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Experimental Study of Cutting Different Materials with a 1.5 KW CO_2 Laser†

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Abstract

Using a CO_2 laser with the power output range of 0.4-1.2KW, a cutting experiment has been systematically carried out on mild steel, stainless steel, titanium and aluminum with various thicknesses with a view in showing the limits of this process. The results obtained have clarified the effect of major cutting parameters such as cutting speed, assist gas pressure, laser power and thickness of the plate, upon the essential factors for estimating the qualities of the cut including kerf width, HAZ width, surface roughness of the cut and the amount of dross deposition. Cutting conditions for the highest productivity and for the best quality of the cut have been shown.

1. Introduction

Cutting metals with CW CO_2 lasers are getting special attention in various fields of industry, because it can provides more precise cuts at higher speeds than any conventional cutting methods. In order to use the laser cutting technique for industrial productions, it is essential to clarify the effect of major cutting parameters on various quality factors of the cuts.

The qualities of the laser cuts were first estimated by the authors in 1969 [1] [2]. Since then many studies [3] - [10] have been done on the estimation of the laser cuts, although the range of cutting parameters and estimation factors of cuts is not wide enough to find optimal cutting conditions. In one of these papers [9], the attempt has been done to outline the major factors determining the quality of the laser cuts in comparison with conventional cutting techniques, although the cutting conditions tested are limited. In the other papers [4] - [5], the relationship between a few laser cutting parameters and qualities of the cuts has been discussed. Recently the effect of cutting parameters on the quality of cuts for mild steel has been systematically studied by using mainly low power CO_2 laser (about 200W) [11] [12].

In the present study, systematic cutting experiments have been done to find the exact relationship between the major cutting parameters and the essential factors for estimating the quality of the laser cuts, using a considerably wide range of CW CO_2 laser power, 0.4-1.2 KW, which makes the cutting of various kinds and thicknesses of metals possible. The results obtained in this study are compared, if possible, with the literature values.

2. Experimental equipment and procedures

The laser cuts were made by using a GTE sylvania, Inc. Model 971 continuous CO_2 Gas Transport laser with the maximum output of 1.5 KW shown in **Fig. 1**.

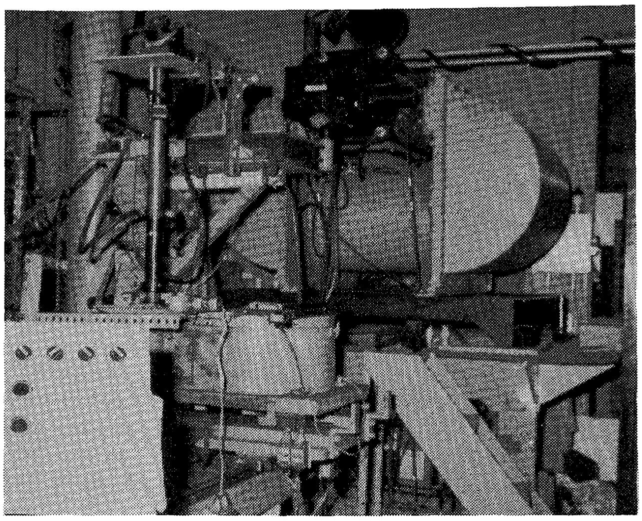

Fig. 1 The general view of experimental equipment for laser material cutting.

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The 10.6 μm beam from the output window of the apparatus is reflected vertically down by a 45° plane mirror and then is focused by a ZnSe lens with a focal length of 127 mm. At the power levels used in the present experiment, the beam spot at the focal point has a power density distribution which is approximated by a Gaussian curve with the diameter of about 0.2 mm at 1/e power point of the center. This means that at a laser power of 1 KW, for example, the power density at the center of the beam spot is about 3.2 x 10^6 w/cm^2.

In laser cutting, the focal point was located just on the upper surface of the cut material, and a convergent nozzle with 1.2 mm in diameter was used. The distance between the nozzle edge and workpiece was 1 mm. The laser power passed through the nozzle was monitored after every 10 samples had been cut, so that the laser power was stabilized within ±5% fluctuation.

Four kinds of metals have been used: mild steel (SS41), austenitic stainless steell (SUS304), titanium and aluminum. The chemical composition and thickness of these samples are given in **Table 1**.

Table 1 Materials used

Material	Content (%)	Thickness (mm)
Mild Steel (SS41)	C-0.03, Mn-0.24, P-0.01, S-0.01 Fe-Remainder	0.5, 1, 2.2, 3.2, 5.2
Stainless Steel (SUS304)	C-0.08, Ni-8-11.0 Cr-18-20.0 Fe-Remainder	2.0
Titanium	O-0.20, N-0.05, Fe-0.25 Ti-Remainder	1.0, 2.0
Aluminum	Fe-0.40, Cu-0.05, Mn-0.05, Mg-0.05, Zn-0.05, Ti-0.03, Al-Remainder	1.0, 2.0

Cutting mild steel, stainless steel and alminum was assisted by oxygen co-axial with the laser beam. In cutting titanium argon gas was used instead of oxygen. The pressure of the assisted gases was varied in the range 0.5-3.5 kg/cm^2. The samples were clamped on a working table with X-Y movement with a speed range 100-10000 mm/min.

The measurement of the kerf and heat affected zone (HAZ) width has been performed using optical projector, and the roughness of the cut surface has been measured with Talysurf-4 device, Tayler Hobson Rank Co. The cross section and surface of the cut were taken by a metallographic microscope and scanning microscope, HSM-2B (Hitachi Co).

3. Results and Discussion

3.1 Evaluation of the Cut Quality

Laser power, cutting speed and assist gas pressure were selected as the cutting parameters. In order to evaluate the quality of the cuts, factors such as the kerf width and the width of the HAZ, the roughness of the cut surface and the amount of dross deposited were chosen.

The kerf width is an important parameter referring to preciseness of cut dimensions and the amount of wasted material. One of the important features of laser cutting is that the kerf width is very narrow in comparison with the conventional ones. Here kerf width was measured at the top surface. The width of HAZ and surface roughness of the cut are essential parameters to know the informations about the thickness which has to be removed after cutting if the post laser machining is required.

In general, HAZ includes the region of material with color changes due to oxidation on the workpiece surface, metallurgical structure changes, microhardness changes and other undersirable changes. In the preliminary experiment for cutting mild steel, it was found that if remarkable dross deposition on the rear surface did not occur, width of the region with metallurgical changes and hardness changes, which was almost constant in width along the thickness, is nearly equal to or somewhat less than the width of the color changed zone. Thus it is considered to be possible to evaluate the HAZ width by that of color changes as the first approximation. In cutting titanium with the assist of argon gas, color changed zone was also observed, but such an estimation is not valid of course. However, the width of color changed zone was also measured for reference, since it may be important depending upon the application.

