most components . laser cutting offers several advantages over conventional cutting methods .The advantages of laser cutting include narrow kerf width (i.e minimal material lost) and minimum heated area , straight cut edge, low roughness of cut surfaces , easy integration with computer numerically controlled (C N C) machines for cutting complex profiles and it is a non- contact process which is suitable for cutting in area limited access . However, since appearance of CO_2 laser it has been widing adopted in industry . The first major step in applications of laser cutting steel was introducing of gas assisted cutting (8) . By using oxygen gas jet which is consider a new technique for cutting metals has been developed by(9 ,10) which employs a laser beam to play as igniter and cutting speeds were improved . In addition , fine cut with negligible heat affected zones have been made in sheet metal . The process is promising to be capable of development for cutting thicker metal .

In addition, concerning with present research , an investigations carried out aiming to optimize the laser cutting process with respect velocity , gas pressure and mild steel thickness. previous works show that the laser cutting velocity is still far below the theoretical and this lead to further optimization of the laser cutting process will be possible.

Main efforts in this research is to find out the importance of the pure oxygen gas pressure as means to increase the cutting speed as well as the thickness of metal . The demands for higher cutting speed is caused by an aim of reducing production cost as a result of reducing the time need to produce a part .Another development goal increasing the maximum thickness with minimum laser power that can be cut is related to the aim of replacing plasma technology .Further investigations of the application of different mixed gases(90% oxygen and 10% air) as cutting gases have been performed.

CO_2 laser

The carbon dioxide molecule is excited by passing through the gas an electrical discharge , and laser action is produced during changes in the vibration energy levels of the molecule .The laser radiation produced in the far infra-red region of the electromagnetic spectrum at 10.6µm wavelength(11).

The nitrogen molecule has several vibrational energy levels which are very close to those of CO_2 and by adding this gas to the discharge , a series of energy resonances is produced between the two molecular types which results in an increase in laser power of about four times .The addition of helium to the CO_2 /N_2 mixture helps to maintain a favorable distribution of energy levels (i . e, a predominance atoms in the excited state) and also, because of its high thermal conductivity it will be help to cool the gas mixture which leads to further increases in the power output .Thus the power output from a CO_2 N_2 He laser is many times greater than from a comparable laser using CO_2 alone ,

and then we can say that the high power carbon dioxide laser can be obtained using a mixture of a bout I part CO_2, I part of N_2 and 10 parts of He . In most of CO_2 laser, the lasing gas is continually pumped along the tube to waste so that, it is completely changed between one and five times every second .

This ensures removal from the cavity of harmful reaction products such as N_2 and CO which tend to "quench" the laser action and reduce the power output. Moreover ,the capability of CO_2 laser output in progressing with an efficiency of 20% which has provide a new heat source of potential value cutting.

This laser generators radiation of a wavelength 10.6 µm has a coherent light properties common to all gas laser. An important characteristic of the CO_2 laser is that the output is continuous allowing an uninterrupted cut to be made.

Mechanism of CO_2 laser – Oxygen gas in cutting process

Laser cutting is a process in which the material is heated to its melting or vaporization temperature. Heating is achieved by concentrating the energy in a very small spot, and this process can be explained as follow:

When a laser beam is focused on to material, photon energy is converted in to energy at the point of incident . If this energy is sufficient then the material will be removed by vaporization , revealing new material to the incident beam . By this successive process a hole may be drilled or if the workpiece is moved a cut will be made(8).

There are many physical phenomena which basically determined the relation between cutting speed and laser power .The reflection of light which is another parameter in determining the efficiency of the energy transfer from the laser beam in to metal . In addition , heat capacity which determines the energy that needed for melting or vaporization of the material . Also , the absorption of radiation is one of the most important factor involved in laser cutting. Obviously cutting at high cutting speed and with thick workpice can only be carried out if the absorption of the laser radiation takes place with high efficiency . The efficiency of the absorption process is determined by several properties of the laser beam such as polarization and intensity distribution in the longitudinal direction (beam divergence) and in the radial direction (mode)(2).

