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Hypertherm Associates presented "Plasma arc cutting to enable high-volume, large HPDC parts manufacturing" at the NADCA Congress & Exposition 2024.

Plasma arc cutting to enable high-volume, large HPDC parts manufacturing

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Abstract

The rise of mega-casting, propelled by the adoption of large high-pressure die-casting (HPDC) systems, has created a pressing need for efficient alternatives for trimming castings. Traditional methods, such as trim presses, have significant drawbacks like high investment, long lead times, costly design changes, and limited effectiveness with large cast parts. Mechanical saws and shears, while used in some assembly processes, face limitations in scalability for high-volume production.

Enter plasma-cutting robotic cells – a flexible, adaptive, and scalable solution. These systems utilize Plasma Arc-Cutting (PAC) technology to trim gates, runners, and flash from castings. Mounted on industrial robots, plasma torches efficiently handle various casting designs within a single cell. Plasma cutting is relatively insensitive to standoff height, making it an ideal choice for complex parts and large-scale production.

High-pressure cast aluminum alloys are designed to have mechanical properties that are largely insensitive to cooling rate1, making them well suited for thermal cutting processes like PAC. This study examines the effects of cutting speed on the edge appearance and metallurgy of Aural 2S and A380 aluminum alloys.

Cast trimming operation

Castings have complex gates, runners, and overflows that must be trimmed. Traditionally, cast trimming is performed by grinding, trim presses, or machining. Even though these technologies are popular, there are significant challenges to using these technologies. Trim presses require high capital and are expensive to operate. These presses require regular maintenance and are prone to breakage. Machining with saw blades has several challenges around navigating tight features, cutting at higher temperatures, and combustible aluminum dust. Cast trimming with plasma cutting technology is becoming more efficient, scalable, and economical in this application. Plasma-cutting torches on robots are being rapidly deployed globally to take advantage of several benefits.

Plasma cutting basics

PAC is a method for rapidly cutting metal into precise shapes using a jet of high-temperature gas. The gas is heated to >20,000K by an electric arc that extends from a negatively charged electrode through a nozzle orifice that focuses and heats the gas to the cut workpiece. A schematic of a typical PAC torch is shown in Figure 1. Heat transfer from the electric arc, the hot gas, and chemical reactions provide the energy to rapidly melt the workpiece. The gas jet provides the momentum to eject the molten material, forming a channel extending through the workpiece as the plasma torch and workpiece are moved relative to each other. Since its introduction in the 1960s, PAC has become recognized as a cost-effective industrial process for cutting mild steel, stainless steel, aluminum, and other non-ferrous metal plates into finished shapes.

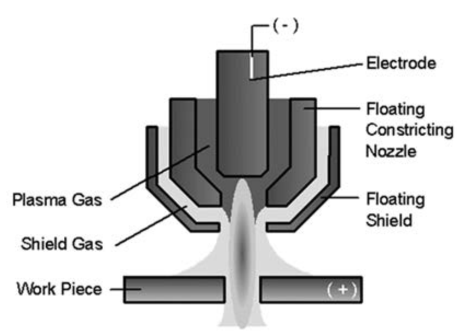

Figure 1 – Cutting torch schematic

Robotic plasma trimming cells

Robotic plasma cutting cells provide a robust and flexible cast-trimming solution. The casting is either fixtured for cutting or presented to the plasma torch using a robot. The cells typically include an enclosure with fume extraction, and chutes and conveyors for removing scrap.

Plasma cutting torches are designed to be mounted on robot arms, and the power supplies are designed to communicate with robot controllers. Plasma cutting is relatively insensitive to the clearance height between the end of the plasma torch and the casting surface, with a 6–7 mm clearance height typical in cast trimming applications. This attribute is a major advantage of plasma cutting that helps prevent torch collisions with the casting, minimizing downtime and system repairs. Plasma cutting torches are small and lightweight and available in various configurations. The torch leads are flexible and can withstand the repeated flexing associated with robotic arms. Multiple plasma torches can simultaneously cut the same casting to increase the cell's productivity.