In laser cutting, since the surface roughness of the cut varies along the thickness especially at high cutting speeds, it was measured near both surfaces of samples and at the middle of the thickness. Furthermore dross deposition at the rear surface and self-burning phenomenon which tends to occur especially at very low cutting speeds are also observed.

3.2 Kerf Width

Mild Steel (SS41)

As shown in **Fig. 2**, it is seen that the kerf width at the upper surface of SS41 is independent of the thickness, whereas it decreases almost linearly with increasing the cutting speed. From this figure, it is also possible to find the maximum cutting speed, which was found to be largely in ivnerse proportion to the thickness. At the

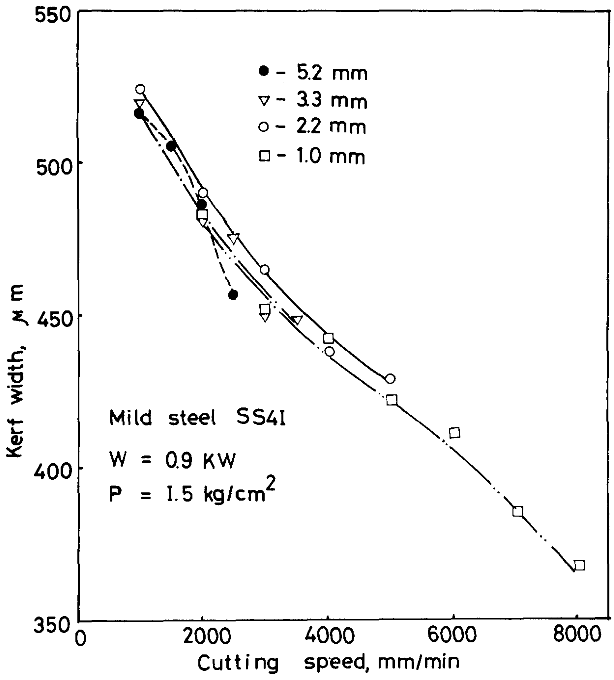


Fig. 2 Kerf width vs cutting speed for mild steel.

maximum cutting speed, the narrowest kerf width can be obtained, but the other qualities of the cut are not good.

Figure 3 shows the relationship between the kerf width and oxygen pressure for various cutting speeds. It was found that for lower speeds there is a peak in curves which occurs between 1-2 kg/cm^2, but with an increase in the speed the kerf width does not depend upon the oxygen pressure at all. The kerf width is also influenced by the laser power; the kerf width at constant speed (1000 mm/min) increased with increasing laser power as shown in **Fig. 4**.

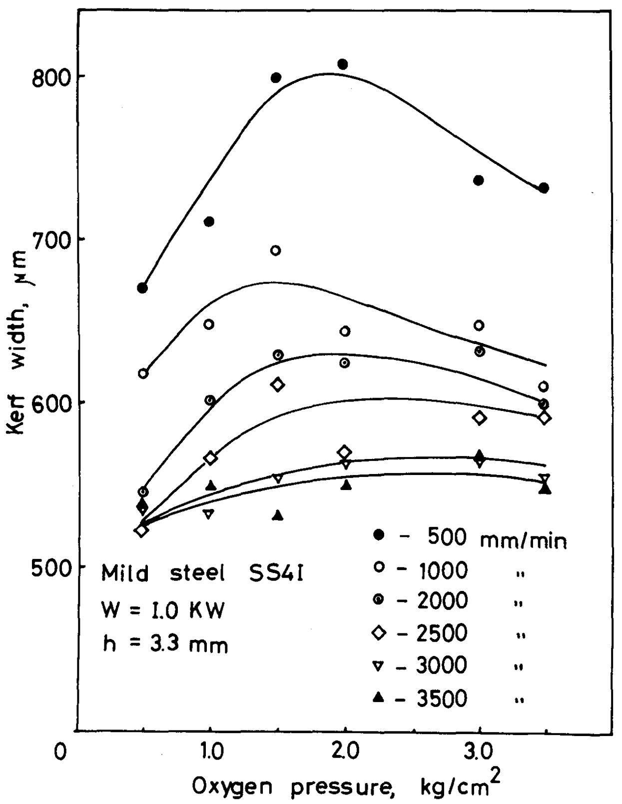


Fig. 3 Kerf width vs oxygen pressure for mild steel.

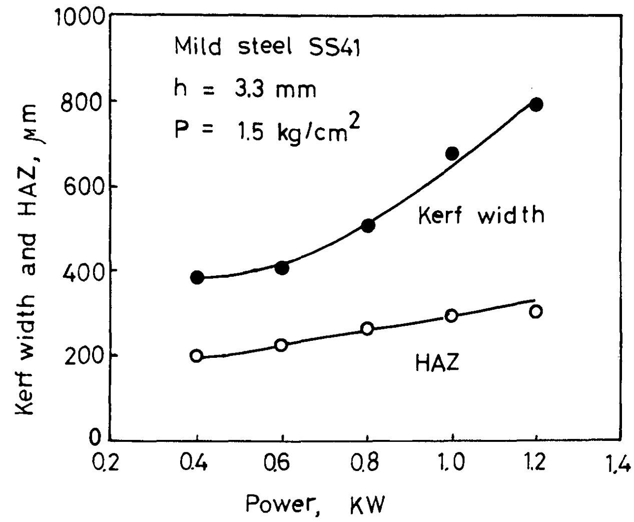


Fig. 4 Kerf width and HAZ vs laser power for mild steel (V=1000 mm/min.)

Stainless Steel (SUS304)

At very low speeds, the kerf width of stainless steel are almost same as that of mild steel, but with increase in the speed it decreased more rapidly than that for mild steel **(Fig.5)**. At very low gas pressures, around 0.5 Kg/cm^2, the kerf width is rather wider, but at the pressures higher than 1.5 Kg/cm^2, it becomes independent of the pressure. In this respect it appears that 1.5 Kg/cm^2 is the optimal pressure for cutting stainless steel of 2 mm thickness. Within the conditions tested, however, the increase in the gas pressure increases the maximum cutting speed and thus decreases the minimum kerf width.

Titanium

With increasing argon pressure, no change in kerf width was found to occure, but the maximum cutting speed increases like stainless steel **(Fig. 6)**.

Aluminum

Unlike the other metals tested, the kerf width of aluminum is almost independent of the cutting speed as shown in **Fig. 7**, where the kerf width and the maximum cutting speed for four kinds of metals of 2 mm thickness cut at same conditions are compared.

