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Investigating the Effects of Cutting Methods for Aluminum Metallic Foams

Investigación de los efectos de los métodos de corte para espumas metálicas de aluminio

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ABSTRACT

The quality of foam metal materials, which are commonly used in industrial applications due to their unique properties, increasingly relies on secondary processing. Metal foams are produced as plates or in the desired shape via direct or indirect foaming. Given their intended use, the primary challenge lies in determining how to cut them with the necessary precision and join them with sufficient strength. However, the most difficult aspect is cutting them in the required shapes and combining them with fixed or removable securing mechanisms. This work involved cutting two sample types: a 10 mm thick AlMgSi foam with a density of 0.5 g/cm^3, using a laser cutter, and a 19 mm thick AlMgSi sandwich structure with a 1 mm thick aluminum outer plate via wire electric discharge machining (WEDM). In addition, the results of manual cutting and angle grinding, which are often utilized in production, were analyzed through scanning electron microscopy. Under certain suboptimal conditions, laser cutting caused aluminum to dissolve into the cavities and form burrs beneath the cutting edge. In contrast, when accurate and undistorted cellular architecture is essential, WEDM is very efficient, even though it is 200 times slower than laser cutting. Hand-sawing caused cellular fractures and frequent dispersion, so it is suitable for applications that do not necessitate accuracy.

Keywords: aluminum foam metals, secondary operations, laser cutting, wire EDM cutting

RESUMEN

La calidad de los materiales de espuma metálica, que se utilizan comúnmente en aplicaciones industriales debido a sus propiedades únicas, depende cada vez más del procesamiento secundario. Las espumas metálicas se producen en placas o en la forma deseada mediante espumación directa o indirecta. Dado su uso previsto, el principal desafío radica en determinar cómo cortarlas con la precisión necesaria y unirlas con la fuerza suficiente. Sin embargo, el aspecto más difícil es cortarlas en las formas requeridas y combinarlas con mecanismos de sujeción fijos o removibles. Este trabajo involucró el corte de dos tipos de muestras: una espuma de AlMgSi de 10 mm de grosor con una densidad de 0.5 g/cm^3, utilizando un cortador láser, y una estructura tipo sándwich de AlMgSi de 19 mm de grosor con placa exterior de aluminio de 1 mm de grosor mediante mecanizado por electroerosión por hilo (WEDM). Además, los resultados del corte manual y del rectificado angular, que a menudo se utilizan en la producción, se analizaron a través de microscopía electrónica de barrido. En ciertas condiciones subóptimas, el corte láser hizo que el aluminio se disolviera en las cavidades y formara rebabas debajo del borde de corte. En contraste, cuando una arquitectura celular precisa y no distorsionada se hace esencial, el WEDM es muy eficiente, a pesar de ser 200 veces más lento que el corte láser. El corte manual causó fracturas celulares y dispersión frecuente, por lo que es adecuado para aplicaciones que no requieran precisión.

Palabras clave: espumas metálicas de aluminio, operaciones secundarias, corte por láser, corte EDM por hilo

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Introduction

Foam metals are typically porous metal structures, primarily made of aluminum, that contain gas-filled voids. Metallic foams surpass polymer foams in a variety of engineering characteristics; they are more resilient, stable at higher temperatures, and combustible, producing no hazardous byproducts during combustion. In addition, their recycling poses no contamination or pollution concerns.

To achieve a more stable production of foam metals, it is now feasible to use secondary post-production techniques outside of mass production, rather than relying on the more difficult modulation of pore and cell size during manufacturing.

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This makes it imperative to examine removable and non-removable connection options such as cutting, drilling, machining, welding, and fastener connection. It is crucial for structures to be demountable and durable, particularly for construction purposes. The pervasive application and utility of foam metals are a result of connection methods that enable the creation of more intricate shapes or the attainment of thicknesses that cannot be produced even through casting.

The secondary operations of metal foams are crucial to their applicability, so they are of great importance. There are five main operations in this category: cutting, forming, joining, finishing, and coating [1].

