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Technical Note

CO_2 laser cutting of metallic coated sheet steels

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Summary

Sheet steels with zinc and aluminium coatings, such as GALVABOND, exhibit an anomalous behaviour when subjected to laser light and pose some severe machining limitations by virtue of the high light reflectivity and thermal conductivity of the coatings as well as the difference in physical properties between the coating and substrate materials. An investigation of the machinability of GALVABOND using CO_2 laser cutting technology is presented. It shows that by proper control of the cutting parameters, good quality cuts are possible at high cutting rate. Visual examination indicates that when increasing the cutting rate to as high as 5000 mm/min, kerfs of better quality than those produced using the parameters in an early study can be achieved. Some kerf characteristics such as the width, heat affected zone and dross with respect to the process parameters are also discussed. A statistical analysis has arrived at the relationships between the cutting speed, laser power and workpiece thickness, from which a recommendation is made on the selection of cutting parameters for process control and optimization.

Keywords: Laser cutting; Sheet metal processing; Metallic coated sheet steels; Process parameter selection.

1. Introduction

Sheet steels with a thin layer of zinc and/or aluminium coatings on both sides have found extensive industrial applications due to their various merits, such as corrosion resistance. Traditionally, the processing of sheet metals relies on processes such as punching, blanking and guillotining. However, manufacturing is getting more time conscious and the requirement for prototyping and small production batch is increasing. This has placed a need for the use of some non-traditional machining technologies, such as laser beam cutting. It is important to note that the coatings on metallic coated sheet steels have high light reflectivity and thermal conductivity, and lower melting point than the substrate materials. This together with the sandwiching influence imposes some difficulties and limitations on processing this kind of materials using lasers and there is little knowledge of the control and optimization of the cutting processes, although a considerable amount of work has been reported on laser processing of sheet metals [1-3].

In a recent study [4], the potential and feasibility to apply CO_2 lasers in the processing of metallic coated sheet steels have been explored. This study focuses on three types of materials, i.e. GALVABOND, ZINCALUME and ZINCANNEAL of 1.0 mm thick, and shows that these materials can be cut at commercially acceptable rates with high laser powers. It also shows that the cuts on GALVABOND are associated with pronounced surface disintegration by distinct oxide formation along the cuts and slightly high (20%) cutting speed should be used, as compared with the other two materials. According to this study, fine and good cuts can be obtained on GALVABOND with cutting speed between 40 and 60 mm/min at the laser power

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from 400 to 550 W, while cutting speed between 15 and 40 mm/min is recommended for the other two materials. However, this work has been based on the experimental findings with the cutting speed varying from 10 mm/min to 60 mm/min. Whether or not the cutting speed can be increased for improved productivity while achieving good quality cuts remains to be further investigated. Furthermore, severe thermal damage on the workpiece has been noticed at these cutting speeds and further study is required to examine the machinability of the materials at high cutting speeds and to suggest appropriate cutting parameters for good quality cuts and high cutting rates.

This paper, written as a short note, summarises and discusses some findings in CO_2 laser cutting of GALVABOND, a material appears to be most difficult to cut with lasers. Three different material thicknesses are considered to examine their machinability as assessed by the cutting rate and cut quality, with a view to increasing these two performances. Kerf characteristics such as the width, heat affected zone (HAZ) and dross in terms of process parameters are also discussed. Finally, the relationships between the cutting speed and laser power for each workpiece thickness are established and optimum parameter combinations recommended for process control and optimization.

2. Experimental

The experiments were conducted on a Cincinnati CL-5 Laser Centre. This machine used 10.6 μm wavelength CO_2 laser with a guaranteed energy output of 750 W for continuous laser generation. The laser beam was focused using a 127 mm focal length lens. A conical nozzle with an exit diameter of 1.7 mm was employed. The nozzle-workpiece standoff distance was controlled at 1 mm by the material follower. For all the experiments, no coolant was used.

The specimens used were GALVABOND of 0.55, 0.8 and 1.0 mm thick. These materials are hot-dipped zinc-coated commercial forming steel with a spangled surface. The coating thickness is about 0.02 mm on each side and the chemical composition and mechanical properties of the substrate are given in table 1. The reason for choosing this kind of materials is that difficulty has been reported in the cutting process [4] and that it was hoped to improve the cut quality and cutting rate through this study.

