

EXPERIMENTAL INVESTIGATION OF MATERIAL REMOVAL RATE FOR VARIOUS CUTTING PROFILES IN PLASMA ARC CUTTING

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Abstract

This study investigates the material removal rate (MRR) of IS2062 Gr B stainless steel, during plasma arc cutting, concerning workpiece geometry. Different cutting profiles of rectangles, fillets, curvilinear, and circles were tested for the material removal rate, cutting time, weight removed, and volume removed. In these experiments, the machine used was a CNC MAXPRO200 plasma arc cutting machine and all of them had constant process parameters such as cutting current, voltage, cut height, and pierce height. Studies made on 20 mm thick stainless-steel plates with various geometries, results showed that profile cutting of material removal rate is dependent on the cutting profile of the workpiece and not on the weight. Curvilinear geometries had the highest material removal rate for the optimized cutting trajectories while the lowest was for circular geometries. The average material removal rate was calculated as $1.63 \times 10^{-5} \text{ m}^3/\text{sec}$ across all experimental studies, with the average weight removal rate being 1.26 kg/s. From these findings, it is inferred that the geometry of cutting should be considered when determining the material removal rate. The study concludes that plasma arc cutting is a highly effective process in producing complex shapes, and the methodology discussed here gives an insight into its operation on an industrial scale. The findings are useful in industries, particularly aerospace, automotive, and metal production, where precision must be cut across various material geometries.

Keywords: Cutting time; IS2062 Gr B stainless steel; Material removal rate; Plasma arc cutting

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Introduction

The type of cutting tools used in the manufacturing, industrial, and material engineering sectors significantly influences the speed and increased productivity in the relevance of time use and economy. The main elements tying the expansion and operations of various industrial sectors together are speed, mass production, and cost optimization. Plasma arc cutting (PAC) is a thermal cutting process widely used for cutting metals and other materials in various industries, including machine fabrication, shipbuilding, railroad wagons, and manufacturing, etc. (Moarrefzadeh, 2011; Sawdatkar *et al.*, 2024). Plasma arc cutting is the most advantageous than other cutting process (Choudhury *et al.*, 2024). Plasma arc cutting is a material removal process in which the material is removed by directing a high-velocity jet of high-temperature ionized gas on the workpiece. The relatively narrow plasma jet melts the workpiece material in its path. Because of the high temperature involved, the process can be used on almost all materials including those that are resistant to oxy-fuel gas cutting (Patel *et al.*, 2023). Plasma Arc Cutting can also be used to cut complex shapes with accuracy and precision (Rana *et al.*, 2013). Compared to conventional cutting techniques, plasma arc cutting has several benefits, including increased cutting speeds, increased precision, a smaller heat-affected zone, and the capacity to cut a broad variety of materials and thicknesses. It is widely utilized for applications ranging from straightforward cuts to intricate shapes and contours in sectors like construction, automotive, aerospace, shipbuilding, and metal fabrication. The primary influential factors in the plasma arc cutting process are arc current, standoff distance, and cutting speed, with each factor carrying varying degrees of significance (Naik and Maity, 2018). The selection of appropriate process factors and their impact on part quality evaluation are essential for improving PAC's cutting quality and performance characteristics (Hema and Ganesan, 2020). Susilo *et al.* (2024) determined how much influence the cutting speed and current variation with an air pressure of 1 MPa on the surface roughness of structural steel 400 plate cutting using Computer Numerical Control (CNC) plasma cutting. The independent variables of the research were variations in cutting speed and current. By evaluating the workpiece's mass reduction and using an empirical calculation, they evaluated the effect of cutting speed on the material removal rate. They also used the surface roughness tester (TR 1200) to measure surface roughness.