In cutting procedures, it is preferable for the cells of the metal foam to retain their shape. The most prevalent techniques for cutting metal foams are band sawing, circular sawing, wire sawing, diamond sawing, chemical milling, wire electric discharge machining (WEDM), laser cutting, and water-jet cutting. While each strategy offers a number of advantages, it also has certain disadvantages and obstacles. With WEDM techniques, for instance, it is possible to prevent cell degradation [2], but the operation's cost and pace must also be considered.

Wire sawing is more effective than circular-sawing, band-sawing, and EDM at minimizing macroscopic surface roughness (*i.e.*, the quality of the walls/struts in relation to their distance from the cutting plane), according to the study on secondary processes on foams [2].

Wire sawing, circular sawing, wire EDM, and band sawing have been employed to obtain both high and low surface roughness values for 10 PPI foam. The WEDM cutting method produces significantly smaller contact points, while wire sawing-cutting exhibits the largest surface contact area, almost equal to the nominal value [3]. In a study involving the laser cutting of 9 mm-thick closed-cell aluminum foams, thermal issues were observed. In spite of this, it was determined that laser cutting allowed for burr-free and parallel-sided cutting without cell damage [4].

In a previous study on the effect of cutting on near-eutectic silumin (AlSi9) metal foam, the edge geometry was determined [5]. The experiment included circular saws, band saws, WEDM, water jets, and thermal cutting techniques (laser and air plasma). Each of the examined approaches had a unique effect on the aspects of the section plane. The problems arose from the cellular structure of the foams and their minimal cell wall thickness (no more than 0.3 mm), while the presence of voids in the materials allowed cutting residues to accumulate in the voids. WEDM was determined to be the most advantageous method for cutting aluminum foam since it provides the highest edge surface quality for welding. Furthermore, among techniques that do not result in the partial ablation of the material, WEDM and water jets with an abrasive agent produce the best results. Regarding the thermal cutting procedures, a highly concentrated laser beam yields the most effective results [5].

In their review, [6] pointed out that, despite the volume of existing research, the quality characteristics of laser-cut metal foam have not been ascertained. This was evident in the summary of input process parameters and quality responses resulting from the cutting process. The authors provided a qualitative report on the extremely low dross attachment at the bottom of laser-cut foam, but the abnormalities generated on its kerf wall were significantly different from the striations found on laser-cut metal sheets. In addition, the authors cited research that utilized bending instead of laser cutting, reporting that, as the thickness increases, problems arise [6]. Consequently, laser cutting research must continue to reach success, particularly when dealing with high thickness. Assembling individual metal foams or metal foam sandwich panels may entail several difficulties. In general, these obstacles originate from the deformability of the foam and the limited surface area that is available for joining.

[7] cut closed-cell metal foams with a laser while trying different parameters, noting that the gas trapped in the closed cells emerged during cutting and disrupted the process. Issues such as spatter dross and kerf formation were reported during their experiments. The authors mentioned that the worst results were observed when cutting with oxygen gas. Nitrogen assist gas created the least amount of dross, whereas argon assist gas provided the lowest kerf width. [8] discussed the importance of having smooth surfaces in foam metal butt welding operations. The goal of this work was to combine metal foams using friction stir and induction welding without deteriorating their cellular structure. It was necessary to perform an additional grinding operation to ensure smooth surfaces.

There are three ways to join sandwich panels: joining two sandwich panels, joining a sandwich panel to another material, and joining the face sheets to the foam core (*i.e.*, adhesive or metallurgical joining). The metallurgical joining of face sheets to the foam core (*i.e.*, brazing) results in greater resistance to tearing than adhesive joining. To join metal foam structures, the literature specifies soldering, brazing, diffusion welding, friction stir welding, laser welding, bonding, and fastening (threaded, riveted, or pinned) as the available methods [9]-[21].

These procedures may produce burrs and other surface flaws, and with metal foams, these issues are somewhat more complicated. During refining, negative burr development (smearing) can be observed in metal foam structures. Failure of subsequent processes, such as joining or coating, may result in defective surfaces. It is important to recall that the functionality, safety, cost, and aesthetic appeal of a product are all dependent on the quality of its margins. Poorly finished edges can result in increased or altered friction, higher wear upon movement or stressed elements, interferences, turbulent flow, and decreased formability

[22], [23]. In a study on the development of a heat transfer, the need for shaped cutting of the foam was mentioned [24]. Moreover, [25] had issues with surface contact for bonding and airflow due to the deformation of a foam metal while cutting a heat sink.