85 A–105 A PAC systems are typically selected for trimming gates, runners, and access holes in cast aluminum parts in the 2–10 mm thickness range. They have small torch sizes, providing high casting-cut access. These systems typically have a pilot arc control mode, which allows the system to maintain an arc absent from any workpiece. This allows the PAC power supply to sense when flash, gates, or runners are present and cut them without any input from the robot controller or restarting of the arc. This simplifies part programming and reduces part cycle time. Recently some PAC systems have developed torches that accept consumables in a cartridge format. This enables automatic consumable changes in the robotic cell potentially eliminating cell downtime.

Cut speed selection

The speed at which a PAC system is used to cut metal is a compromise between the maximum rate and quality of the resulting cut edge. Production cut speeds are influenced by numerous factors such as cutting current, plasma gas, cut material, and thickness. For this study, the cut speed needed to be adjusted for the clearance height and the type of cast aluminum material. Cut testing using an 85A air plasma and a clearance height of 6.4 mm was completed on a structural grade of cast aluminum, Aural 2s, and a non-structural grade of cast aluminum, A380. In both cases, the material was 3 mm thick. The best quality speed was selected to optimize productivity and minimize the need to remove resolidified molten material from the bottom of the cut edge. Figure 2 shows the bottom view of three A380 samples cut at various speeds. The far-right sample shows resolidified material sticking to the base of the cut edge when the cut speed is too large. The clean, sharp edges seen in the center sample are typical for a quality PAC system.

Figure 2 – Bottom view of three A380 samples cut at shown speeds using 85A air plasma with a 6.4 mm clearance height

The cut speed of the middle sample was selected as the best quality cut speed. Figures 3 and 4 show the cut-edge appearance of both materials.

Figure 3 – Appearance of cut edge

Figure 4 – Appearance of cut edge

The experimentally determined optimum cut speeds for 3 mm A380 and Aural 2S of 285 in/min (7,240mm/min) and 258 in/mi (6550 mm/min), respectively, differ slightly from established aluminum cut speeds suggested in the PAC system user manuals2. Assuming the fractional change in speed is the same for all thicknesses; published aluminum cut charts can be offset to predict recommended cut speeds across the 2–10 mm thickness range.

Figures 5 and 6 show plots of these recommended best-quality cut speeds for 85A and 105A. These graphs highlight the speed at which plasma can process cast aluminum.

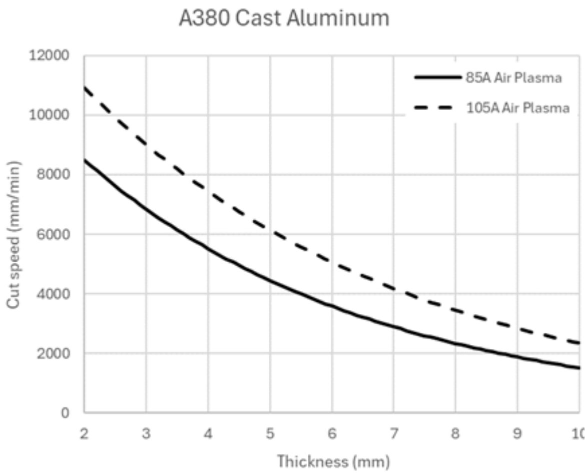

Figure 5 – Recommended best-quality cut speeds for 85A and 105A processes for A380 cast aluminum

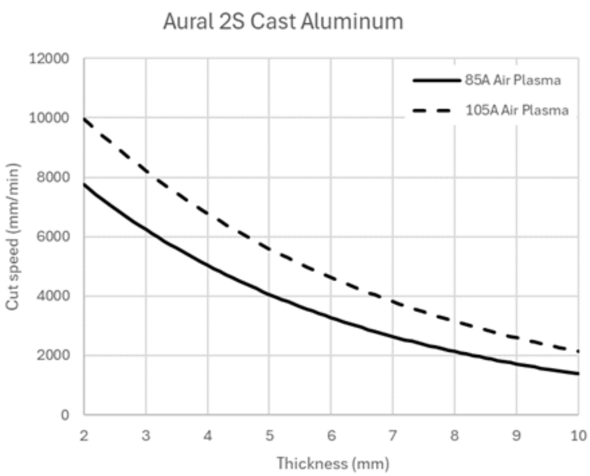

Figure 6 – Recommended best-quality cut speeds for 85A and 105A processes for Aural 2S cast aluminum