Table 1. Chemical composition and mechanical properties of the substrate of the specimens.

Chemical Composition		Mechanical Properties	
Carbon (C)	0.10	Yield strength (MPa)	280-330
Phosphorus (P)	0.025	Tensile strength (MPa)	330-380
Manganese (Mn)	0.45	Hardness (HR30T)	50-60
Sulphur (S)	0.03		

The selection of the cutting conditions was based on experience for similar workpiece and some trial runs. When using oxygen as an assist gas at pressures varying from 200 to 800 KPa (or 2 to 8 bars), it was found that cutting speeds as high as 5,000 mm/min and 3,500 mm/min for laser power of 700 W and 400 W, respectively, could produce through cuts on the specimens. It was also noticed that at low cutting speeds, severe burn and thermal damage to the workpiece occurred. Thus, cutting speeds between these values were considered with a view to locating the appropriate cutting conditions to increase the economic and technological performances. In this experimental design, four levels of laser power (continuous wave) and cutting speed were considered at three levels of the gas pressures for the three thicknesses of specimens. Details of the cutting parameters are given in Table 2. Thus, it involved 144 tests to cut 100 mm long straight slits.

Table 2. Process parameters used in the experiments.

Material thickness (mm)			0.55	0.8	1.0			
Assist gas (oxygen) pressure (KPa)			200	500	800			
Laser power (W)	400		500		600		700	
Cutting speed (mm/min)	2,000	2,500	2,500	3,000	3,000	3,500	3,500	4,000
	3,000	3,500	3,500	4,000	4,000	4,500	4,500	5,000

In addition, more than 50 cuts using the recommended parameters [4, 5] were undertaken in order to further examine the machinability at low cutting speeds and for comparison purpose. For this set of tests, three levels of laser power (400, 500 and 600 W) were considered at three levels of cutting speed. These cutting speeds were: 45, 55 and 65 mm/min for 1.0 mm specimens, 50, 60 and 70 mm/min for 0.8 mm specimens, and 55, 65 and 75 mm/min for 0.55 mm specimens. Oxygen and compressed air at various pressures were used as assist gases. It should be noted that at low cutting speeds, compressed air did not result in noticeable improvement in kerf quality as compared to oxygen, while oxygen showed great advantage in increasing the cutting speed for acceptable through cuts. Therefore, oxygen was the primary assist gas used in this study.

3. Results and discussion

3.1 Machinability analysis

The machinability of the materials and the cut quality are assessed based on the three classes of cuts (for through cuts only) as shown in Fig. 1. In addition, kerf width, HAZ, dross deposition on the lower edges (or burrs) and thermal damage to the coatings are also considered in this analysis. From the 144 tests, it is found that when 400 W laser power and 200 KPa assist gas (oxygen) pressure were used for cutting 1.0 mm specimens, non-through cuts occurred. For the remaining 140 tests, class III or II through cuts were achieved, which will be further analyzed later in this section. However, it is noticed that for over 50 cuts using the low cutting speeds and other parameters recommended in Refs. [4, 5], only class II cuts were obtained with massive dross attached at the bottom edges and the surrounding area. Visual examination under optical microscope revealed that the kerfs produced by high cutting speeds are slightly rougher than those from using the low speeds, as indicated in Fig. 2. This may be attributed to any incomplete cutting action and melt resolidification on the side walls (rather than at the lower edges). Nevertheless, the cuts are still considered to have good quality, given the nature of laser metal processing.

It appears that the assist gas pressure played an important role in the formation of kerf geometry. At the pressure of 200 KPa, most cuts on 0.55 and 0.8 mm specimens are class III cuts with minimum dross at the exit. It is also found that at 700 W laser power, the control of cutting in achieving class III cuts for these two materials was not possible for all the cutting speeds and gas pressures used in the study. In such cases, dross was found at the lower edges and larger HAZ was noticed. The cutting speed did not show any discernible effect on the kerf geometry for the range considered.

When examining the HAZ and dross deposition, it is found that for all the cuts using low cutting speeds (45 to 75 mm/min), there were severe thermal damage to the workpiece. A moderate case is shown in Figs. 2(a) and (b). Up to 1.5 mm of the coatings from the upper edges were molten down from the substrate (coating in almost all area covered by Fig. 2(a) has been molten down). The molten material draws towards the sides of the cuts and is propelled downwards by the gas jet together with the molten substrate. The melt eventually deposits at the exit to form excessive burrs, as shown in Fig. 2(b). Slag can also be noticed to deposit in the surrounding area of the exit kerf. There was no marked difference in quality between the kerfs from different cutting speeds, possibly due to the small spacing between the speeds.