In other word , once the laser beam has raised the metal to enough high temperature , the oxygen reaction begins providing additional heat and forming fluid oxides of the metal which are then expelled from the kerf by the action of the gas jet. The result is that substantially thicker metal may cut than with laser alone with a relatively small increase in the width of the cut kerf (8) . During the evaporation process much of energy is carried out a way by the vapor , which can attain high temperature either obtained directly at the cutting surface or by subsequent energy absorption of the beam (12).

The vapor released from the irradiated material turns into plasma layer above the surface which absorbs the incident light and re-radiates the energy into metal surface .But in other side , where the plasma propagates as a wave towards the laser focusing optics , it absorbs the laser light and shields the target i, e the energy transfer to the target becomes insufficient for cutting process(13) .

As well as , the pressure that builds up in the interaction area is large enough to blow molten material a way from the cutting region and the cut kerf can absorbs energy by different ways such as(4 , 13 , 14):

a-Molten material may flow along the walls of the cut kerf and the metal may condense on them .

b- Heat may also be transported from the hot plasma to the wall through conduction , radiation or convection .

when a gas jet used simultaneously is carried in to the cut as it progresses .Therefore, energy which would normally has escaped from the cut is new made available for further use. The temperature of the molten zone also depends on the amount of heat lost by different cooling process ; heat conduction , heat convection, ejection of liquid material at the bottom of the workpiece and evaporation from the surface of the molten layer(8 ,9 ,15) . The energy loss by convection and melting has been considered to be small compared to that caused by heat conduction and evaporation . Finally, it can concluded that the mechanism for utilizing the high energy density beam of laser for cutting of metals in three points as follows (14) :

a-The metal a long the trajectory of the beam is hcated through the boiling point and leaves the cut regions as a vapor.

b- The metal in the region of the laser beam is brought to melting point by direct heating from the laser beam and a jet gas is employed to blow the melt out of the cut region.

c-When the reactive gas is used, the energy required to melt the mild steel in the vicinity of the laser beam is generated from the exothermic reaction between an active gas and hot metal. The metal brought to a high temperature to catalize the reaction with the reactive gas via the laser beam.

According to(13 ,15) the oxygen gas jet enhances the cutting performance on metal for three main reasons :

a-The metal is oxidized by an exothermic reaction which adds heat to the reaction zone.

b-Oxides are good absorber in contrast to clean metal surface and therefore more effective use is made of the incident energy.

c-The momentum of the gas jet blows molten oxide out of the cut.

Wandera (12) has been pointed out that the energy balance for laser cutting process is such that the energy supplied to the cutting zone and can be divided into two parts ; The first is energy used in generating a cut and the second is energy losses from the cut zone. Also he claims that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken . Therefore , the energy lost from the cut zone decreases with increasing of cutting speed which resulted to increase in the efficiency of the cutting process.

Equipments and Parameters

Gas jet –laser Cutting head:

An excellent technique for oxygen cutting metal has been used. This technique is named as "laser gas cutting method "in distinction from " laser cutting method " which employs laser alone . In this technique , laser beam used for pre-heating before oxygen –metal reaction begins.

The laser beam is focused by a lens through a nozzle on the surface metal.An assisting oxygen gas is blown Coaxially with the laser beam through nozzle and then through cut kerf.

The equipment cutting Parameters and material:

In the following, review of the equipment, cutting parameters and material which are employed in the present research: with laser.

a-CO_2 laser system :The 500W CO_2 laser system (525 Ever laser model) is typical of equipment used for mild steel processing which is now regularly carried out in industry .

b-Power : The maximum power available is about 500 watt.

c-Cutting speed : The maximum speed is a bout 33.34 mm/s .

d-Pure oxygen and mixed gases (90% oxygen and 10 % air)were used.

e-Pressure :The range of pressure employed was (15-45)psi

f-Metal :sheets of mild steel were investigated with thickness (1.5and 3) mm.

Results and Discussion

a-Relationship between laser power and laser cutting speed :

Figure (1) and figure (2) show the relationship between minimum laser power with cutting speed for different pressure of pure oxygen gas and different thicknesses (1.5mm and 3mm) of mild steel respectively. It can be observed that minimum power which is called threshold power and at this point , the cutting process is not possible . Figure (1) shows that the minimum power is proportional to the cutting speed which is in agreement with references (8 , 15 , 17 ,19) .

Houldcroft (9) also mentioned similar result to the present work but he suggested that there is a threshold power beyond which the cutting speed may increase out of proportion to laser power.

