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Fibre Laser Cutting of Thick Closed Cell Aluminium Foam

Mohammad Shahid Raza*, Susmita Datta, Jogender Singh, Partha Saha

Department of Mechanical Engineering
Indian Institute of Technology Kharagpur, Kharagpur - 721302, INDIA

Abstract

Laser cutting of thick closed cell aluminium foam was performed using a 2 kW Fiber Laser. A 10 mm thick foam was cut with laser system having a cutting head of 0.5 mm nozzle diameter. The process parameters were laser power (1350 W – 1750 W), scan speed (400 mm /min –1000 mm/min) and gas pressure (6-8 bar). SEM and optical microscopic images were taken to measure the kerf width and kerf quality. Taper percentage was also studied. Among the investigated process parameters laser power and scan speed were the most influencing parameters for kerf width and taper percentage based on kerf quality. SEM images indicate that the dross attachment is higher at the bottom surface as compared to the top surface. For a spot diameter of 0.5 mm, the average kerf width is about 0.6-0.8 mm. The taper percentage is about 3-6%. Finally, it was concluded that laser cutting of thick porous Al foam could be carried out satisfactorily with the acceptable quality of kerf width and limited dross attachments.

Keywords: Fibre laser cutting, closed cell metal foams, aluminium foam, kerf width, kerf quality.

1. INTRODUCTION

A metal foam is a class of material where two different phases like solid and gas coexist together. The pores are gas filled while the walls of the pores are made of solid material. Metal foams are basically of three types: Closed cell metal foam, Open cell metal foam and Sandwich structured with closed cell core foam. Closed cell metal foam differ from open cell metal foam in terms of their pore type. As per the name suggests the pore in the closed cell is not open and the gases produced during manufacturing process remains trapped inside the pores. The manufacturing route of closed cell metal foam is through melting while open cell metal foams are made through powder metallurgy process, where some space holders are used to create the pores. The main characteristics that metal foam possess include low density, high porosity, high energy absorption rate and different overall mechanical properties than the parent material. The applications of closed cell metal foam include structural components, high energy absorbing beams, lightweight structural floors, staircases, automobile bumpers, roof panels etc. Open cell metal foams are basically used in functional applications like heat exchangers, radiators, filters etc. Due to its large number of applications issues like processing of metal foams becomes very important. Closed cell metal foams were chosen for the present study because the pores contain some trapped gases, Also the behavior of cutting parameters with respect to dross amount on different walls can be studied clearly. Cutting of metal foams can be performed using different techniques like a band saw cutting, wire EDM cutting, laser cutting etc. Laser cutting has got an advantage over other methods in terms of complexity of profile that can be cut, very high cutting time and less distortion.

Various researchers have experimentally studied the laser cut qualities of metal sheets such as kerf width and kerf taper in order to analyse the effect of various process parameters on these quality characteristics [1, 2, 3, and 4].The effect of focal point position with respect to the work surface as well as spot overlap was also studied by various researchers [5, 6, and 10]. Apart from these some optimisation studies were made to find the effect of process parameters on laser cutting of metals [7, 8 and 9]. Meanwhile, the study of laser cutting of metal foams was introduced in the 21st century and very few papers were reported regarding laser cutting of metal foams [11, 12, and 13].

Very few attempts were made to analyse the effect of laser cutting of closed cell metal foams. The objective of the present research paper is fibre laser cutting of thick closed cell aluminium foam sheet and to study the effect of three process parameters (laser power, scan speed and gas pressure) on kerf width and taper percentage. Also, the characterization of cut samples for kerf quality and kerf dimensions was carried out in order to understand the effect of process parameters on the cut quality of the Aluminium foam.

2. MATERIALS AND METHODS

2.1 Materials

Closed cell aluminium foam is used for this experimental work. The sample dimension is 125 x 30 x 10 mm^3. The aluminium porosity is around 70% and the pore diameter is around 2-4 mm. The chemical composition of the material is as per table 1.