Plasma cutting heat affected zone

The 3 mm thick aluminum alloys were cut using an 85A Air plasma with a 6.4 mm clearance height. The A380 sample was cut at a speed of 7240 mm/min. The Aural 2S sample was cut at a speed of 6550 mm/min. A small section was cut from each sample and mounted in epoxy oriented so that the metallurgy near the cut edge could be examined. The samples were studied in the bulk material far (4–5 mm) from the cut edge and at the cut edge for comparison. The samples were prepared sequentially and sanded with 240, 320, 420, and 600 grit silicon carbide paper then polished with 9µm, 3µm, and 1µm diamond slurry.

In the microstructure images, Figures 7 and 8, the darker gray regions are the silicon phase, with the lighter phase being aluminum. Comparison with the bulk microstructure reveals that within 40–80 microns of the cut edge there is refinement of the silicon phase. For clarity, a dashed blue line was added to the images of the edge microstructure to highlight where the transition from the bulk microstructure to the heat-affected zone occurred. The observation that the size of the silicon phase is reduced near the cut edge suggests that there is some melting and re-solidification of the metal. This is expected based on the alloy compositions and the Al-Si phase diagram. The alloys in this study have a silicon content between 7.5 and 11.5 wt% which is generally below the eutectic composition of 11.3wt% Si. As a result, the alloy does not melt/solidify congruently but rather forms a mushy mix of solid and liquid over a range of temperatures. At least some portion of this partially melted alloy would remain on the cut edge and solidify with a refined microstructure. However, since a reduction of size and spacing of the silicon phase is desirable for increasing both strength and ductility3, the observed changes are not expected to have an adverse effect on the mechanical properties of these cast aluminum alloys. A low mag image of the cut edge of Aural 2s alloy Figure 9 reveals that the 85A Air plasma process used can leave some residual resolidified material on the cut edge. Protrusions residing on the cut edge contain pores of varying size and shape consistent with a molten metal solidifying in a strong gas flow. The size and orientation of the protrusions and pores suggest they are unlikely to adversely affect mechanical properties.

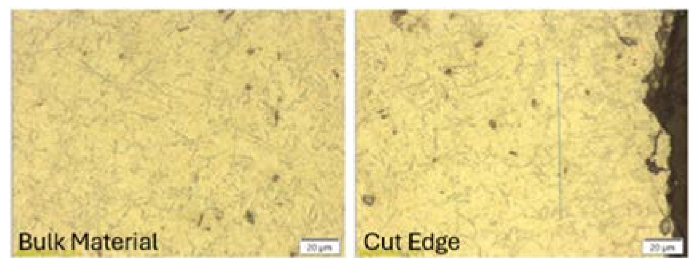

Figure 7 – Material type = A380, Material thickness = 3 mm, Process = 85A air plasma, Clearance height = 6.4 mm, Cut speed = 7240 mm/min

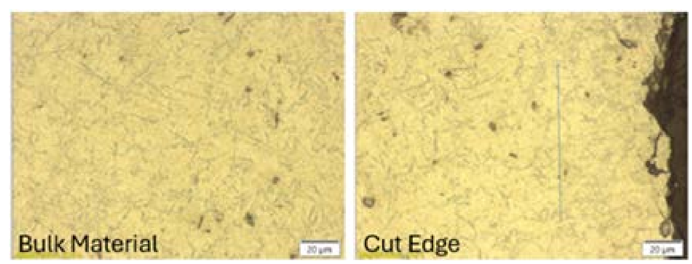

Figure 8 – Material type = Aural 2S, Material thickness = 3 mm, Process = 85A air plasma, Clearance height = 6.4 mm, Cut speed = 6550 mm/min