At very low cutting speed , self burning was clear which contains irregulars spaced holes. This result is nearly similar to that reported by Arata (7) . This phenomena is due to the oxidation reaction spread out beyond the circle of the exothermic reaction because the thermal conduction becomes predominant in the temperature distribution .This effect will be accelerated by the large amount of heat contained within the dross which easily deposited to the bottom surface of the thin plate in low speed cutting .In accordance with the conclusion which is reported by Sullivan (8) it was found that the burning holes are vanished when the velocity is increased .This case can be attributed to the fact that the reaction is inhibited from spreading sideways because the workpiece is moved out of the oxygen stream before exothermic reaction can occur.

In the other words, when the cutting speed increases, the interaction time decreases . As the interaction time becomes shorter, less power is available to strike the irradiated area , also less exothermic energy is produced since less oxygen gas reacts with the metal.Therefore a thinner molten layer is created . As the cutting speed increases the thickness of molten layer becomes thinner and complete cut may stop . Therefore to cut the same thickness with higher speed, the laser power required should be increased . Rajaram and Sheika (17) have been pointed out that as a result of the limited exposure time of the melt the laser- oxygen combination , not all of the iron in the melt is oxidize and may be reduces of cutting speed .

Figure (1) and figure (2) show that when increasing the thickness of mild steel the laser power increases too, see table (1).

b- Relationship between power , cutting speed and pure oxygen gases pressure:

For certain pressure and cutting speed , higher laser power is required to cut thicker samples as shown in figures (1 and 2) . when all cutting parameters are constant (power , pressure and cutting speed) , a thinner molten layer is produced during cutting thicker samples due to the fact that the temperature gradient is higher . Therefore a thicker molten layer is required . To meet this requirement (thicker molten layer) , one or more of the following parameters should be increased : laser power and gas pressure .Increasing laser power , for instance , will increase the temperature even further and reduces the temperature gradient followed by a thicker molten layer . when the gas pressure is high enough to remove the molten product and to keep heat conduction in the cut direction at the same rate thicker material can be cut unless layer thickness decreases . .

To overcome the above problem in order to cut thicker samples, it is necessary to increase either power or pressure . Work which was reported by Houldcroft (3) shows that the power increases when the material thickness increases.Fletcher (6) was gave a graphical relationship between cutting speed and sheet thickness of steel. He shows that when the thickness increases , cutting speed becomes smaller .

A study of the relationship between cutting speed and mild steel thickness was reported by Powell (18)and Powell and Menzies (19) which showed that cutting speed is inversely proportional to the thickness for all the thickness range.

Nilson and Sarady (8) showed that the laser power required to cut 0.8 mm steel at a speed 5 – 6.7 mm / sec . is 400w .

In general , all these results agree with the current conclusion .

c- Relationship between power and cutting speed with mixed gas pressure (90% oxygen and 10% air) :

It was found that cutting velocities decreased and cut quality slightly improved with using mixed gases as cutting gas . This phenomena is attributed to the cooling effect by presence of nitrogen in air . Nitrogen plays a major role in reducing the exothermic reaction between oxygen and metal. Thus less energy contributes in cutting process which need more laser power to substitute . Also, the heat affected zone near cut kerf which is one parameter of cut quality becomes narrower and cut kerf smoother at upper part but little burrs were noticed underneath .

Figure (3) and table (1) shows relationship between cutting speed and power for both pure oxygen and mixed gases . However , the momentum of the mixed gases in relation to the removed of the molten fluid from the cutting kerf ,does similar job to the pure oxygen gas although a little burrs at the bottom surface of the workpiece were found while nothing found with the employment of the pure oxygen gas jet.

Conclusion

The pressure of the pure oxygen gas is very important parameter for cutting mild steel by CO_2 laser which played a major role in decreasing laser power and increasing both cut speed. The metal sheet thickness which is very necessary for minimizing cost production. This is due to the fact that the oxygen reacts exothermally with metal which produce additional energy to be used in cutting process . When mixed gases are used , cutting velocity decreased in comparison to employment of pure oxygen gas. In addition ,cut quality is slightly improved through minimizing heat affected zone and smoothness of cut kerf

Table (1) Cutting mild steel parameters.