At given speed, the kerf width of aluminum is the narrowest, titanium comes second and next in order are stainless steel and mild steel. Except for aluminum, the

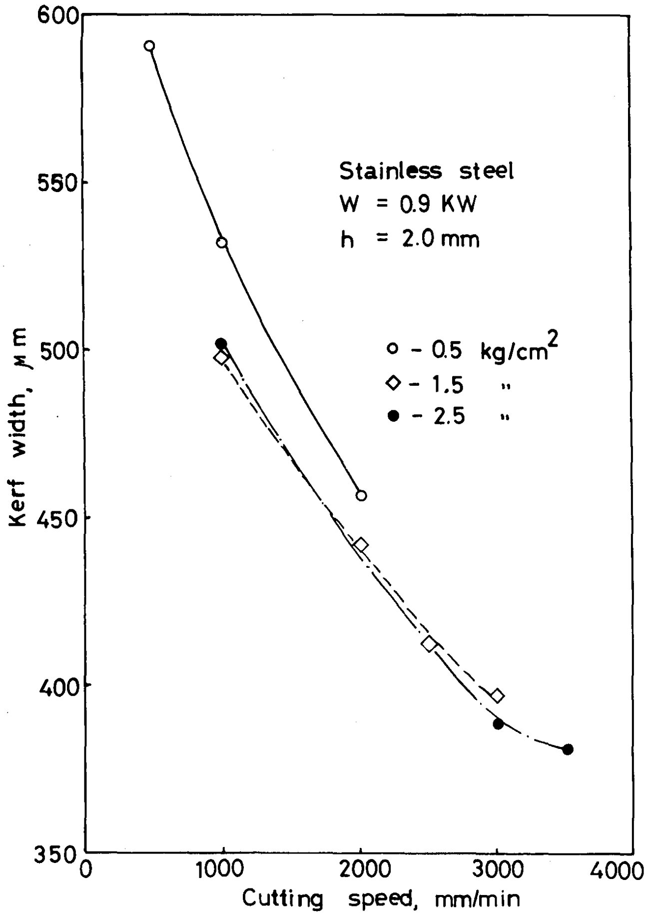


Fig. 5 Kerf width vs cutting speed for stainless steel.

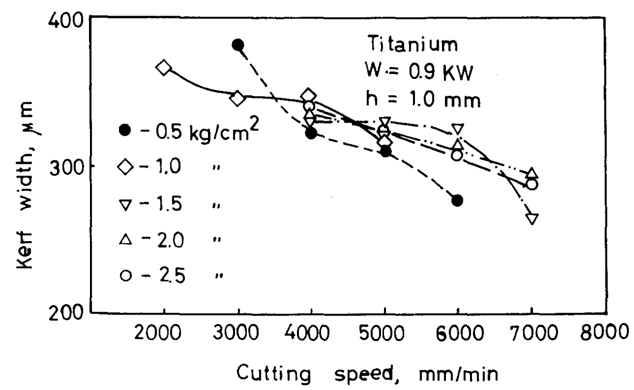


Fig. 6 Kerf width vs cutting speed for titanium (h=2mm).

kerf width for each metal can be extraporated to the same value, about 550 μm at the speed of zero. Decreasing order of changing rate of kerf width with increase in the cutting speed is as follows: titanium > stainless steel > mild steel > aluminum. Whereas decreasing order of the maximum cutting speed is as follows: mild steel > stainless steel > titanium > aluminum.

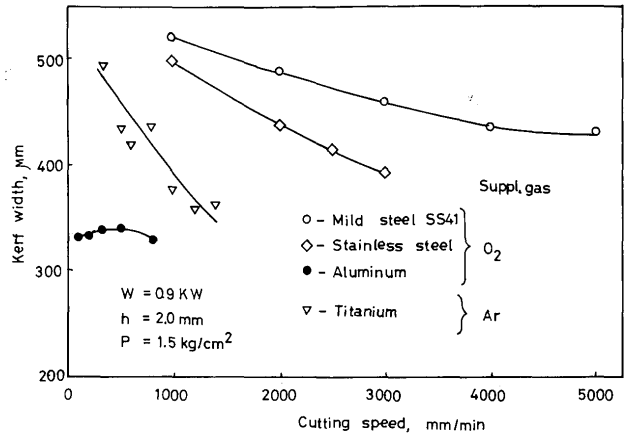


Fig. 7 Kerf width vs cutting speed for various materials.

3.3 Heat Affected Zone (HAZ)

Mild Steel

With increasing the cutting speed, the width of HAZ decreases, but the ratio of the width between HAZ and kerf also decreases **(Fig. 8)**. The width of HAZ is

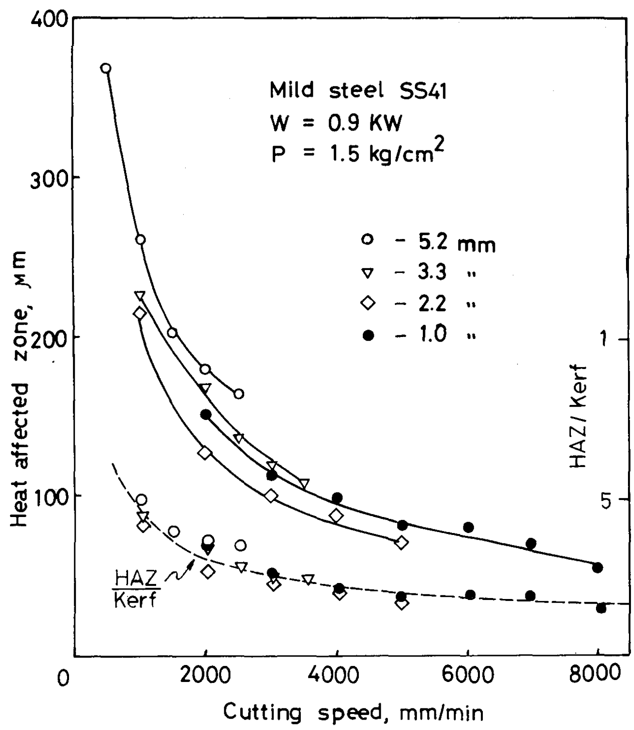


Fig. 8 Heat affected zone vs cutting speed for mild steel.

considered to be practically independent of the sample thickness, although it tends to increase shightly with increasing the thickness.