Petare *et al.* (2024) conducted experimental research where oxygen was introduced alongside compressed air during plasma cutting of 10 mm thick C-20 carbon steel plates, focusing on its impact on the quality of the cut surface. Patel *et al.* (2023) utilized stainless steel 410 material in the experiment for measuring the material removal rate. Sharma *et al.* (2017) confirmed that cutting speed, current, and gas pressure are important factors influencing MRR, utilizing Taguchi and ANOVA methodologies for optimization. Singh (2012) also used the Taguchi technique to improve PAC parameters, achieving a particular material removal rate of 0.8331 g/sec under ideal conditions. Sonu and Singla (2017) optimize plasma arc cutting process parameters and conduct experimental investigations for EN-45A material. The study focuses on the machinability of the EN-45A material to identify the impact of various process variables as well as the optimal condition for achieving the lowest feasible degree of bevel angle, Kerf width, and maximum material removal rate. Air plasma cutting has been found suitable for various construction materials, including high-strength steels, aluminum alloys, and copper (Rzeźnikiewicz *et al.*, 2023). Hang *et al.* (2020) experimented with a Bruco CNC plasma cutting machine for CT3 steel with different thicknesses. Bhuvnesh *et al.* (2012) have done an experimental investigation on the plasma arc cutting of structural steel (IS 2062 E250 BR) material.

The present research aims to study the material removal rate using plasma arc cutting according to the workpiece geometry of IS2062 Gr B stainless steel. It intends to innovatively investigate how the different cutting profiles such as rectangular, curvilinear, fillet, or circular affect material removal rate. This study also aims to assess and compare the time of cutting with different workpiece geometries. The study also deals with the assessment of weight removal, volume removal, and average material removal rate for plasma arc cutting.

Materials and Methods

When a gas comes into contact with tremendously high temperatures, plasma is produced. The basic principle of plasma arc cutting involves creating an electric arc between an electrode and the workpiece. This arc ionizes the gas passing through a constricted nozzle. The basic plasma cutting system consists of a power supply, an arc starting circuit, and a torch.

Material Specification

In this experiment, stainless steel of grade IS2062 Gr B is used. The integrated component of the 2062 Gr B material makes it more resistant to corrosive and oxidative environments. Numerous micro-alloyed sheets, plates, coils, and other parts utilized in various industries are made possible by this material. This grade's components are more ductile and exhibit better stability at higher temperatures. The components of IS2062 Gr B stainless steel are carbon (C), silicon (Si), phosphorus (P), manganese (Mn), and sulfur (S). Table 1 provides the material's chemical composition, while Table 2 lists the material's mechanical and physical characteristics for IS2062 Gr B. This experiment uses a rectangular plate measuring 1340 mm long, 570 mm wide, and 20 mm thick.

Experimental Setup

The experiment was carried out in a Computer Numerical Control (CNC) MAXPRO200 plasma arc cutting machine shown in Figure 1. The equipment comprised major parts such as an air compressor, alternating current plug, power supply, plasma torch, ground clamp, electrode, nozzle, guide rail, computer, and cutting table. The torch position is kept vertical concerning the workpiece. The maximum thickness that can be cut with a 100% duty cycle is known as the maximum production

capacity. It is 22 mm for stainless steel in this system. The maximum pierce capacity is 25 mm for stainless steel and the maximum severance capacity is 63 mm for stainless steel.

Table 1. Chemical composition of IS2062 Gr B

Property name of IS2062 Gr B	Value
Density	8000 Kg/m ³
Coefficient Of thermal expansion	0.000013/°C
Thermal conductivity	0.032 KW/m°C
Specific heat	481.000 J/Kg°C

The gas used in the plasma arc-cutting process is air. Throughout the cutting process, some parameters are kept constant like cutting current at 200 A, open circuit voltage at 166 V, cut height at 3.5 mm, and pierce height at 20 mm shown in Table 3. These constant factors dictate the gas pressure, which remains constant to maintain a regulated experimental setting. The torch and its consumable parts, in a CNC plasma arc machine, play critical roles in ensuring a high-quality and precise cut (Kudrna *et al.*, 2019). A series of intensive trial experiments were carried out in accordance with the manufacturer's instructions, and finally, an air consumable 200 A plasma cutting nozzle type was chosen for the experiment, along with its equivalent electrode, nozzle, swirl ring,

Table 2. Physical and mechanical properties of IS2062 Gr B

Grade Designation	Quality	Ladle Analysis, Maximum Percentage					Carbon Equivalent (CE), Maximum %	Mode of Deoxidation
		C	Mn	S	P	Si		
2062	Gr B	0.22	1.50	0.045	0.045	0.40	0.41	Semi-killed/killed