It is not always possible to obtain complex component shapes through molding, which is also an expensive procedure. It would be more practicable to create the required shapes by cutting, punching, machining, bonding, welding, and fastening standard foam materials, among others. Foam materials are not suitable for post-production due to their characteristics; because of their compressibility, they are not suitable for forming, which is made challenging by low tensile strength.

Coating is made difficult by irregularities in cell walls and surface layers. The surface is frequently covered with an oxide layer, which makes coating, brazing, and welding difficult. The presence of melting-stabilizing ceramic particulates also hinders machining.

The outer shell significantly improves the characteristics and appearance of foam material. Consequently, if this layer is not required for functionality, its removal, which would increase production costs, is unnecessary. During the design phase, the most difficult aspect is machining. Nonetheless, the components may require additional machining and drilling. In theory, foam materials are amenable to all conventional processing methods, but it is difficult to achieve a high level of surface quality.

[26] mentioned that geometric accuracy is very important for critical design parts such as crash boxes in automobiles, highlighting the importance of obtaining surface parallelism. In this vein, they examined the integrity of the surface as a result of turning the foam upon reaching different parameter values. If ceramic particles were added to the melt to stabilize the liquid foam, especially in large quantities of SiC particles, significant tool wear could not be avoided [27]. In brittle metals, the typical procedure induces cell wall bending and compression, as well as fractures and tearing. This leads to a lack of quality and sensitivity on the surface. The partial melting of the microscopic pore walls and their subsequent diffusion into the cutting tool has a significant effect on the precision and quality of the cutting surface. Low thermal conductivity and high porosity prevent effective heat convection cooling. Conversely, the melting and bending of the pore walls reinforce the cutting surface; as they press into the pores, the curved walls thicken and densify the affected region.

There is no study that combines methods such as laser and WEDM with traditional techniques such as hand-sawing and grinding saws. In this field, it is important for the use of foam metal to become widespread in small workshops, given its functionality, lightness, and low material requirements, in addition to its environmentally friendly nature and its contribution to reducing the carbon footprint [28]-[31]. Foam metals have different applications in many different areas [32], [33]. Aluminum (Al) foam materials, with superior characteristics compared to traditional materials, are currently vying for a position in the market. To ensure their extensive adoption, it is essential to understand their mechanical properties and post-production suitability. In this study, in addition to secondary processes such as WEDM and laser cutting, which are used to cut Al foam materials, experimental research and SEM observations are conducted in relation to the post-production processes of hand saw cutting and angle grinding, which is commonly used in the industry but has received little attention from the literature. A comparison is made as a result of this visual examination. Given the incidence of different factors on laser cutting and WEDM, several parameters were tested prior to the comparison. The *Materials and method* section provides information on the materials and cutting methods used in this work. The focus of the comparison was on the deterioration of cell wall surfaces after employing different cutting methods.

Materials and methods

Material characterization studies were carried out based on the information provided by the manufacturer. The selection of cutting parameters is detailed later in this document. After cutting, SEM images of the samples were taken. The flowchart of this study is presented in Fig. 1.

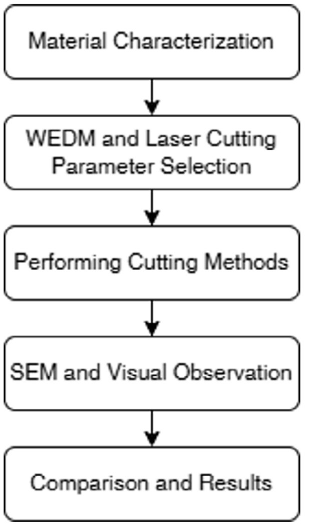


Figure 1. Flowchart of this study
Source: Authors

Materials

Compression tests of Al foam were carried out in accordance with the ISO 13314 standard [34]. To this effect, five 30 x 30 x 30 mm^3 specimens were prepared (Fig. 2), and they were compressed at a rate of 20 mm/min. All samples in this research utilized the same foam product.