By contrast, cutting with high cutting speeds has resulted in high quality cuts with minimum HAZ, as evidenced by Fig. 2(c). By properly selecting the process parameters, the oxides presented on the outlet face can also be minimized to form class III cuts. From the study with high cutting speeds, it is found that the size of HAZ generally increases with increases in laser power and assist gas pressure, but reduces slightly with an increase in cutting speed. Specifically, the ranges of HAZ for the 0.55, 0.8 and 1.0 mm specimens are respectively about 200 to 315 μm, 210 to 290 μm and 194 to 270 μm. These figures also reveal the effect of material thickness on HAZ, although this is expected. It appears that assist gas pressure has pronounced burring effect and most class III cuts formed at the pressure of 200 KPa.

The kerf width generally increases with increases in assist gas pressure and laser power and a decrease in cutting speed. For all the cuts carried out on the three different specimens, the top kerf width varied from 110 to 270 μm, which in most cases are about 50% of those produced by using the low cutting speeds, as shown in Fig. 2. As such, kerf width is not only dependent on the combination of laser-lens-metal, as claimed in earlier studies [4, 5], but also cutting speed to a considerable extent.

3.2 Selection of process parameters

The overall cut quality as assessed by kerf geometry (class III cuts), HAZ and the deposition of dross on the lower edges has been analyzed and the graphs indicating the combination of parameters for class III cuts with minimum HAZ and dross are given in Fig. 3. Based on the ranges of parameters considered in this study and the experimental findings, an assist gas pressure of 200 KPa is generally favoured and recommended for cutting the materials under consideration. When cutting 0.55 mm specimens, laser power at 700 W could not produce class III cuts at the cutting speeds and assist gas pressures considered and oxides or burrs were found along the lower edges. The results also show that although the cutting speed may be increased for good quality cuts as the laser power increases, this does not apply when the laser power is above 500 W. A similar trend was also found when cutting 0.8 mm specimens, where the threshold value for laser power was found to be 600 W. Analyzing the results for cutting 1.0 mm specimens has found that at laser power of 400 W and assist gas pressure of 200 KPa, the laser beam could not penetrate the workpiece at any cutting speeds considered, while 500 and 800 KPa at this laser power could produce good quality cuts at cutting speed up to 3000 mm/min. Fig. 3(c) also shows the potential to increase cutting speed by increasing laser power for class III cuts, but the capacity of the laser cutting centre has limited this attempt. From this analysis, if cutting speed and energy consumption are considered as economic measures while cut quality is the technological performance measure, the combinations of process parameters which should be used for good quality cuts are given Table 3. The calculated cutting speeds for given laser power and assist gas pressure from two predictive models in the literature [6] for sheet metals are also obtained for comparison. It is apparent that Querry's model does not give cutting speeds to obtain class III cuts for the materials. By contrast, Miyazaki's model may be applicable although the cutting speed for 1.0 mm specimens is below the test range in the present study. Nevertheless, higher productivity can be achieved by using the recommendation from this study.

Table 3. Recommended combinations of parameters for cutting GALVABOND and model predicted cutting speeds.

Thickness (mm)	Assist oxygen pressure (KPa)	Laser power (W)	Cutting speed (mm/min)	Querry's model: $V = 7430e^{-1.06}p^{0.63}$	Miyazaki's model: $V = 3500e^{-0.56}p^{0.5}$
0.55	200	500	4000	9048	3459
0.80	200	600	4500	6823	3072
1.00	200	700	5000	5935	2928

where e = material thickness (mm) and p = laser power (KW).

4. Conclusions

An investigation of the machinability of metallic coated sheet steels, i.e. 0.55, 0.8 and 1.0 mm GALVABOND, using CO_2 laser has been presented. It has been shown that these materials can be cut at high cutting rate of up to 5,000 mm/min while the cut quality is superior to that from low speed cutting. Some kerf characteristics such as kerf width, dross and HAZ with respect to the process parameters have been discussed. It has revealed that although high laser power permits high cutting speed to be used for good quality cuts, this trend does not apply when the laser power is above a threshold value in which case no class III cuts can be produced. The graphs showing the combinations of process parameters for class III cuts with minimum HAZ and burrs and the recommendation on parameter selection have provided the means for process control and optimization.