On the other hand, there is a tendency of decrease in HAZ width with increasing oxygen pressure especially at lower cutting speeds **(Fig. 9)**. At the higher speeds, however, the HAZ width is almost independent of the

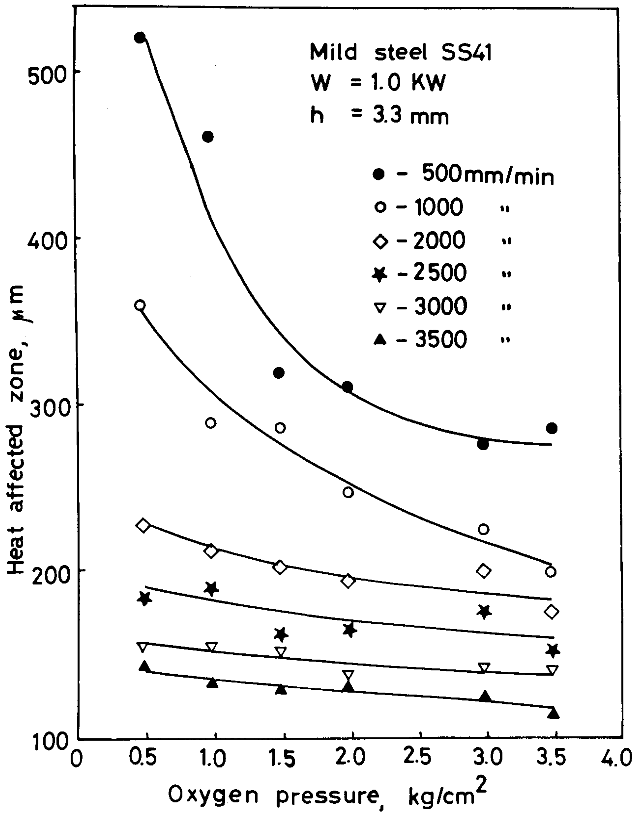


Fig. 9 Heat affected zone vs oxygen pressure for mild steel.

pressure. It was also found that the HAZ width increases with increasing the laser power as shown in Fig. 4.

Stainless Steel

The increase in the pressure above 1.5 Kg/cm^2 was found to bring little change in HAZ width especially at higher cutting speeds **(Fig. 10)**. This fact and the

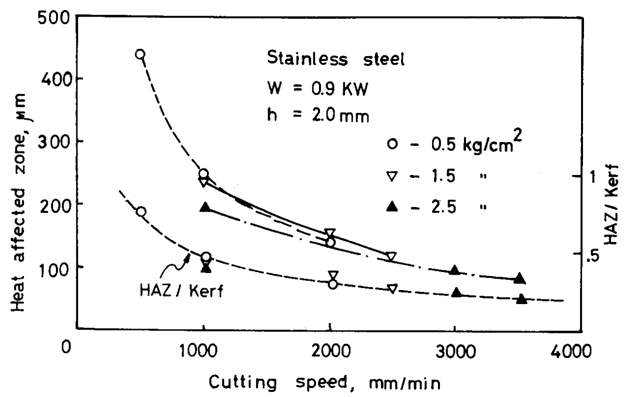


Fig. 10 Heat affected zone vs cutting speed for stainless steel.

tendency of the kerf width described above mean that 1.5 Kg/cm^2 is a quite sufficient pressure for cutting stainless steel. The ratio of the width between the HAZ and kerf was found to decrease with increasing the cutting speed as the case in mild steel.

Titanium

From this experiment, it is obvious that argon pressure affects the HAZ width very much. If the amount of argon is large enough to shield the cutting region from oxidation and the cutting speed is fast enough to prevent overheating of material adjacent to the kerf, then the HAZ width is very small or sometimes is even absent. In **Fig. 11** some conditions are shown at which HAZ

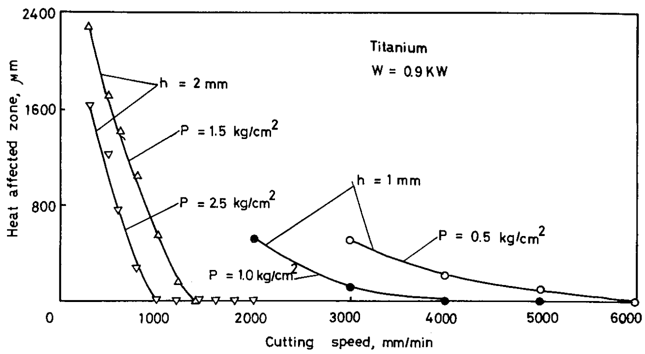


Fig. 11 Heat affected zone vs cutting speed for titanium.

has been observed. For 2 mm titanium samples at P=3.0 Kg/cm^2, and for 1 mm samples at P=1.5, 2 and 2.5 Kg/cm^2 heat affected zone has not been observed in the whole range of examined speeds (if HAZ is evaluated by color changed region).

From these results one may conclude that for cutting titanium without HAZ the mentioned conditions are optimal for high quality processing.

Aluminum

No heat affected zones evaluated by color change were found in this material in a wide range of working conditions. This corresponds with the reported results on studying piercing holes with pulsed laser beam [13] where no HAZ adjacent to the holes has been observed.

3.4 Surface Roughness

Mild Steel

In cutting thin mild steel (h=1 mm) it was found that the surface of the kerf is very smooth and the surface roughness R_z is almost uniform along the entire depth. It was found that the cutting speed influences R_z and that there is some optimal speed at which the roughness is the lowest **(Fig. 12)**.

In higher thicknesses the surface roughness is not uniform along the thickness any longer. At the region adjacent to the entrance of the laser beam into the material R_z is smallest **(Fig. 13)**. In the middle depth of the kerf the value of R_z is higher and is higher still at the part of the kerf close to the exit of the beam from the material. With cutting speed variation surface roughness

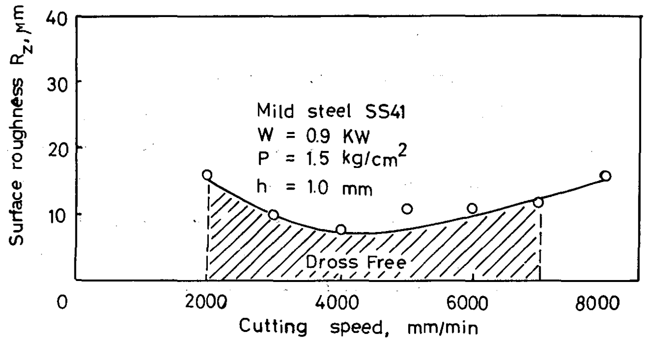


Fig. 12 Surface roughness vs cutting speed for mild steel (h=1 mm).

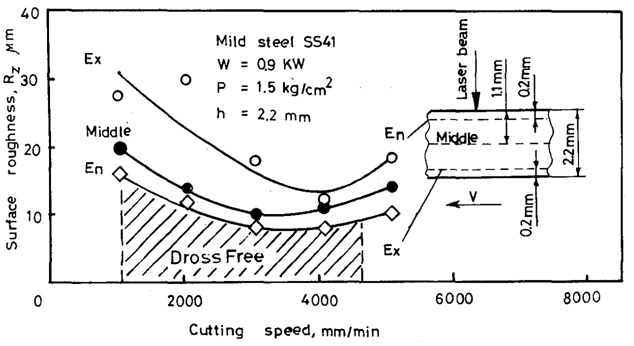


Fig. 13 Surface roughness vs cutting speed for mild steel (h=2.2 mm).

in all these different parts of the kerf changes in the similar way.