Figure 2. Compression test sample of aluminum foam metal
Source: Authors

Two types of Al foam, sandwich and foam-only, were used as test specimens. The sandwich-structured foam material was produced from a casting foam material (AlMgSi) and 1.2 mm of Al alloy plate. Its total thickness was 19 mm. The other type of foam was AlMgSi foam metal, with a thickness of 10 mm and a closed-cell structure. The length of each sample was 70 mm, the bulk density of the foams was 0.5 gr/cm^3, and their modulus of elasticity was 5 GPa (Table I). The chemical properties of the foam metal are outlined in Table II.

Table I. Specifications of the aluminum foam

Specification	Value
Production	Melting with blowing agent
Type	Closed-cell foam
Blowing agent	$CaCO_3$
Stabilizing additive	SiC and MgO
Bulk Density	0.500 gr/cm^3
Elastic Modulus	5 GPa
Yield strength	~2 MPa
Poisson ratio	0.3

Source: By courtesy of Alupam

Table II. Chemical composition of the AlMgSi foam

Chemical element	Weight %
Fe	0.50
Si	1.30
Cu	0.10
Mn	0.80
Mg	1.20
Zn	0.20
Ni	0.10
Ti	0.10
Pb	0.05
Sn	0.05
Cr	0.25

Source: By courtesy of Alupam

Laser cutting

The variables that determine laser cutting quality are cutting speed, gas type, gas pressure, cutting power, focal length, nozzle diameter, and nozzle-to-sheet distance. In our experiments, the effects of nozzle diameter, focal length, gas type, and nozzle-to-sheet distance were kept constant because they are negligible. It is worth adding that the material and the desired cutting technique determine the gas type. In our work, nitrogen gas was utilized, given the difficulties in regulating the oxygen reaction and its influence on the cutting quality of Al foam. The diameter of the nozzle is a material thickness-related characteristic. There are specific nozzle diameter values for removing slag at specific cutting thicknesses and obtaining the appropriate gas flow. The distance between the nozzle and the sheet determines the laser beam's focal point, *i.e.*, the region of the material on which the beam will be focused following lens selection [6], [35]-[37].

Since nitrogen-based laser cutting does not result in an exothermic reaction, the laser beam was focused on the bottom surface of the material. In this context, cutting speed, gas pressure, and power were considered to be the most significant variables, whereas the gas type and the focus point were kept constant due to the method and the material type used. To conduct our cutting experiments, three distinct parameters were varied, with cutting speed and surface quality serving as comparison criteria. Attempts were made to adjust power and pressure parameters, hoping to address issues such as the inability to conclude the operation at high cutting speeds and the inability to remove molten material from the environment at low speeds.

The cutting process of the AlMgSi closed-cell foams was carried out while considering various parameter values (Table III). Using a Durma Hybrid CNC laser cutter with a maximal output of 3.3 kW, CO_2 laser cutting was performed.

Table III. Parameters used in laser cutting

Parameters	1. Level	2. Level	3. Level
Cutting speed (m/min)	1	3	5
Laser power (kW)	3	3	3.3
Assist gas pressure (bar)	17	15	16
Assist gas type	N_2	N_2	N_2
Nozzle diameter (mm)	1	1	1
Distance between the nozzle and the work piece (mm)	1	1	1
Focal length (mm)	5	5	5

Source: Authors

Wire EDM cutting

In WEDM cutting, also referred to as *wire erosion*, there are specific requirements for certain material categories. For materials such as Al and steel, we considered the manufacturer-specified fundamental parameters. As a variable parameter, only the cutting speed could be altered when necessary. WEDM cutting is a comparatively slow procedure that, by its very nature, allows obtaining fine surface qualities. Sparks and chemical reactions need a certain amount of time to eliminate fragments from a substance. This is the most significant disadvantage of this method.

Using a Makino EV64 CNC wire erosion cutting machine and a Master Brass 0.25 mm diameter CuZn37 wire, sandwich plates with a total thickness of 19 mm were cut into 30 x 67 mm pieces. Tables IV and V list the cutting parameters for the sandwich plates and the closed-cell foam.