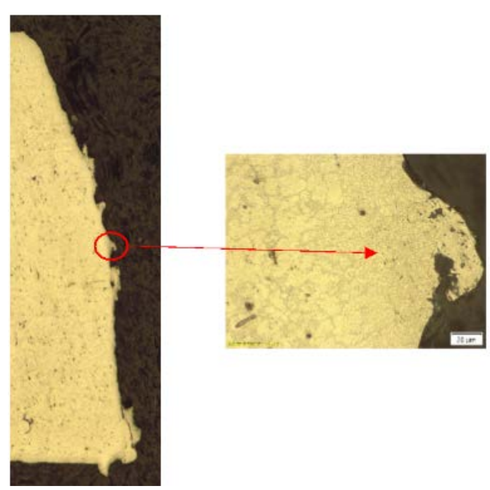

Figure 9 – Low magnification images of the Aural 2S alloy plasma cut edge

Plasma cutting additional casting features

A PAC system can add cast features like access openings and drain holes. A tolerance study was conducted using an 85A Air plasma process, cutting 12.5 mm and 20 mm diameter holes in a 6.4 mm thick 6061 aluminum plate. The clearance between the plate surface and the end of the torch was maintained at 6.4 mm (0.25 inch). The holes were programmed to pierce the plate in the center of the hole, move in a straight line to the hole perimeter at 254 mm/min; move around the hole perimeter at 1346 mm/min for the 12.5 mm holes and 1981 mm/min for the 20 mm holes; upon completing a full perimeter circle, the torch would move 1.9 mm into the hole on a line oriented 31 degrees from a line tangent to the hole perimeter at a perimeter speed. Note that the cut speeds for these small features are significantly below the cut chart recommended speed. The motion acceleration was set to 200mG in this study. A total of 33 12.5 mm diameter holes and 24 20 mm holes were cut using 3 sets of new consumable parts. Figures 10 and 11 show the hole quality achieved in the study. The hole diameter and cylindricity were measured twice using a CMM. One measurement was made of the total hole diameter, the other measurement included only half of the hole opposite the plasma entry/exit location. The study measurement results are summarized in the table, with the diameter tolerance representing 6 standard deviations of the measurements. A very tight (~ 0.5 mm) half cylindricity, whereas ~ 1.5 mm full cylindricity is typical for a thermal hole-cutting feature. This is due to the entry /exit location of the plasma arc on the hole feature. This is typically not a problem for holes/features with functional needs like drain holes, access slots, visibility slots, etc. The PAC cut quality is acceptable and used to add access openings and drain holes in castings.

Table 1 – Plasma-cut hole measurement summary

Hole diameter	Full hole measurements		Half hole measurements	
	Dia tol (+/- mm)	Cylindricity (mm)	Dia tol (+/- mm)	Cylindricity (mm)
12.5	0.47	1.06	0.28	0.56
20	0.48	1.34	0.25	0.64

Acknowledgments

Rio Tinto provided the Aural 2S plate used in this study.

References

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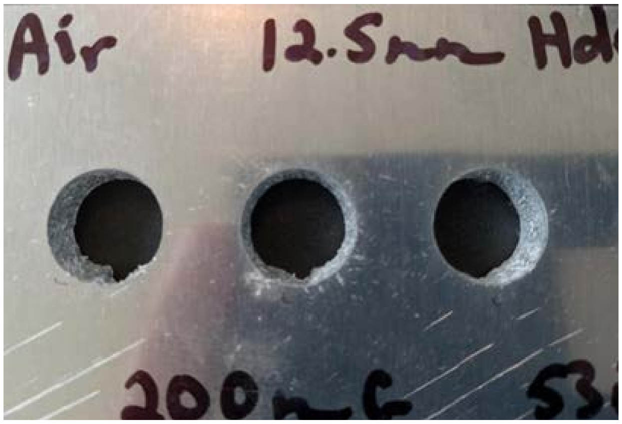

Figure 10 – 12.5 mm diameter plasma-cut holes in 6.4 mm thick 6061 Aluminum

Figure 11 – 20 mm diameter plasma-cut holes in 6.4 mm thick 6061 Aluminum

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