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References

[1] M. Bass, Laser materials processing, North-Holland, New York, 1983.

[2] G. Buness and S. Weber, New sheet metal cutting using CO_2 lasers, ZIS Mitt. 19(1) (1977) 120-129.

[3] J.S. Ekersley, Laser cutting of sheet steel with the revolutionary turbolase T1000 CO_2 laser, Proc. Mater. Process. Symp. Vol. 31, September 1982, Boston, pp. 131-134.

[4] G.V.S. Prasad, E. Siores and W.C.K. Wong, Laser cutting of metallic coated sheet steels, Journal of Matrials Processing Technology 74(1988) 234-242.

[5] G.V.S. Prasad, Laser cutting of metallic coated sheet steels, M. Eng. Sc. Project Report, Queensland University of Technology, 1995.

[6] M. Querry, Laser cutting. In: High power lasers, Ed. by A. Niku-Lari and B.L. Mordike. Institute for Industrial Technology Transfer, Pergamon Press, 1989, pp. 195-211.

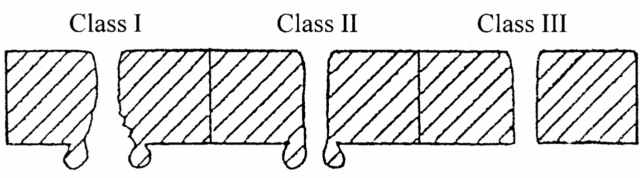
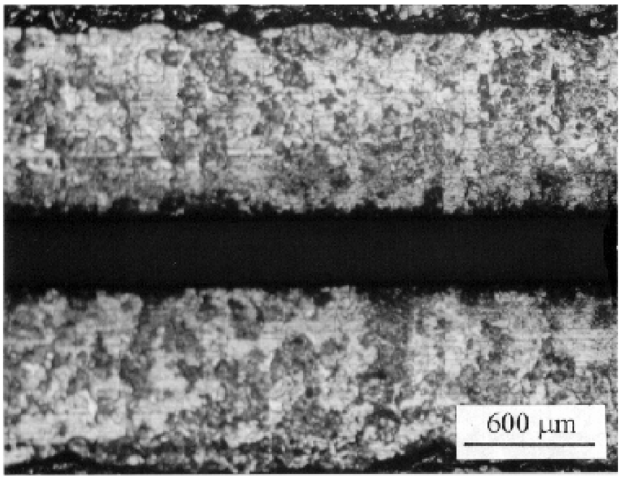
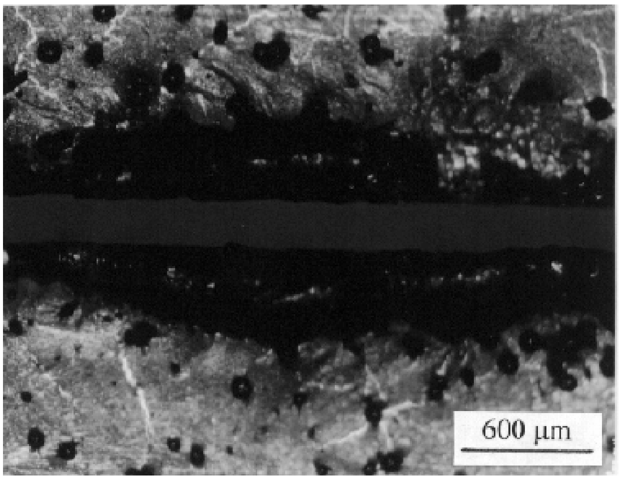


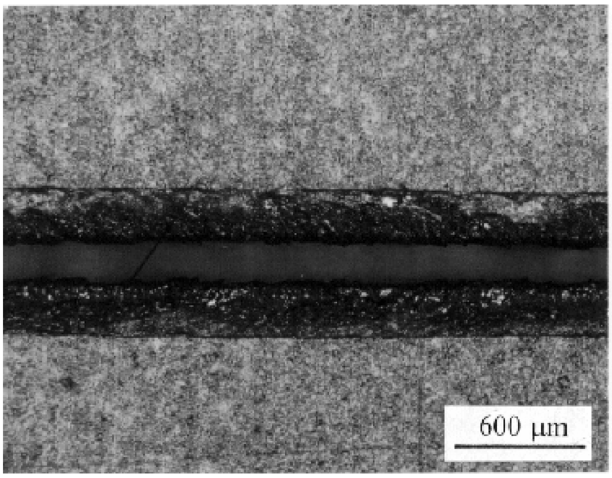
Fig. 1.Three classes of through cuts.