The minimum surface roughness at each part could be obtained at some speed lower than the highest cutting speed. For 2.2 mm thick samples this speed is about 3000 mm/min, and for 3.3 mm thick samples - 2000 mm/min at beam power W=0.9 KW and oxygen pressure P=1.5 Kg/cm^2. But for still thicker samples the surface roughness at the exit of the beam is much higher **(Fig. 14)**

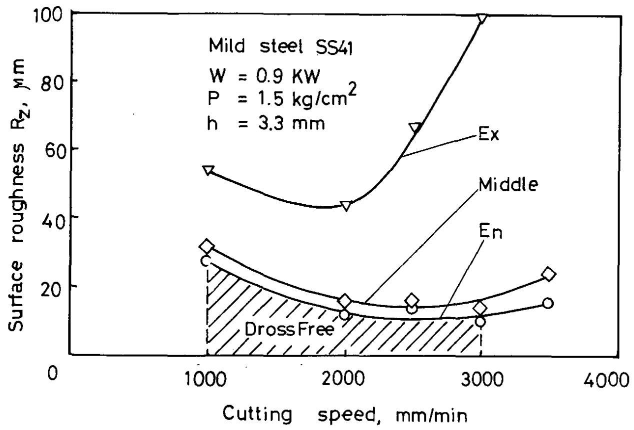


Fig. 14 Surface roughness vs cutting speed for mild steel (h=3.3 mm).

than one for thinner samples, especially at the speeds higher than that for minimum R_z of the uppr surface. The minimum value of R_z at the entrance is of the same magnitude (the value equals to R_z=10μ m or even less) for samples of different thicknesses (Fig. 12-14).

It was difficult to find the distinct influence of oxygen pressure on surface roughness for mild steel. But speaking in general there was a slight tendency of getting more uniform and smaller roughness in gas pressure range of 1-1.5 Kg/cm^2, rather than at P=2.5 Kg/cm^2 or P=0.5 Kg/cm^2.

Stainless Steel

As shown in **Fig. 15**, it was found that R_z near the

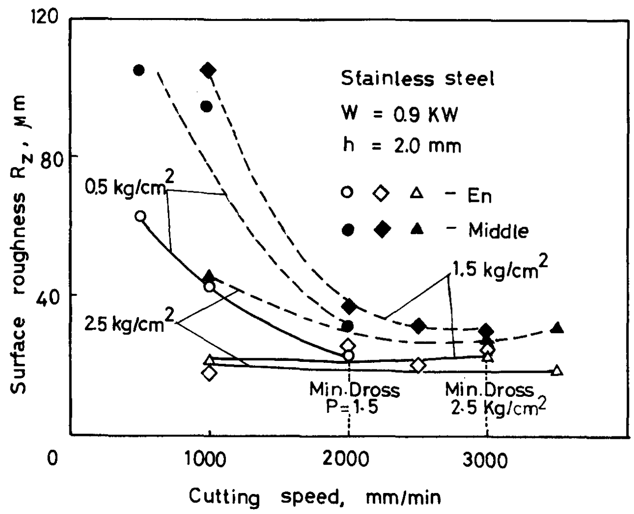


Fig. 15 Surface roughness vs cutting speed at different oxygen pressures for stainless steel.

upper surface, of which lowest value is twice as large as that of mild steel, is independent of the cutting speed except for the low gas pressure. At the middle part, on the other hand, R_z tends to decrease with increasing cutting speed. It can also be seen that at the cutting speeds higher than 2000 mm/min there is not so large difference between R_z at the entrance and R_z at the middle.

Whereas R_z near the bottom surface was very high (R_z > 100 μm). From these results the optimal cutting conditions are: v = 2500-3000 mm/min and P=1.5-2.5 Kg/cm^2.

Titanium

There is only slight improvement in surface roughness R_z of 2 mm thick titanium with increasing argon pressure as shown in **Fig. 16**. At the entrance of the beam into the material, R_z is almost independent of the cutting speed showing about 20 μm, whereas R_z at the exit decreases with increasing the speed and approaches to the entrance's value at a speed around 1500 mm/min, which appears to be the optimal cutting speed for titanium of 2 mm

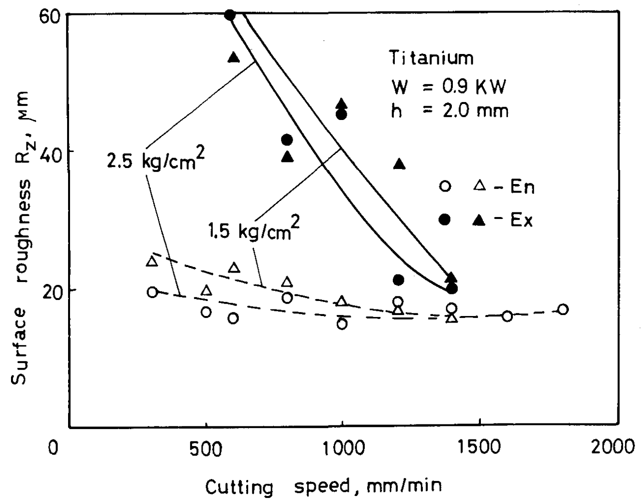


Fig. 16 Surface roughness vs cutting speed at different argon pressure for titanium (h=2 mm).

thickness.

In cutting 1mm thick titanium, the lowest surface roughness, about 10 μm, was observed at 0.5 Kg/cm^2 (**Fig. 17**). At a pressure higher than 0.5 Kg/cm^2, the

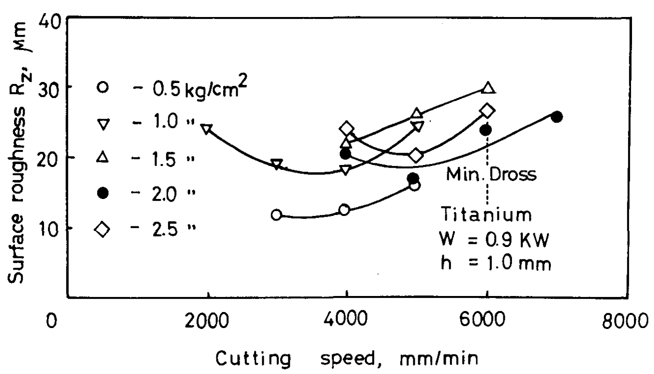


Fig. 17 Surface roughness vs cutting speed for titanium (h=1 mm).

best values of R_z are almost same, about 20 μm. The cutting speed for the lowest R_z at each argon pressure appears to be different within the data obtained here; it seems to increase with increasing argon pressure.

Aluminum

In cutting 1 mm thick aluminum at P=1.5 Kg/cm^2, it was found that surface roughness R_z has its own lowest value around 35 μm at v=800 mm/min. The value R_z tends to decrease wih increasing oxygen pressure.