Gas Pressure			15 ps:	30 ps:	45 ps:	Note
Gas	Thickness (mm)	Cutting speed U%	Power (w)	Power (w)	Power (w)	
Pure Oxygen	1.5	10	100	92	80	Maximum cutting speed 100%=33.34mm/s
		25	122	114	95	
		50	150	145	128	
		75	193	164	143	
		100	225	204	180	
Pure Oxygen	3	10	206	195	186	
		25	240	224	215	
		50	336	295	250	
		75	392	354	323	
		85	447	369	343	
		100	-----	421	357	
Gas mixture 90% oxygen 10% air	1.5	10	130	121	112	
		25	148	132	130	
		50	169	160	148	
		75	207	183	159	
		100	256	215	185	

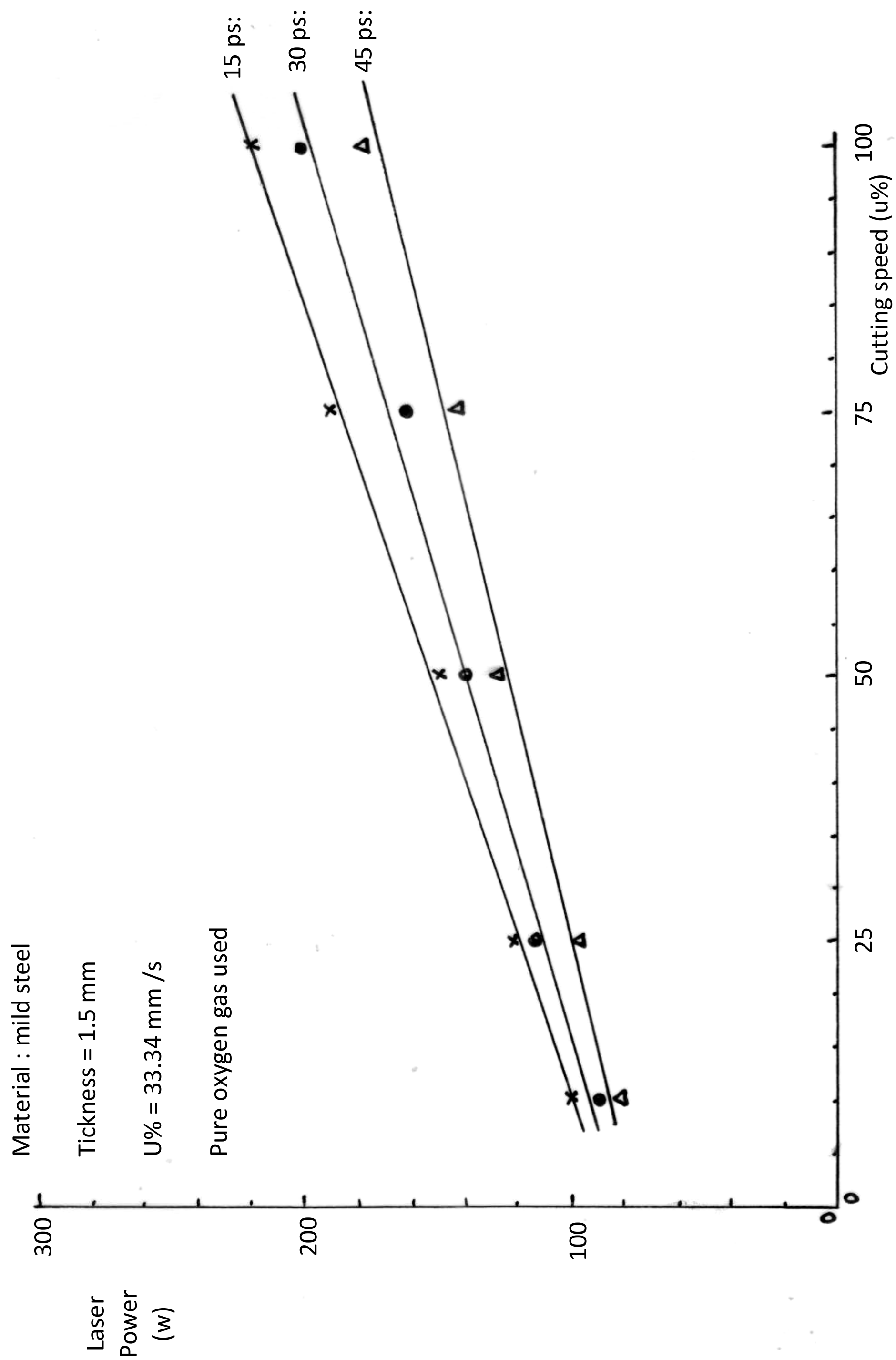

Fig (1) : Variation of the laser power with the cutting speed