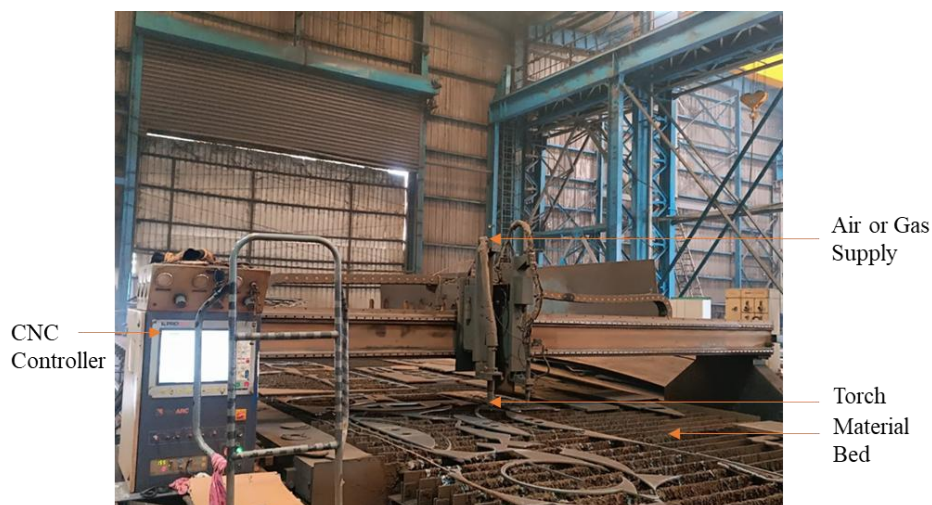


Figure 1. CNC Plasma Cutting Machine

Table 3. Process parameters

Arc voltage (Volts)	Arc current (A)	Cutting speed (mm/min)	Cut height (mm)	Pierce height (mm)
166	200	1200	3.5	20

Table 4. Specification of machine

Maximum Open Circuit Voltage	360 VDC (Volts Direct Current)
Maximum Output Current	200 Amps (Ampere)
Output Voltage	50 – 160 VDC
Duty Cycle Rating	100% @33 KW, 40° C (104° F)
Ambient Temperature/Duty Cycle	Power Supplies Will Operate Between -10° C and +40° C
Power Factor	0.98 @ 33 KW output
Cooling	Forced Air (Class F)
Insulation	Class H

**Figure 2. Air consumable 200 A plasma cutting nozzle and torch parts**

shield cap, and nozzle retaining cap, as shown in Figure 2. Plasma arc machine torch consists of nozzle assembly which consists of various components. These include electrode, nozzle, swirl ring, shield cap, and nozzle retaining cap. The assembly of different parts of the plasma torch is important. Each part takes part in the formation and direction of the plasma arc and allows the torch to cut properly and accurately into any metal. The proper alignment and secure attachment of each component are essential to the torch's performance and longevity. The electrode is essential to the plasma-generating process, facilitating the arc discharge required for plasma formation (Vithelingum *et al.*, 2014). The shape and accuracy of the plasma jet are determined by the nozzle, which concentrates the plasma arc as it exits a portion of the torch part (Praveen *et al.*, 2016). According to Praveen *et al.* (2016), the swirl ring contributes to the plasma arc stabilization through the creation of swirling motion in the shielding gas flow, ensuring that the plasma flows smoothly and

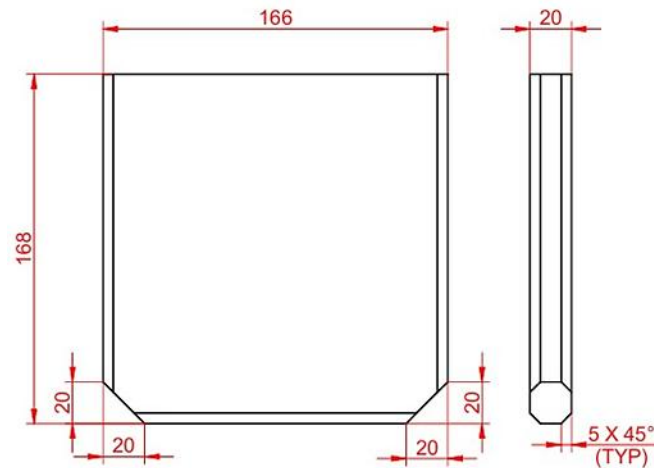
at the correct angle. The nozzle retaining cap serves as a barrier protecting the nozzle and electrode from excessive wear and tear (Deegan *et al.*, 2019).