In cutting 2 mm thick aluminum, the surface roughness R_z seemed to decrease slightly with increasing oxygen pressure (at P=1.5 Kg/cm^2, R_z > 100 μm; at P=2.5 Kg/cm^2 and v=100-200 mm/min, R_z=50-80 μm). It was, however, difficult to detect the influence of cutting speed on R_z which was usually higher than 100 μm, using Talysurf-4.

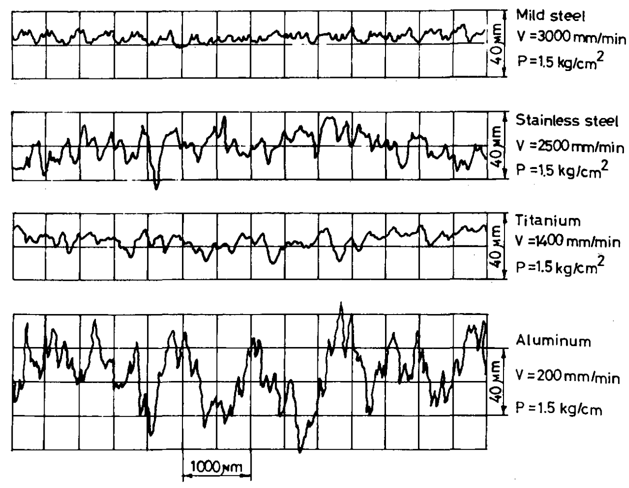


Fig. 18 Surface microtopography for different materials at the upper part of the cut edge (cutting at optimal conditions for each material)

Figure 18 illustrates the topography of the cut surface obtained at conditions for the lowest R_z near the upper surface. It can be seen that the structure of surface topography is different according to material; It is obvious that the microprofile of mild steel has smaller pitch and more regular shape than the other materials tested. Mild steel provides the lowest surface roughness; titanium comes second; next in increasing order are stainless steel and aluminum.

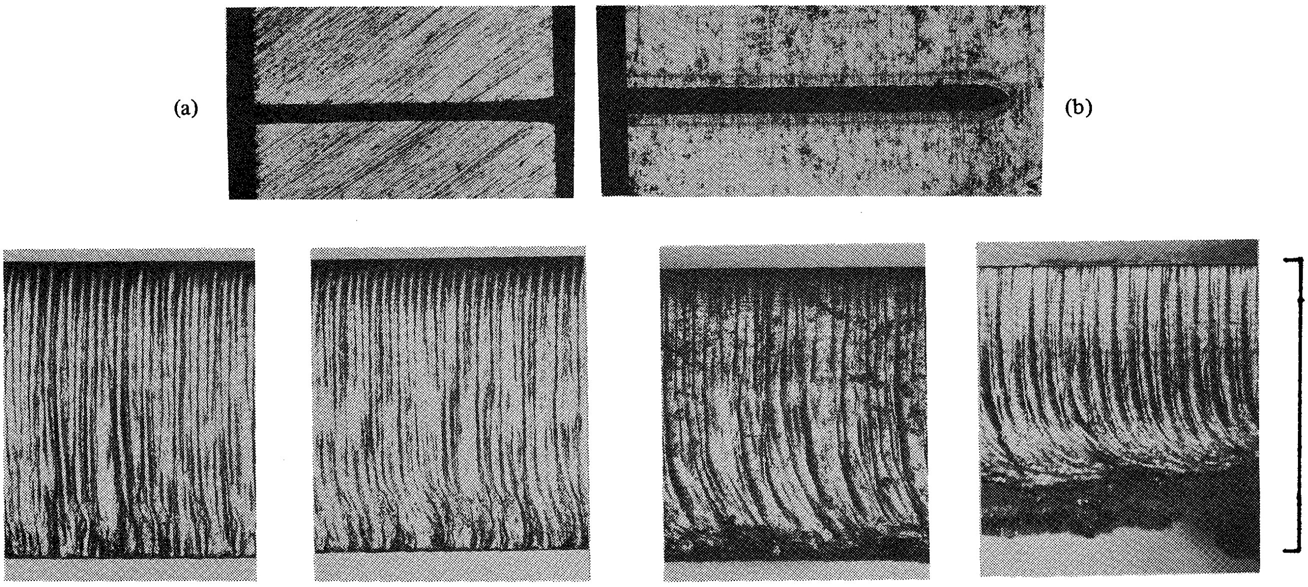
3.5 Other Features

Mild Steel

At very low cutting speeds, an unstable self-burning phenomenon during cutting was observed to occur, in which the kerf suddenly became 4-6 times wider and irregular in shape, after the cutting had progressed long enough probably to heat up the cutting sample. The self-burning phenomena occured in a speed range below 400-600 mm/min, and the speed range had a tendency to increase slightly with increasing thickness.

At the speeds higher than this range, the dross was observed to deposit to the rear surface,although the self-burning was surpressed. This speed range was found to increase with decreasing the material thickness. Then the speed range of complete dross free cuts followed. At the power level of 900 W and P=1.5 Kg/cm^2, this speed range also increased with a decrease in thickness of the sample as shown in Figs. 12-14: 2000-7000 mm/min for 1 mm thickness, 1000-4500 mm/min for 2.2 mm thickness, 1000-3300 mm/min for 3.3 thickness and 500-1500 mm/min for 5.3 mm thickness. In very thin plate (where the surface roughness R_z was uniform across the thickness of the plate), the speed corresponding to the lowest R_z near the top surface largely located to the center of the dross free range, but became higher than the center with an increase in thickness. Within the speed range of dross free cuts, striations observed on the kerf surface were very regular, straight and vertical to the sample surface accompaning fairly parallel kerf across the thickness.

As the speed increased above this range, the striations began to incline to the vertical in the direction opposite to the cutting direction, resulting in the increase in surface roughness there and initiation of the dross attachment again **(Fig. 19)**. This can be explained as follows: As oxygen gas flows down along the inclined moving oxidation front which coincides with the striations in shape, the horrizontal component of the oxygen flow momentum transmits the dross back along the rear surface of the sample, resulting in dross attachment. Since the dross attached is still hot enough to burn steel with help of oxygen, the kerf width increases around rear surface. The increase in oxygen pressure tended to decrease the amount of dross attachment to some extent.



(c) (d) (e) (f)

Fig. 19 Plane veiw (a) side veiw (b) and cross section (e-f) of 5.2 mm thick mild steel samples (p=1.5Kg/cm², w= 0.9KW)
a, b, c) – V = 1000 mm/min,
d) – V = 1500 mm/min,
e) – V = 2000 mm/min,
f) – V = 2500 mm-/min.

Stainless Steel

One of the most serious problems in cutting stainless steel seems to be the strong tendency of dross attachment, since it is more difficult to tear off from the sample than the case of mild steel **(Fig. 20)**.