Table IV. WEDM cutting parameters for the sandwich foam material

Parameters	1. Level	2. Level
Wire diameter (mm)	0.25	0.25
Wire material	Brass	Brass
Cutting speed (mm/min)	15	22

Source: Authors

Table V. WEDM cutting parameters for the 10 mm closed-cell foam

Parameters	1. Level	2. Level	3. Level	4. Level
Wire diameter (mm)	0.25	0.25	0.25	0.25
Wire material	Brass	Brass	Brass	Brass
Cutting speed (mm/min)	13	16	22	25

Source: Authors

Hand-sawing and grinding saw cutting

In this study, hand-sawing and angle grinding, which are commonly preferred for metal cutting in small workshops, were evaluated for cutting Al foam. Depending on the operator's attention, strength, and dexterity, the results of using these instruments may vary. This cutting equipment is frequently used because it is convenient, saves time, is easily accessible, and requires no specialized personnel. The effect of cutting foam metals with such tools during maintenance, repair, or production is a crucial concern, as these materials can be utilized in a variety of applications.

In this research, an 11 000 rpm Makita angle grinder with 720 W of power was utilized. The cutting disc had a diameter of 115 mm, a thickness of 1 mm, and aluminum oxide as abrasive material. The blade length of the handsaw used was 300 mm, and it was made of HSS and had 24 teeth per inch.

Results and discussion

The compression test revealed a modulus of elasticity of 5 GPa and a yield stress of around 2 MPa, confirming the accuracy of the manufacturer's data. The results of the test conducted on the samples are illustrated in Fig. 3.

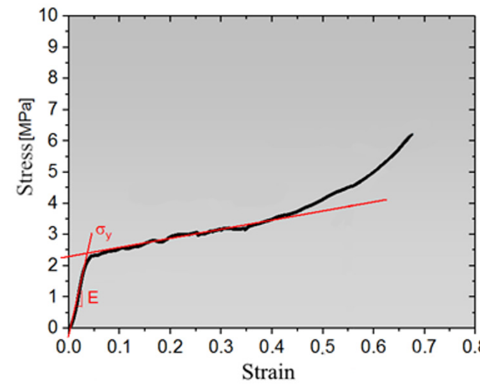


Figure 3. A stress strain graph was observed during the compression testing of foam metal
Source: Authors

During the laser cutting procedure, the molten metal adheres to the cell walls and disrupts the structure of the cells. In this context, changing parameters becomes essential. [4] studied a single-parameter experiment, with very poor outcomes in laser-cut foam. This may be misleading when comparing against other cutting techniques, underscoring the relevance of parametric work in the laser cutting of foam metal. Due to the high speed of 5 m/min in level 3, the bottom surface of the foam metal was not completely decomposed. The anticipated power of 3.3 kW, which is comparatively high, was deemed enough for a speed of 5 m/min. High-speed cutting was expected to sever the walls without slag formation or heat accumulation. Nonetheless, a subpar surface and inadequate cutting led to the rejection of this proposal. Due to the cutting speed, there is insufficient time for the material to dissolve and be removed from the environment, preventing the completion of the process.

The speed value of 3 m/min in level 2 was enough for laser cutting. Here, the nitrogen pressure was decreased by 1 bar, and the power was decreased to 3 kW (less power was required because the speed was reduced and the nitrogen pressure was adjusted to 15 bar, since this gas removes molten metal and serves as a coolant). Even if the cut surface has burrs, it can be used in non-sensitive applications or after a secondary grinding or sanding.

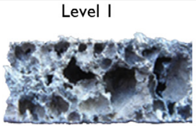
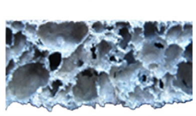
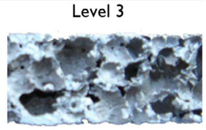
In level 1 laser cutting, the cutting speed was 1 m/min, and, during the experiments, the molten Al could not be removed from the environment. This was due to the slow progression of heat density in the cutting zones. Since the speed was slow, we chose a high gas pressure, knowing that excessive melting would occur due to excessive heat accumulation. We expected the fast flow to cool the surface. However, the high gas pressure was not sufficient to cool the surface and created a slag problem. Despite the high pressure (17 bar), the molten metal filled the foam cavities, and the quality of the surface decreased significantly. Under these conditions, it is not possible to combine the foam material with the cut surfaces, or to align the cut surfaces and use them as reference. The molten metal adhered to the cutting surfaces, and, since it could not be removed from the environment, it cooled and solidified, compromising the uniformity of the surface. This suggests that a slower process cannot increase the quality of the surface. However, this does not mean that the speed can be increased as the power increases. Similarly, increasing the gas pressure does not mean that the material will be cut more smoothly and that the slag will be removed.