This also fosters stability for the arc and aids in the direction of gas flow. The shield cap, or outside nozzle, protects the torch and nozzle against heat, debris, and plasma spatter (Deegan *et al.*, 2019). Further, it aids in stabilizing the plasma arc with additional airflow or cooling that prevents torch overheating from occurring. The shield is usually placed over the nozzle and attached to the torch body. Electrical current is transferred from the power supply to the plasma torch through a power connector and leads. These leads supply the electrical energy required to create the arc throughout the cutting process.

Table 4 illustrates the plasma arc cutting machine's essential operational features and capabilities. In this study, four experiments have been carried out by cutting a 20 mm thick workpiece constructed of IS2062 GR B steel. The trials aimed to assess the machine's performance under specific

Table 5. Material shapes to be cut

Experiment No.	Cutting profile dimensions	Quantity	Weight removed (in kg)
1	A 166 mm × 168 mm × 20 mm plate with two 20 mm, 45° fillets	1	42.26
2	1193 mm × 250 mm × 20 mm plate with a 920 mm radius curvilinear cut from the workpiece center	1	424.50
3	φ70 mm round and 20 mm thick	1	5.92
4	A 166 mm × 198 mm × 20 mm plate with two 20 mm, 45° fillets	1	50.08

**Figure 3. The cutting profile of experiment 1**

settings. Air was employed as both the primary plasma gas and the secondary shielding gas.

Results and Discussion

Table 5 shows the experimental results for all experiments with the same thickness but a different sample size. Every experiment is carried out using workpiece material that is 1,340 mm long, 570 mm wide, and 20 mm thick. The selected cutting profile is cut from the same material for all the experiments performed.

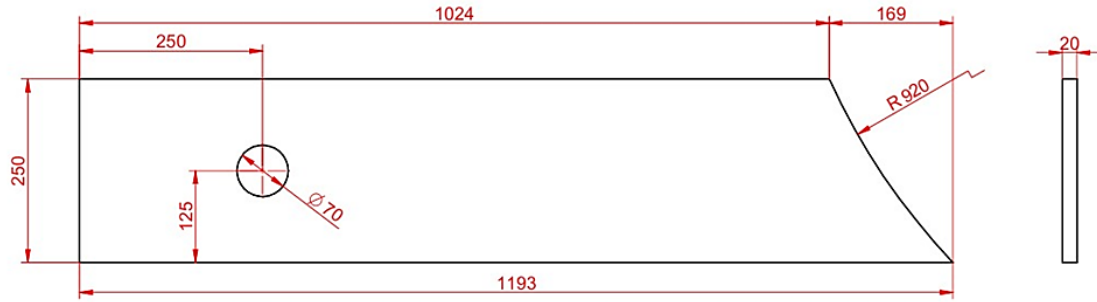
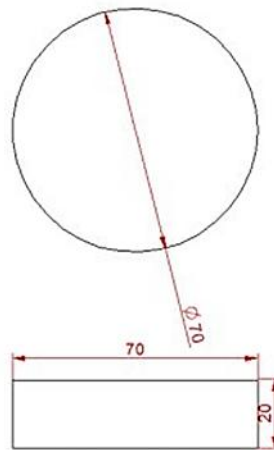
In these experiments, various dimensions were initially designed in Solid Edge software (Dft.) and then converted to AutoCAD (Dwg.). The AutoCAD drawing is then imported into OmniCAD for nesting, which allows for a more efficient cutting process. Nesting in Computer Numerical Control (CNC) is the process of optimizing the arrangement of pieces or components on a material sheet to reduce waste and increase efficiency. Once the drawing is successfully nested, it is uploaded into the plasma arc CNC controller, and then after thorough checking the machine is ready to start cutting. A stopwatch was used to measure the time required for each experiment. The material removal rate is determined using the volume of the machined

plate and the time taken to cut the material. The material removal rate calculated is presented in Table 6. The material removal rate is a key parameter that measures the amount of material removed per unit of time during a machining or material processing operation. The weight difference before and after carrying out the machining operation serves as a basis for calculating the material removal. The volume eliminated is calculated using the weight difference and the density of the materials (Bhaskaran *et al.*, 2022). The time required for each experiment has been measured by a stopwatch.