For given oxygen pressure, the amount of dross attachment was minimum around the speed, one half of maximum cutting speed. With increasing oxygen pressure, the amount of attached dross tends to decrease, and the cutting speed for minimum amount of dross attachment, v_{min}, increases (at P=1.5 Kg/cm², v_{min}=2000 mm/min and P=2.5 Kg/cm², v_{min}=3000 mm/min for 2 mm thick sample: Fig. 20. It should be noticed that there was no cutting condition for dross free cuts in cutting stainless steel unlike mild steel.

Titanium

In cutting very thin titanium plate (especially 1 mm thickness), peculiar dross deposition was observed. It was seen that most dross deposited to only one side of the kerf edge at low speeds **(Fig. 21** c, d and e), and that the increase in cutting speed tended to provide symetrical dross deposition (Fig. 21 b). The dross was seen to stick to the rear surface as a succession of frozen droplets with a certain pitch depending upon cutting speed. The same effect but to less extent could be observed in cutting thicker samples.

The asymetrical dross deposition sometimes seems to be desirable because we can choose one of them which has no dross attachment. Within the conditions tested, at P=2-2.5 Kg/cm² the minimum dross attachment for 1 mm

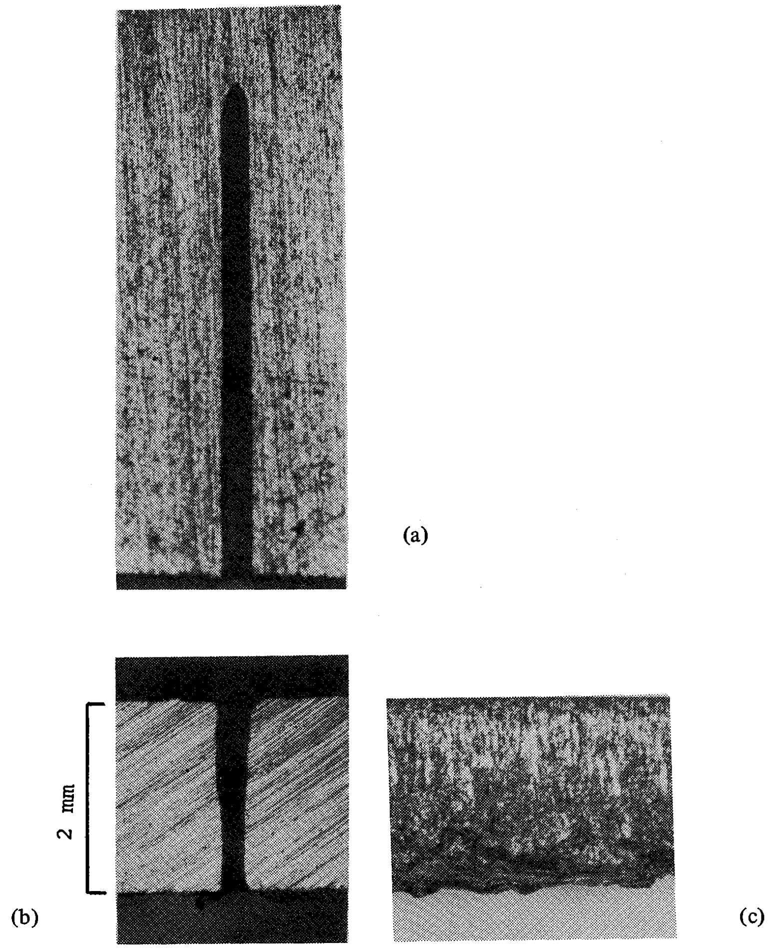


Fig. 20 Plane view (a), cross section (b) and side view (c) of the stainless steel sample (V=3000 mm/min; P=2.5 Kg/cm^2, w=0.9 KW, h=2 mm).

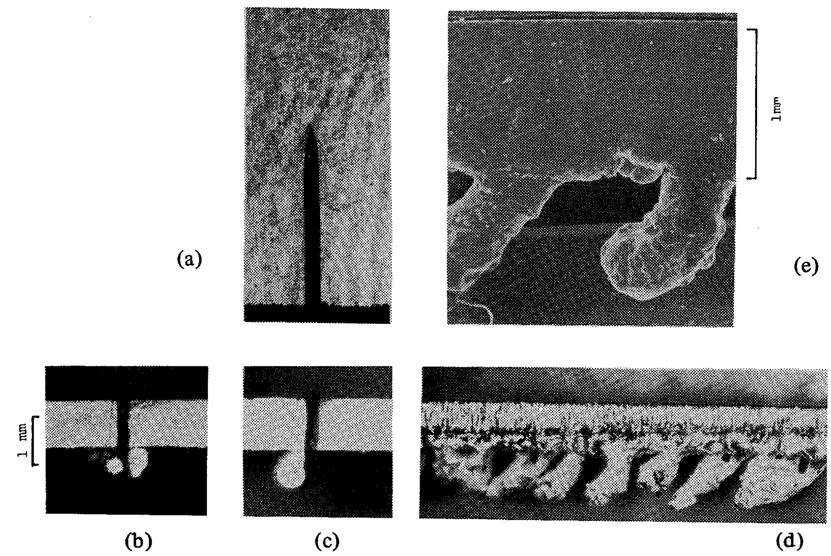


Fig. 21 Plane view (a), cross section (b, c) and side view (d, e) of titanium samples 1 mm thick (e – SEM photo)
a, c, d, e) – V = 4000 mm/min; P=1.5 Kg/cm^2
b) – V = 6000 mm/min; P=2 Kg/cm^2.

thickness was observed at v=6000 mm/min, which is somewhat higher than the speed for minimum R_z.

Aluminum

In cutting aluminum, the amount of the dross

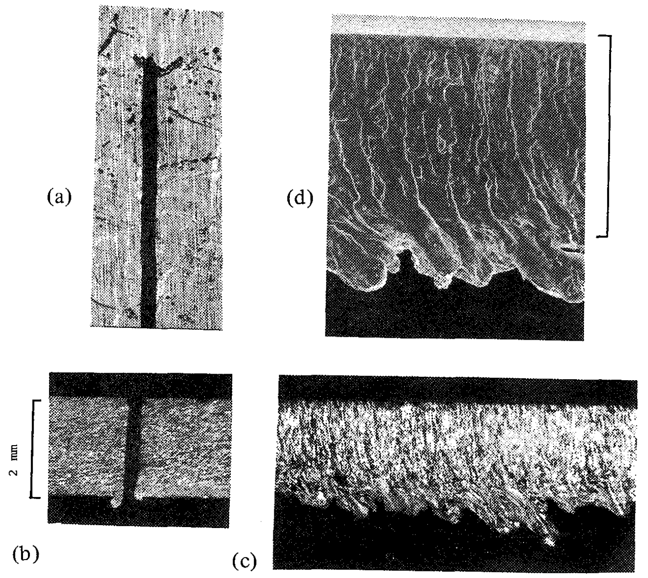


Fig. 22 Plane view (a), cross section (b) and side view (c, d) of aluminum samples 2 mm thick (d – SEM photo) (V=100 mm/min; P=2.5 Kg/cm^2; w=0.9 KW).

deposition was the most, and the dross deposited most strongly of the materials tested, resulting in very bad appearance of the cut **(Fig. 22)**.