Table 1. Chemical composition of the Al foam

Element	N	O	Mg	Al	Si	Ca
Wt. %	0.63	4.73	0.32	83.81	0.34	10.17

2.2 Methods

The wavelength of Yb-doped fibre laser used for the experiment is 1.07 µm. For cutting operation, the high power focused laser beam is impinged on the metal surface along with a high-pressure coaxial gas jet. The laser melts the material and gas jet ejects out the molten materials to perform cutting. The kerf width, striation and taper angle in cutting process depends on various parameters such as laser power, scan speed, gas jet pressure, type of gas, laser spot size on the surface, the location of focal spot w.r.t. surface, stand-off distance, sheet thickness and material characteristics. Nozzle with 0.5 mm focal spot

* Author to whom correspondence should be made, Email: msraza@iitkgp.ac.in

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diameter and 3.5 mm focal length is set at 1 mm stand-off distance so the focal point takes place at 2.5 mm depth in work piece. The laser cutting parameter for the Aluminium foam cutting is as per table 2. Kerf width is measured using optical microscope for both the top and bottom surfaces. Kerf width at the lower surface is found greater than the top surface so the reverse taper percentage is calculated.

Reverse taper % = {[L (outlet) - L (inlet)]/T} x 100

Where L (outlet) is the bottom kerf width, L (inlet) is the top kerf width, and T is the thickness of the sheet. For the characterisation of the kerf quality, the sample is cut perpendicular to the kerf and the cut surface is analysed for striation marks, dross attachment and pore deformation by scanning electron microscope (SEM).

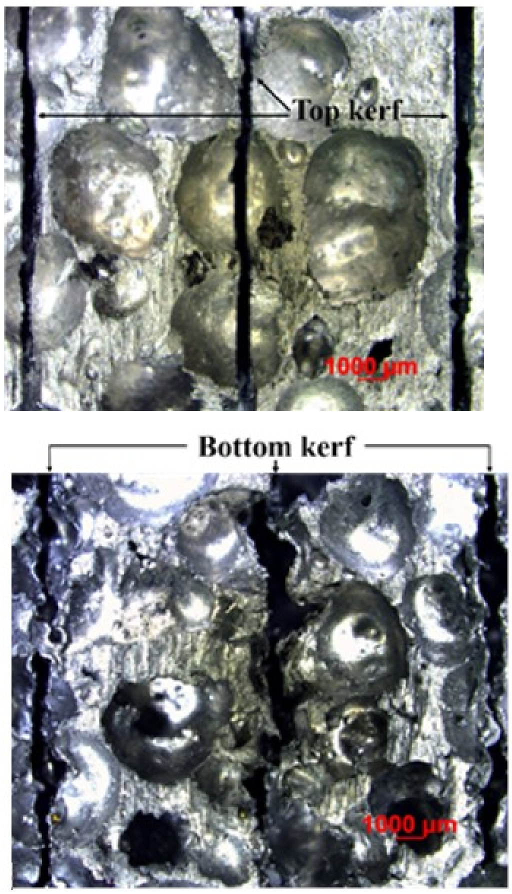


Fig. 1. Cut away tracks of Aluminium foam

3. RESULTS AND ANALYSIS

3.1 Optical Microscopic Analysis

An optical microscope was used for the measurement of the top and bottom kerf width. It was found that among the investigated process parameters laser power and scan speed are the most influencing parameters for kerf width and taper percentage. The minimum kerf width of top surface was obtained for 1350 W power and 1000 mm/min scanning speed with 6, 7 and 8 bar gas pressure respectively. This suggests that it is the best parametric window for laser cutting of the Aluminium foam. For this parameter set taper percentage is around 4 % which is also very low. Higher laser power causes more surface to melt leading to increase in kerf width and taper percentage. Dross attachment is also found to be high for higher power.