The cutting profile of experiment 1 is depicted in Figure 3. The rectangular plate of size 166 mm by 168 mm and thickness 20 mm was cut in experiment 1, holding two 20 mm, 45° radius fillets at the corners. This has caused the removal of 42.26 kg of material. Figure 4 displays the cutting profile of experiment 2. A larger plate of size 1,193 mm by 250 mm and thickness of 20 mm was processed in experiment 2. It was cut, making a curvilinear profile of the workpiece starting from the center and having a radius of 920 mm. This complex cut removed 424.50 kg of material. The cutting profile of experiment 3 is shown in Figure 4. Experiment 3, the processing involved cutting a round piece of 70 mm diameter and 20 mm thick. It caused

Table 6. MRR calculation sheet

Experiment No	Material removal (kg)	Volume removal (m ³)	Time (s)	Rate of weight removed (kg/sec)	MRR (m ³ /sec)	Average rate of weight removed (kg/sec)	Average MRR (m ³ /sec)
1	42.26	0.000549	34.44	1.23	1.60×10^{-5}	1.26	1.63×10^{-5}
2	424.50	0.005518	304.45	1.39	1.81×10^{-5}		
3	5.92	0.000077	5.05	1.17	1.52×10^{-5}		
4	50.08	0.000651	40.65	1.23	1.69×10^{-5}		

**Figure 4. The cutting profile of experiment 2****Figure 5. The cutting profile of experiment 3**

an extraction of 5.92 kg of material. Figure 5 displays the cutting profile of experiment 4. Experiment 4 consists of cutting yet another rectangular plate of dimensions 166 mm by 198 mm and thickness of 20 mm, also having two 20 mm, 45° fillets. This operation resulted in material removal of 50.08 kg which is slightly more from experiment 1, as the length of the plate has increased.

Table 6 displays the material removal data analysis from the plasma arc cutting experiments, including weight removal, volume removal, cutting time, and material removal rate (MRR). Cutting

time varied greatly between studies, depending on the size and shape of the workpieces. Experiment 2, which had the largest workpiece, required the longest cutting time, 304.45 s. Experiment 3, which had a circular profile, took 5.05 s to complete. Experiments 1 and 4, which used moderate-sized workpieces, took 34.44 and 40.65 s, respectively. The MRR for experiment 1 was 1.60×10^{-5} m³/sec. In experiment 2, its MRR was higher at 1.81×10^{-5} m³/sec. Experiment 3 had the lowest MRR of 1.52×10^{-5} m³/sec. Experiment 4 had the MRR, 1.69×10^{-5} m³/sec. It is seen that, The MRR is followed by the cut geometries rather than

the amount of weight eliminated. Experiments 1 and 4 demonstrate equal MRR, however the removed weights are different. This is because both have identical cut geometries. The MRR is highest for curvilinear geometry and lowest for circular geometry.

During the process of plasma arc cutting, it is the cutting geometries that affect the rate of material removal. The relationship between cutting path length and material removal rate (MRR) is important because longer paths result in lower effective MRR, even at constant cutting speed. Longer distances require more time, which decreases the amount of material removed per unit time (Shen, 2024). According to Bagci and Yüncüoğlu (2017), the curvilinear approach lowers cutting forces and tool deflection, resulting in higher MRR. Some of these cutting parameters such as cutting current, cutting speed, cut height, and pierce height determine the rate of material removal (MRR) (Agarwal and Patel, 2019). The MRR is also dependent on the thickness of the material being cut (Bhuvnesh *et al.*, 2012). However, in this study, all the parameters were kept constant, and hence the MRR was studied concerning the shapes of the workpiece. However, in this research, there is a very minor gap between the peak and low values of MRR. The average rate of material removal across all experiments was 1.63×10^{-5} m³/sec. The average MRR in terms of weight is 1.26 kg/s. The cutting geometries under this investigation suggest the geometry effects upon the MRR. It would then be of importance to the industries for optimizing their plasma arc cutting processes and thus the operational efficiency.