The possible explanation for this may be found in the fact that the melting point of aluminum is much lower than that of aluminum oxide (the difference ΔT between the melting point of aluminum and that of alumina is about 1300°C) . The same approach may be applied to the other metals: Assuming that Cr_2O_3 and FeO are predominant oxides of stainless steel and mild steel, respectively, one can designate metals tested in order of decreasing ΔT as aluminum, stainless steel and mild steel. The amount of dross deposition also arranged in that order.

In cutting aluminum, the amount of dross attachment was almost independent of cutting speed, but there was, if any, a speed for minimum amount of dross attachment as follows: for 1 mm thickness v=1400 mm/min and for 2 mm thickness v=200 mm/min (P=1.5 Kg/cm^2). Further increase in oxygen pressure up to 2.5 Kg/cm^2 did not provide decrease in the amount of dross attachment.

Maximum cutting speed of sheet aluminum depends very much upon the surface condition of the sample. Samples with very shiny surface were very difficult to cut, sometimes even impossible. The reflectivity of polished aliminum to 10.6μm beam is so high that the laser power level used in this experiment is sometimes not high enough to initiate the oxidation. Namely, minimum laser power with the spot diameter of 0.2 mm for melting aluminum is about 1.2 KW [12] [20]. In order to cut aluminum sheet more effectively, higher power or lens with shorter focal length seems to be necessary.

4. Summery and Conclusions

Some results obtained in this study alongside of the data of the other authors are given in **Table 2**. It is very difficult to compare our results with the other published data, because not all working conditions are known. Moreover from the quoted papers it is not clear what criteria have been chosen - highest speed or highest qualities. But still some data coincide with ours, although others are quite different.

In the present study, the relationship between the major cutting parameters and the essential factors for estimating the quality of the laser cut has been clarified.

Remarkable points obtained from this study are summerized as follows:

(1) Except for aluminum, the kerf width at the surface does not depend upon the kind of metal at very low cutting speeds, and it decreases with increasing cutting speeds. Decreasing order of changing rate of the kerf width with speed is as follows: titanium > stainless steel > mild steel > aluminum. Whereas decreasing order of the maximum cutting speed is as follows: mild steel > stainless steel > titanium > aluminum. Within the conditions tested, the kerf width was almost independent of the gas pressure except for very low gas pressure.

(2) In cutting mild steel, cuts with unstable self-burning, dross deposition, no dross, dross deposition again were observed in order of increasing cutting speed. The speed range for each cut was given.

(3) In mild steel and stainless steel, with increasing the cutting speed the HAZ width decreases faster than the kerf width. At lower cutting speeds the HAZ width decreases with the oxygen pressure.

(4) In mild steel, the surface roughness of the cut, R_z, has a minimum value at a certain cutting speed. The value of R_z near the top surface of the samples was almost independent of the plate thickness. In thin plate, R_z was almost constant across the thickness of the plate, but with increasing the thickness R_z near the rear surface became much higher than that of the upper surface. Decreasing order of R_z was as follows: aluminum > stainless steel > titanium > mild steel.

(5) Only in mild steel, there was a speed range of dross free cutting which decreased with increasing sample thickness. The cutting speed for minimum R_z existed within this range, but the maximum cutting speed was outside this range. In stainless steel, the speed for the minimum amount of dross deposition provided small R_z. Decreasing order of dross deposition was as follows: aluminum > Stainless steel > mild steel, and a possible explanation for this effect

Table 2 Comparison of cutting performances for various materials

Material	Power kw	Thickness mm	Cutting speed mm/min	Cutting kerf width mm	HAZ mm	Other details	Reference
Mild steel	1.5	2	4500	0.5	–	–	Fletcher [14]
	0.85	2.27	1778	–	–	–	Adams [15]
	0.85	2.2	1740	–	–	–	Houldcroft [16]
	1.0	3	2400	–	–	–	Whittle H [17]
	0.9	3.3	3500	0.45	0.108	Highest speed P=1.5 F=127	Our results
	0.9	3.3	2000	0.49	0.168	Lowest roughness P=1.5 F=127	Our results
	0.9	2.2	5000	0.43	0.07	Highest speed P=1.5 F=127	Our results
	0.9	2.2	4000	0.44	0.088	Lowest roughness P=1.5 F=127	Our results
Stainless steel	1.0	6.35	508	0.1–0.2	0.05	–	Iron Age [18]
	0.85	5.08	762	–	–	–	Adams [15]
	0.85	9.00	372	–	—	–	Houldcroft [16]
	1.0	3.0	5000	–	–	–	Culham Lab [19]
	0.9	2.0	3500	0.38	0.089	Highest speed P=2.5	Our results
	0.9	2.0	3000	0.39	0.098	Lowest roughness P=2.5	Our results
	0.9	2.0	3000	0.40	0.089	Highest speed P=1.5	Our results
	0.9	2.0	2000	0.41	0.118	Lowest roughness P=1.5	Our results
Titanium	1.0	1.57	3840	0.1–0.05	0.05	–	Iron Age [18]
	0.85	5.8	3300	–	–	–	Adams [15]
	0.9	2.0	1400	0.419	0	Highest speed Lowest roughness	Our results
	0.9	2.0	2000	0.361	0	P=1.5 Highest speed	Our results
	0.9	2.0	1600	0.354	0	P=2.5 Lowest roughness	Our results
	0.9	2.0	2200	0.397	0	Highest speed Lowest roughness P=3.0	Our results
Aluminum	3.0	1	6250	–	–	–	Whittel H [17]
	3.0	3.2	2500	–	–	–	
	0.9	2.0	500	0.344	–	Highest speed P=1.5	Our results
	0.9	2.0	200	0.377	–	Lowest roughness	Our results
	0.9	2.0	400	0.329	–	Highest speed P=2.5	Our results
	0.9	2.0	200	0.335	–	Lowest roughness P=2.5	Our results

was suggested. The dross deposition made the kerf wide and irregular in shape near the rear surface.

From the results described above, one can conclude as follows: In laser cutting of metals one has to choose the cutting speed depending upon his purpose; the highest productivity at poor quality or the highest quality at reasonably low productivity. From the view point of the quality of the cut, the laser cutting process seems to be suitable for thinner plate at this stage, because the qualities of the cut are deteriorated around the rear surface in thicker plate. However, if the qualities of the cut around the rear surface are improved, the laser cutting can be of still major industrial importance.

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