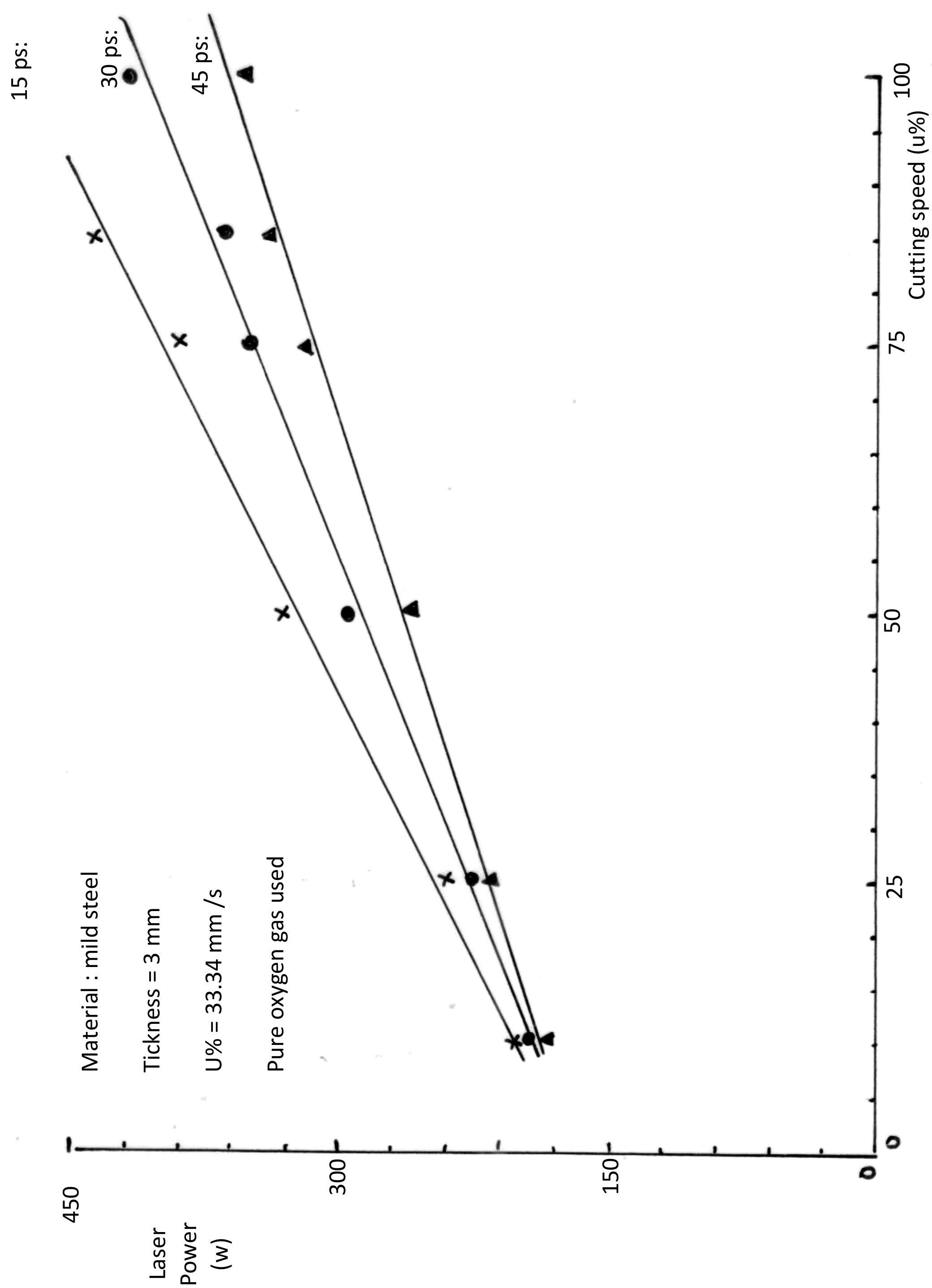

Fig (2) : Variation of the laser power with the cutting speed

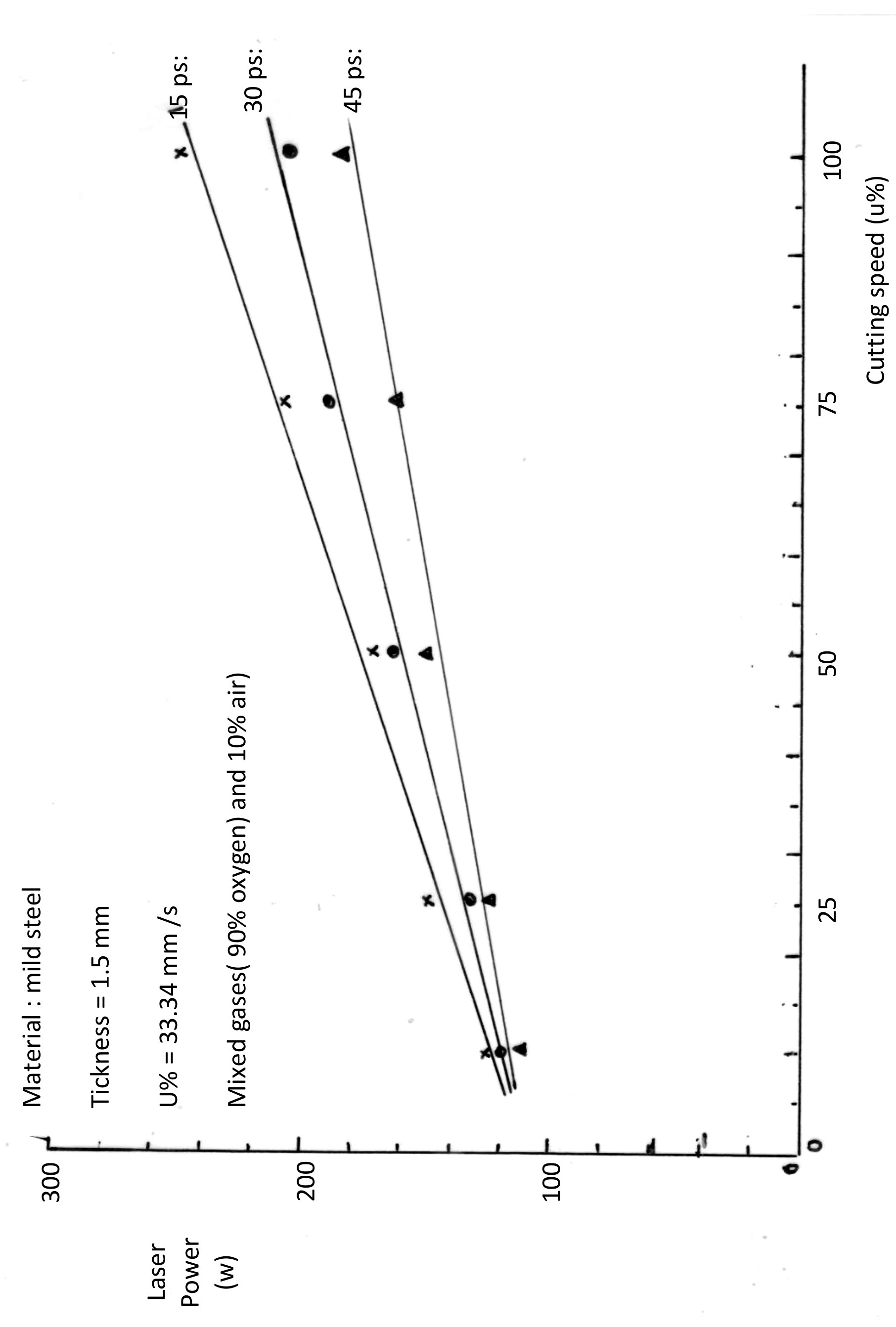

Fig (3) : Variation of the laser power with the cutting speed

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