The influence of geometry on MRR demonstrated in the current work may also exist for lightweight metal geometries such as aluminium. However, because aluminium has a much higher thermal conductivity and a lower melting temperature, its heat dissipation and time-to-material removal behavior may vary significantly (Chakravarti and Sen, 2023a; 2023b).

Conclusions

Plasma arc cutting is one of the frequently used unconventional machining processes that are capable of producing complex shapes. In this study, experiments were conducted on the CNC plasma cutting process of IS2062 Gr B stainless steel to analyze the material removal rate with different shapes of design for the cutting process. The experimental results showed that the geometry of the workpiece has a substantial influence on the material removal rate in plasma arc cutting.

The material removal rate is highest for curvilinear geometry and lowest for circular geometry due to increased cutting complexity. The cutting time varied with the size and shape of the workpiece, with heavier weights necessitating longer cutting time. The experiment also determined that the same geometries but variable dimensions gave similar material removal rate values, demonstrating that cutting path length and trajectory are more essential than workpiece weight alone. Finally, the average material removal rate has been calculated. Although there is just a tiny difference between the high and low values of material removal rate. The average material removal rate was 1.63×10^{-5} m³/sec. The average material removal rate for weight is 1.26 kg/s. This study concludes that the proposed methodology may be viewed as a very effective and powerful approach for correlating the material removal rate with cutting geometry, as most industries use the plasma arc machine for the cutting process.

This experiment was conducted using IS2062 Gr B stainless steel material. This study can be expanded to include other materials. Future studies can include optimizing or investigating the effect of arc current, arc voltage, cutting speed, material thickness, and pierce height on material removal rate and surface roughness utilizing IS2062 Gr B stainless steel material.

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References

- Agarwal, P.H. and Patel, K.R. (2019). Optimizing plasma arc cutting parameters for structural steel using grey relational analysis. *International Journal of Engineering Research and Technology*, 8(1):27-30.
- Bagci, E. and Yüncüoğlu, E.U. (2017). The effects of milling strategies on forces, material removal rate, tool deflection, and surface errors for the rough machining of complex surfaces. *Journal of Mechanical Engineering/Strojniški Vestnik*, 63(11):643-656. <https://doi.org/10.5545/sv-jme.2017.4450>
- Bhaskaran, B., Jayaram, R.S., and Saravanamuthukumar, P. (2022). Machining parameter effects on MRR and SR for monel 400 material: A Taguchi Method Investigation. *Neuroquantology*, 20(8):4781-4789. <https://doi.org/10.14704/nq.2022.20.8.NQ44504>
- Bhuvnesh, R., Norizaman, M.H., and Manan, M.S.A. (2012). Surface roughness and MRR effect on manual plasma arc cutting machining. *International Journal of Industrial*