Table 2. Observation table of Al foam cutting

Exp. No.	Power (W)	Scan Speed (mm/min)	Gas Pressure (bar)	Kerf Width (Top) (µm)	Taper %
1	1350	400	8	762.7	6.82
2	1750	700	7	737.2	6.03
3	1550	1000	8	628.2	3.97
4	1350	400	7	764.2	5.44
5	1750	400	6	781.7	8.84
6	1550	400	6	793.4	6.09
7	1350	1000	7	607.8	4.49
8	1350	400	6	749.0	5.36
9	1350	1000	6	607.0	4.16
10	1350	700	7	716.1	5.54
11	1750	1000	7	713.3	5.03
12	1350	700	6	725.8	4.44
13	1750	400	7	803.5	8.87
14	1750	1000	6	706.0	5.01
15	1750	1000	8	691.4	4.43
16	1550	400	7	775.9	6.48
17	1550	700	8	752.6	5.68
18	1350	1000	8	607.8	4.61
19	1350	700	8	752.5	4.95
20	1550	700	6	756.9	4.98
21	1750	700	6	759.1	6.08
22	1550	1000	6	642.7	5.04
23	1550	1000	7	711.8	3.84
24	1750	400	8	794.1	6.80
25	1750	700	8	752.5	6.04
26	1550	400	8	792.6	6.08
27	1550	700	7	729.3	6.08

3.2 SEM and EDS Analysis

3.2.1. SEM Analysis

From fig. 2(a) of top zone of laser cut Al foam it can be observed that the dross attachment is less but the striation marks present are very prominent. This is because the gas velocity is significant at the top section but as gas flows downward it interacts with multiple walls of the foam resulting in sharp decrease of pressure. Thus it can be seen in fig. 2(b) that striation marks decrease and dross attachment starts to take place. At the bottom section dross attachments are high as shown in fig. 2(c). The bottom kerf of the cut section does not show any clear cell wall boundary. The molten material causes this uneven boundary of the bottom kerf width. Striation marks do not appear on the lower cell wall present in fig. 2(b).This shows that the gas pressure becomes very low to penetrate this wall and this causes the generation of dross on the surface. Laser cutting at very high gas pressure is one of the possible solution to reduce the amount of dross.

3.2.2. EDS Analysis

The EDS analysis was done in three regions: top, middle and bottom of metal foams. From Fig. 3 it is clear that the dross attachment is the result of melting of Al-Ca alloy. The oxide formed in the lower zone does not come out in the form of dross. The aluminum oxides have a much higher melting point, so they are retained in the metal without getting melted and forms an oxide layer on its surface.

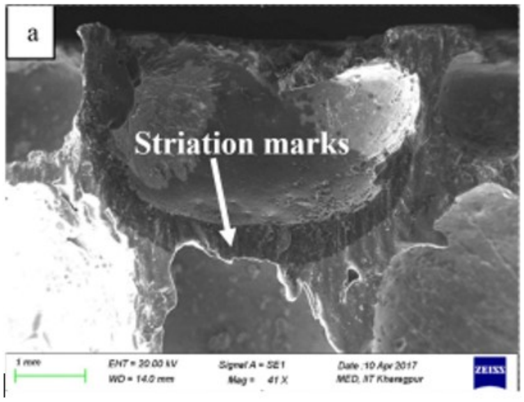


Fig. 2(a) Upper cross-section of sample cut at 1350 W, 1000 mm/min and 7 bar gas pressure

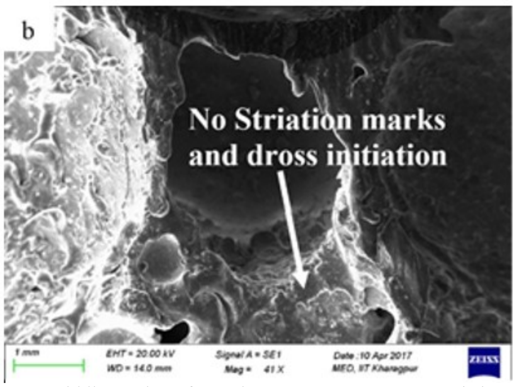


Fig. 2(b) Middle Section of sample cut at 1350 W, 1000 mm/min and 7 bar gas pressure