Table VI shows the resulting cut surfaces for each level. In their parametric study of metal foam laser cutting, [23] stated that the gas was unable to remove the dross well, which was associated with the porous structure under the impact of gas pressure. Furthermore, low power and high cutting speeds were seen to be beneficial in their research. In this study, we discovered that, when using excessively high speeds, the power is insufficient and the operation cannot be completed. When the cutting speed is regulated with respect to the power, more unspoiled cell walls may be obtained. Similarly, it cannot be claimed that removing dross by increasing gas pressure results in a smooth cell wall structure, yet it has been seen that decreasing gas pressure improves this aspect.

Even after the parameters were modified, the laser beam varied slightly as it passed through the air space between the foam metal and the other cell wall, resulting in an inhomogeneous cut between the layers. The greatest advantage of laser cutting is the ability to reach fast cutting speeds (3-5 m/min). Still, poor surface quality in the cut areas of the outer walls, the adhesion of molten Al to the cell walls, and the degradation of the porous structure are among the disadvantages of this method. [5] cited tapering during cutting as an application constraint in their review work, and they discovered laser-cutting research to use a maximum thickness of 10 mm.

During the wire erosion cutting operation, no degradation of the cut surfaces was observed. When compared to other cutting techniques, the quality was deemed to be very good, as the surface retained the shape of the cell walls, could be mounted with direct contact, and did not require a second operation. The surface could also serve as a surface of reference. In a similar study employing EDM during cutting, [2] discovered that the cell walls were not distorted. When filler material was employed, the surface became flat and the cells were closed, indicating good assembly capabilities. As a result, the authors avoided recommending EDM for filler material connection procedures. Moreover, it should be noted that the cutting speed of EDM was approximately 200 times slower than that of laser cutting, which constitutes the greatest disadvantage of this method. Fig. 4 depicts the sandwich panel that was sliced using EDM.

Table VI. Surfaces resulting from different laser cutting parameter levels

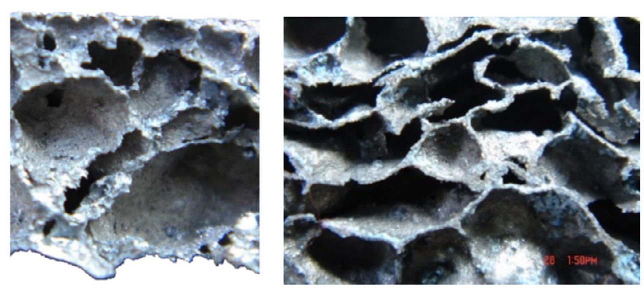
Laser cutting macro view		
Level 1	Level 2	Level 3
		

Source: Authors

Samples of sandwich Al foam were cut at different speeds (15 and 22 mm/min) at wire erosion levels 1 and 2. In both instances, the cutting process was completed without incidents. For wire erosion levels 1 (13 mm/min), 2 (16 mm/min), and 3 (22 mm/min), the cutting surface provided an excellent cut of the 10 mm thick closed cell; there was no cell deformation. Throughout the cutting process, there were no difficulties. At level 4 (25 mm/min), the wire broke, bringing the operation to a halt. The speed increase was expected to make a significant difference in the cut surface. However, excessive speed only caused the wire to break faster and the process time to increase. There was no significant difference in the surfaces.