- and Manufacturing Engineering, 6(2):459-462. <https://doi.org/10.5281/ZENODO.1062515>
- Chakravarti, S. and Sen, S. (2023a). An investigation on the solidification and porosity prediction in aluminium casting process. *Journal of Engineering and Applied Science*, 70(1):1-24. <https://doi.org/10.1186/s44147-023-00190-z>
- Chakravarti, S. and Sen, S. (2023b). Study on the behaviour of surface wear and friction for a pure aluminium casting product using permanent mould. *Key Engineering Materials*, 944:41-49. <https://doi.org/10.4028/p-y1qvb0>
- Choudhury, M.R., Dutta, H., Deka, U., Bhavani, B., Saxena, K. K., and Borah, A. (2024). Optimization of process parameters in CNC plasma cutting of commercial-grade aluminium plate. *High Temperature Materials and Processes*, 43(1):20220329. <https://doi.org/10.1515/htmp-2022-0329>
- Deegan, D., Langridge, S., and Hockley, S., Inventors; Tetronics Limited, Assignee. May 16, 2019. Plasma Torch Assembly. U.S. Patent No. 9241616.
- Hang, P.T., Chau, N.T., Khang, A.D., Anh, N.H., and Son, P.H. (2020). An investigation on the effect of cutting parameters in CNC plasma cutting process for carbon steel. *Vietnam Journal of Agricultural Sciences*, 3(4):831-842. <https://doi.org/10.31817/vjas.2020.3.4.06>
- Hema, P. and Ganesan, R. (2020). Experimental investigations on SS 304 alloy using plasma arc machining. *SN Applied Sciences*, 2:624. <https://doi.org/10.1007/s42452-020-2350-y>
- Kudrna, L., Fries, J., and Merta, M. (2019). Influences on plasma cutting quality on CNC machine. *Multidisciplinary Aspects of Production Engineering*, 2(1):108-117.
- Moarrefzadeh, A. (2011). Numerical simulation of workpiece thermal profile in plasma arc cutting (PAC) process. *WSEAS Transactions on Applied and Theoretical Mechanics*, 6(4):160-166.
- Naik, D.K. and Maity, K.P. (2018). Optimization of dimensional accuracy in plasma arc cutting process employing parametric modelling approach. *IOP Conference Series: Materials Science And Engineering*, 338:012039. <https://doi.org/10.1088/1757-899X/338/1/012039>
- Patel, H., Gohil, H., Vasawala, N., and Patel, J. (2023). Experiment and analyse material removal rate in plasma arc cutting of SS410 for various parameters using ANOVA. *International Journal of Advances in Engineering and Management*, 5(2):179-187.
- Petare, A.C., Khan, A.U., and Madhukar, Y.K. (2024). An experimental study on oxygen assisted plasma air cutting of low carbon steel. *Research Square*. <https://doi.org/10.21203/rs.3.rs-3872510/v1>
- Praveen, K. and Namburu, K., Inventors; Lincoln Global Inc., Assignee. March 31, 2016. Plasma Cutting Torch, Nozzle and Shield Cap. U.S. Patent No. 4662202.
- Rana, K., Kaushik, P., and Chaudhary, S. (2013). Optimization of plasma arc cutting by applying Taguchi method. *International Journal of Enhanced Research in Science Technology and Engineering*; 30 2(7):2319-7463.
- Rzeźnikiewicz, A., Górka, J., and Przybyła, M. (2023). The air plasma cutting quality of selected construction materials. *International Journal of Modern Manufacturing Technologies (IJMMT)*, 15(1):18-24. <https://doi.org/10.54684/ijmmt.2023.15.1.18>
- Sawdatkar, P., Parmar, V., and Singh, D. (2024). Review of plasma arc cutting process and its comparative analysis with laser beam machining process in terms of energy consumption. *Materials and Manufacturing Processes*, 39(9):1163-1186. <https://doi.org/10.1080/10426914.2024.2362620>
- Sharma, S., Gupta, M., Kumar, R., and Bindra, N.S. (2017). Experimental analysis and optimization of process parameters in plasma arc cutting machine of EN-45A material using Taguchi and ANOVA method. *International Journal of Mechanical and Industrial Engineering*, 11(7):1394-1398.
- Shen, Y. (2024). Study of optimal cutting paths for steel plates based on Enumeration and Nonlinear programming. *Academic Journal of Science and Technology*, 12(3):217-220. <https://doi.org/10.54097/b18yqz13>
- Singh, V. (2012). Analysis of Process Parameters Of Plasma Arc Cutting Using Design of Experiment, [M.Tech Thesis]. Rourkela, India: National Institute of Technology, Institute of Engineering, 107p.
- Sonu, S.S. and Singla, S. (2021). A review paper on optimization of influence parameter of en-45a material using plasma arc cutting machine. *International Research Journal of Engineering and Technology (IRJET)*, 8(7):747-751.
- Susilo, G.B., Sasongko, B.T., and Wardhana, P.B.W. (2024). Analysis of the effect of cutting speed and current on surface roughness with CNC plasma cutting on steel plates SS400. *Jurnal Dinamika Vokasional Teknik Mesin*, 9(1):26-35. <https://doi.org/10.21831/dinamika.v9i1.72268>
- Vithelingum, K., Maocec, C., De Laurentis, C., and Renault, T., Inventors; Lincoln Electric Co France SA, Assignee. July 11, 2014. Plasma Arc Torch, Useful for Cutting A Metal Part. U.S. Patent No. 13501171.