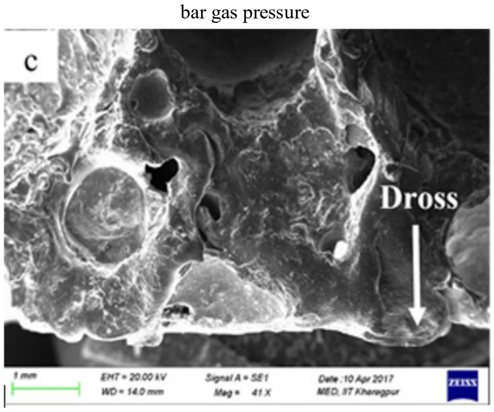
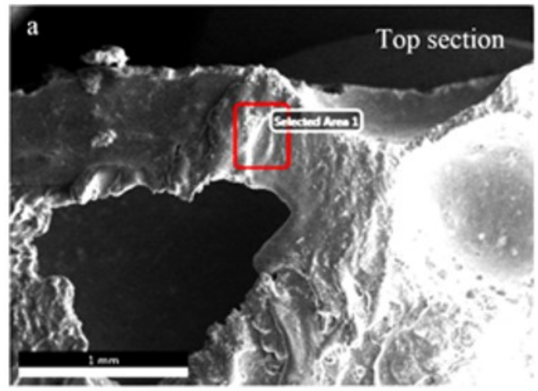


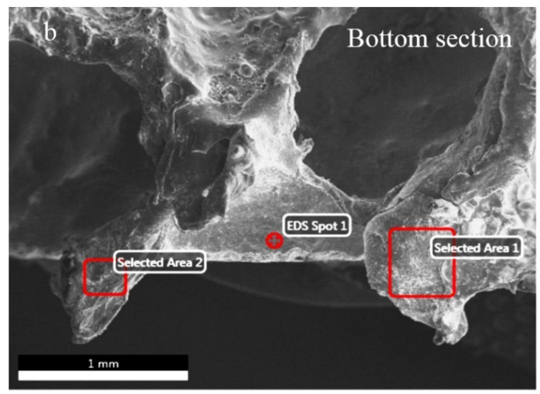
Fig. 2(c) Bottom Section of sample cut at 1350 W, 1000 mm/min and 7 bar gas pressure

3.3 XRD Analysis of Cut Section

The XRD results (fig. 4) clearly indicate that while there was not any significant change in the compound present in the cut section. The value of 2 theta angle shifted by some small degrees. It can be explained that the heat energy supplied to the cut section has resulted in some amount of residual stress to get accumulated in the HAZ zone and this residual stress may be the reason for the shifting in 2 theta angle. Calcium aluminium oxide ($Ca_3Al_2O_6$) was largely present in the cut zone and the affinity of aluminium for oxygen may have resulted in the generation of such oxide compound.



Wt. %	Al	Ca	O	Fe
Area 1	94.02	5.98	---	---



Wt. %	Al	Ca	O	Fe
Spot 1	77.71	10.55	6.82	4.92
Area 1	93.06	6.94	---	---
Area 2	93.35	6.65	---	---

Fig 3. EDS Analysis of (a) top section and (b) bottom section of a sample

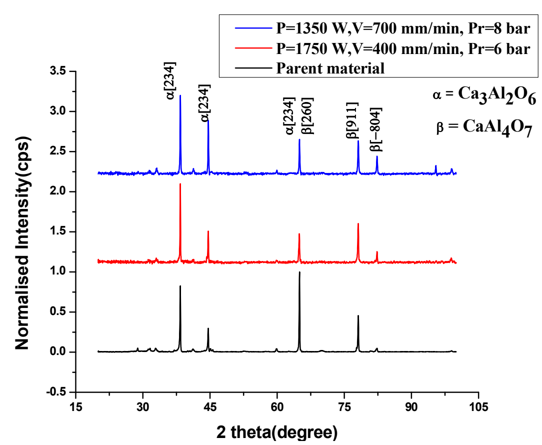


Fig. 4. XRD analysis of parent material and some cut sections

4. CONCLUSION

Following conclusions can be drawn from the analysis of laser cutting of Al foams.

- It is possible to cut thick Al foam from a fibre laser with good cut quality at very high gas pressure.
- The dross attachment is a major concern in the cutting of Al foam. Dross height varies for different parameters of laser cutting.
- The optical analysis shows that lower kerf width value fluctuates more due to different amount of dross attachments. Because of this taper percentage value does not follow any clear trend.
- An average top kerf width of around 700 µm can be obtained with around 6 % taper on an average.
- XRD results show that there is no change in chemical composition of laser cut zone and a small amount of stress accumulation takes place in laser cut HAZ.

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