Figure 4. Surface obtained via the wire erosion cutting of sandwich plates
Source: Authors

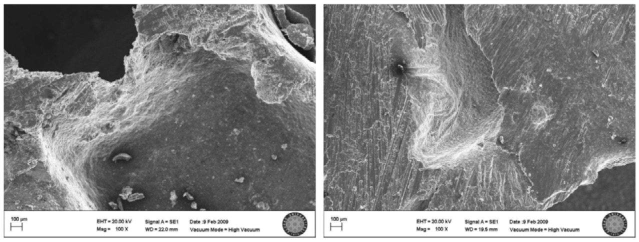
Among other factors, electrode deterioration depends on the material's electrical and thermal conductivity, melting temperature, and WEDM electrical signals. Wire fracture occurred when the cutting speed exceeded a certain threshold during the process, which varied depending on the alloys, pore structure, and electrical conductivity. This value represents the maximum velocity for the cut's thickness. Fig. 5 illustrates how WEDM and laser cutting alter the cell structure. The best quality obtained for laser cutting was considered.



(a) (b)

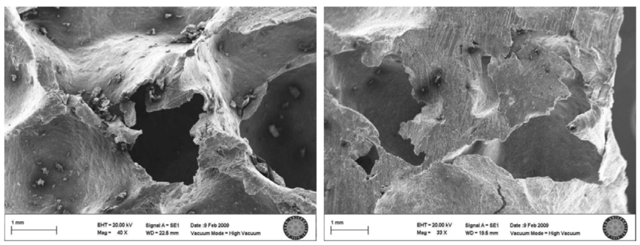
Figure 5. Comparison between a) laser cutting and b) WEDM cutting
Source: Authors

The handsaw cutting experiment demonstrated the role of mechanical force in the fragmentation and crushing of cell walls. Crushed and broken cells were observed since the pressures generated during the process forced the cell walls inward, and hand-sawing is a continuous process involving a frequency-induced mechanical strain. On the other hand, despite the lack of fragmentation, the angle grinding drove the cell walls inward and left visible traces in the cut regions (Figs. 6 and 7). For comparison, after the tests using a circular saw in angle grinding [2] and [4], it was discovered that the pore structure had deteriorated, and the pores had become partially clogged.



(a) (b)

Figure 6. SEM images (x100): a) manual sawing, b) angle grinding
Source: Authors

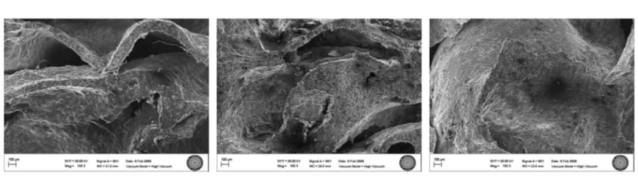


(a) (b)

Figure 7. SEM images: a) manual sawing (x40), b) angle grinding cutting (x33)

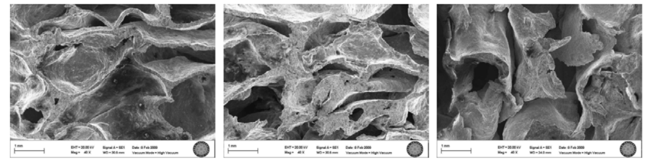
Despite the changing parameter values, there was no deterioration or change in surface quality. Wire breakage was observed above certain cutting speeds, and the cutting operation could not be completed. Cutting of exceptional quality was accomplished through wire erosion. During this process, a highly clean and smooth pore structure was generated due to the absence of metal melting (which is common after a thermal operation such as laser cutting) and mechanical stress on the cell walls. The cell structure did not change as a result of wire erosion cutting. The anomalies that occur during manufacture include variations in pore size and inhomogeneous distribution. No surface quality degradation was noticed even after increasing the speed increase up to the wire breakage point. Figs. 8 and 9 show the surface patterns of the speed-dependent SEM images.

Due to thickness and focusing challenges during the laser operations, molten Al flowed over itself because of canonicalization and thermal effects, resulting in the closure of pores and the formation of a burr with rounded edges. Certain issues were resolved by modifying the settings, but the burr and conical surface remained. As previously indicated, throughout the WEDM tests, no damage to the cells was seen. Fig. 10 compares the relative cell deformation yielded by the different cutting techniques.