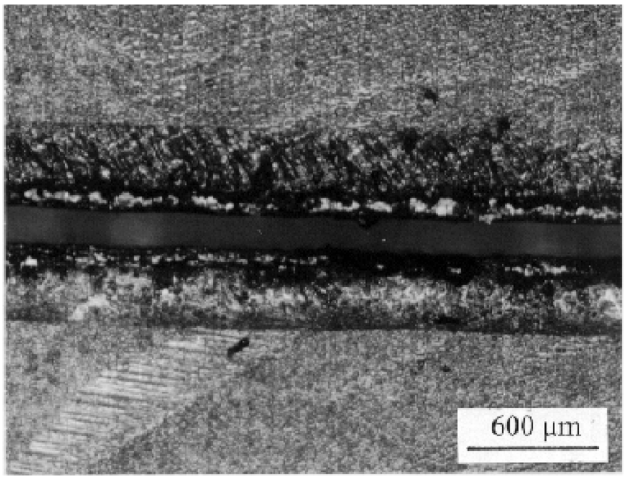
(a) Top view.



(b) Bottom view.

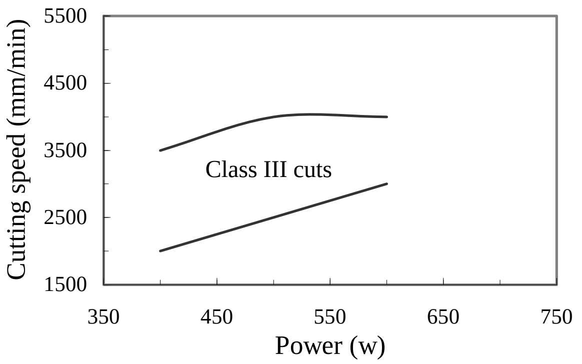


(c) Top view.

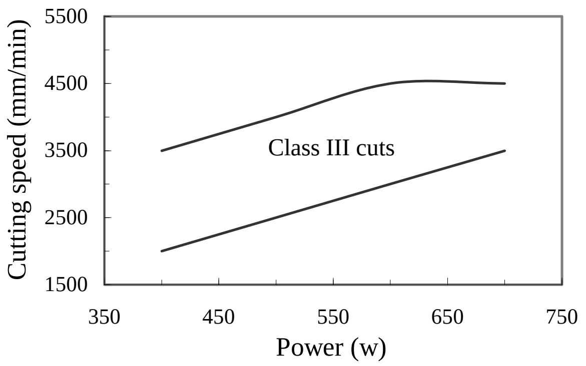


(d) Bottom view.

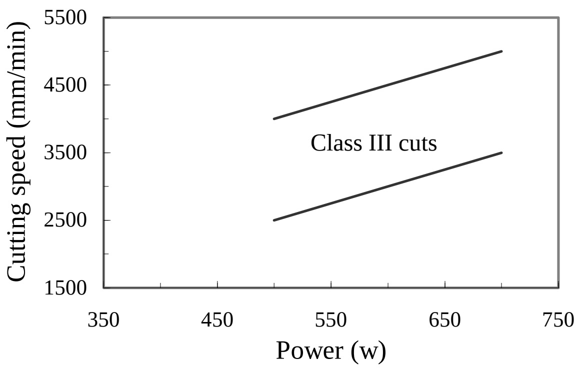
Fig. 2. Kerf and kerf quality produced by CO_2 laser on 1.0 mm specimens.
Views (a) and (b): laser power = 500 W, cutting speed = 45 mm/min, assist gas pressure = 500 KPa;
Views (c) and (d): laser power = 500 W, cutting speed = 4000 mm/min, assist gas presure = 200 KPa).



(a) 0.55 mm thick GALVABOND.



(b) 0.8 mm thick GALVABOND.



(c) 1.0 mm thick GALVABOND.

Fig. 3. Combination of process parameters for quality (class III) cuts with minimum HAZ and dross (assist gas pressure: 200 KPa or 2 bar).