(a) (b) (c)

Figure 8. WEDM cutting SEM images (x100): a) V = 13 mm/min; b) V = 16 mm/min; c) V = 22 mm/min
Source: Authors



(a) (b) (c)

Figure 9. WEDM cutting SEM images (x40): a) V = 13 mm/min; b) V = 16 mm/min; c) V = 22 mm/min
Source: Authors

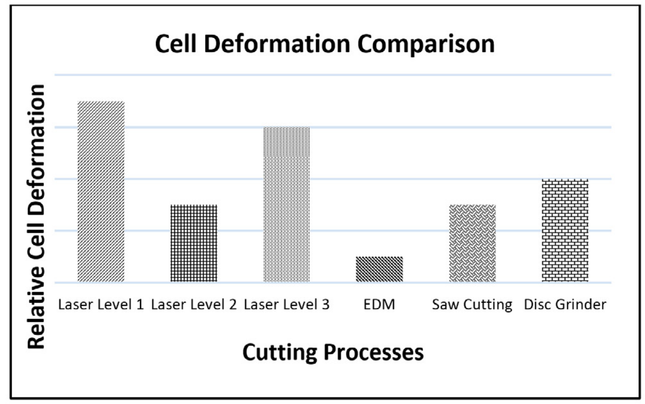


Figure 10. Comparison of relative cell deformation results
Source: Authors

One of the most significant aspects to consider when selecting the cutting technique is where the post-cut parts will be used. For non-precise mass production applications, laser (thermal) or saw (mechanical) cutting is acceptable, but wire erosion is ideal for applications demanding surface quality, shape, and measurement precision.

These values are regarded as average. Deviations of up to 6 s were observed in the hand-sawing of the sandwich plate, whereas a deviation of 2 s was noted during angle grinding. Both methods limited the variations in foam cutting to 1-2 s. The most suitable speeds for achieving the best surface integrity were 3 m/min for laser cutting and 22 mm/min for the WEDM method. The latter was 136 times slower than the former in terms of processing times, and the cutting speed of the grinding discs was competitive. Nonetheless, it relied on the operator's proficiency in executing shaped cuts. Similarly, the duration of cutting may fluctuate based on the operator's weariness and proficiency. The processing times of the studied cutting methods are presented in Table VII.

Table VII. Processing times of the studied cutting methods

Cutting method	Foam-only processing time (s)	Sandwich processing time (s)
WEDM	190.9	190.9
Laser	1.4	-
Grinding saw	3.2	5.8
Handsaw	13.4	33.8

Source: Authors

Conclusion

The final state of foam metals is dictated by the use of secondary techniques beyond mass production, as well as by the challenging control of pore and cell size. As a result, it is critical to investigate removable and non-removable connection methods such as cutting, drilling, machining, welding, and bolt connection.

This study examined the subsequent operations on aluminum foam metals. Closed-cell foam samples were processed via CO_2 laser cutting technology, WEDM, hand-sawing, and angle grinding while also studying their machinability. The results were compared in terms of the methods used and the resulting surfaces. Structural changes were evaluated using a scanning electron microscope (SEM). The following conclusions can be drawn from this study:

- WEDM can cut foam metal cell walls with minimum deformation compared to other methods.
- The parameters need to be adjusted to achieve low cell wall deformation during laser cutting.
- Hand-sawing and angle grinding break the cell wall surface.

Laser cutting may be used to quickly and precisely cut aluminum metal foams (especially for intricate shapes) up to 19 mm thick, as long as the planned applications do not require a high degree of accuracy. A saw cannot be used to cut a star form, but a laser can cut any shape. Although slower than laser cutting, EDM can be employed in thick and delicate applications where the pore structure must be maintained. Hand-sawing and angle grinding can be used in applications where fractures on the outer cell surface are not important. Following these operations, the most important factors to consider are the components' application areas, cell structure, and pore size.

Future research could explore a method that utilizes digital image processing, machine learning, and artificial intelligence to optimize laser cutting settings and rapidly adjust them based on foam thickness [38]. Water-guided laser cutting technology, which has shown remarkable precision, could be also studied [39], [40], comparing it against WEDM – attempting to achieve a comparable accuracy at the speed of laser cutting would be an intriguing endeavor. Furthermore, other studies evaluate the peeling and bonding strength outcomes of foams with surfaces cut by various techniques.

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CRediT author statement

All authors: conceptualization, methodology, formal analysis, investigation, writing (original, draft preparation, writing, reviewing, and editing), data curation, supervision, project administration, resources, funding acquisition.

Conflicts of interest

The authors declare no conflict of interest.

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