International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)

ISSN: 2456-236X

Vol. 10 Issue 01 | 2025

An Experimental Analysis of Cutting Quality in Plasma Arc Machining: An Extensive Review

Kunal Kharote[1], Dipak P Kharat[2], Santosh R Shekokar[3], Nitin A Kharche[4], P. V. Chopde[5]
[1]PG Student, department of Mechanical Engineering,
[2,3,4,5] Assistant Professor, Department of Mechanical Engineering,
Padm. Dr. V. B. Kolte College of Engineering, Malkapur

DOI: 10.5281/zenodo.16403158

Abstract

This literature review provides a comprehensive analysis of the Plasma Arc Cutting (PAC) process, which has gained prominence as a significant non-conventional machining method for cutting electrically conductive materials, particularly in contexts where conventional techniques are inadequate. The review highlights the evolution of PAC in addressing challenges such as complex geometries and tool wear, and emphasizes its advantages, including high accuracy, efficiency, and economic benefits over traditional cutting methods. Key parameters influencing cutting quality, such as arc current, cutting speed, gas pressure, and stand-off distance, are discussed, alongside their effects on critical quality metrics including kerf width, surface roughness, heat-affected zone, and dross formation. Various materials, including nickel-based superalloys, steel alloys, and aluminum, are explored for their unique challenges and the need for tailored optimization strategies. Methodologies for enhancing PAC quality, including the Taguchi method, response surface methodology, and multi-objective optimization techniques, are examined, alongside innovations in equipment design such as torch configurations and nozzle treatments. Despite the advancements, limitations in precision and metallurgical effects remain, suggesting opportunities for further research and development. The review concludes that ongoing experimental analysis is crucial for refining PAC capabilities and expanding its industrial applications amidst growing demands for precision cutting in advanced materials.

Keywords: Taguchi method, RSM, plasma arc cutting, kerf width, surface roughness etc

1. Introduction to Plasma Arc Cutting

Plasma Arc Cutting (PAC) has emerged as a significant non-conventional machining process widely employed for cutting electrically conductive materials, particularly when conventional methods prove ineffective for complex shapes or difficult-to-machine materials. The PAC process was developed specifically to overcome the inefficiency and ineffectiveness of conventional machining methods when dealing with complex shapes and excessive tool wear due to contact between the tool and workpiece [1]. The process utilizes ionized gas as a heat source and a high energy stream known as plasma [1]. The growing importance of PAC can be attributed to its ability to process a wide range of materials with varying thicknesses while achieving acceptable cutting quality.

The significance of PAC is particularly evident in industries where precision cutting of hard materials is required. As one of the most important nonconventional machining methods, PAC's high accuracy, high finishing capabilities, ability to machine hard materials, and capacity to produce intricate shapes have increased its demand in the market [2]. Furthermore, PAC offers economic advantages, being cheaper than laser cutting and approximately ten times faster than oxyfuel cutting for many applications [2].

PAC is an unconventional process widely utilized in the manufacturing of heavy plate products [3]. Its high accuracy, finishing capabilities, ability to machine any hard materials, and capacity to produce intricate shapes have significantly increased its market demand [4]. The PAC process offers distinct advantages such as the ability to cut all electrically conductive materials and to process various steel materials with medium and large thicknesses. It is also used in cutting high-strength structural steel with lower heat input and offers higher cutting speeds compared to conventional machining processes [5].

This literature review synthesizes recent experimental studies on cutting quality in plasma arc machining, examining various parameters affecting quality, measurement techniques, material-specific considerations, optimization approaches, and equipment design factors.

2. Key Parameters Affecting Cutting Quality in PAC

Experimental studies have consistently demonstrated that process parameters significantly influence cutting quality in plasma arc machining. The quality of the cutting process primarily depends upon plasma gas pressure, scanning speed, cutting power, and cutting height [6]. Understanding these parameters is crucial for achieving optimal cutting results.

2.1 Arc Current and Voltage

- Arc current and voltage are among the most significant parameters affecting cutting quality. Studies have analyzed the impact of arc current (AC) on evaluating metrics such as kerf width (KW), kerf taper (KT), and heat-affected List Item - 4

zone (HAZ) of materials like Inconel 718 superalloy [7]. Research on cutting mild steel E350 grade sheets has identified current as one of the important parameters influencing quality, contributing approximately 12.08% to the variation in bevel angle according to ANOVA analysis [2].

Arc current has been identified as the most significant parameter in altering surface roughness in the PAC of commercial-grade aluminum plates [8]. Parameter contribution analysis has shown that cutting current dominates the cutting process, accounting for 79.42% of the contribution, followed by cutting speed when processing aluminum 5083 [9]. The influence of current varies with material thickness and composition, requiring careful optimization for specific applications.

2.2 Cutting Speed

Cutting speed has emerged as one of the most critical parameters affecting various quality metrics. Experimental studies have monitored kerf width quality by examining edge roughness, kerf width, and the size of the heat-affected zone (HAZ) [6]. ANOVA studies have revealed that cutting speed influences the bevel angle the most, with a contribution of 62.18%, significantly higher than other parameters like arc gap (15.16%) and current (12.08%) [2].

Research on the effect of cutting speed on copper sheets has shown that increased cutting speed at the beginning of the cutting path results in lower kerf width, which has a clear effect on increasing cutting quality [10]. Conversely, when cutting speed decreases, kerf width increases and cutting quality decreases [10]. In a study on stainless steel plate cutting, cutting speed was found to be the most influential factor on surface roughness with a contribution value of 90.76%, significantly higher than height torch (2.42%) and electric current (0.23%) [11].

The quality of cut surfaces is primarily affected by the cutting rate. An increase in cutting rate is accompanied by deterioration of the geometric features of cut surfaces. However, higher cutting rates also translate into significant reduction of the HAZ width and the size of the zone of chemical composition changes [12]. For 14 mm-thick plates made of steel S235JR, studies have determined that the optimum cutting rates are restricted within the range of 600 mm/min to 1500 mm/min [12].

2.3 Gas Pressure and Type

Gas pressure and gas type significantly influence cutting quality in PAC. Experimental work has analyzed the impact of gas pressure (GP) on kerf width, kerf taper, and heat-affected zone [7]. Studies on carbon steel have considered gas pressure (bar) as one of the key process parameters, analyzing its effect on surface roughness and material removal rate [13]. In investigations of spatter and dross formation on S275JR mild carbon steel, gas pressure has been kept constant at 6 bar while varying other parameters like cutting speed, arc current, and stand-off distance [5].

Research has examined the influence of plasma gas (specifically air) on cut surface quality, structural transformations, and changes in chemical composition of structural steel. The tests carried out have determined the influence of the active plasma gas (oxygen, nitrogen) both on changes in the chemical composition of the tested steel and on the quality of the cut surfaces obtained [12]. Studies on cutting steel plates like Hardox 400 have considered plasma gas pressure as a key parameter affecting cut quality metrics including kerf width, surface roughness, and heat affected zone [14].

2.4 Stand-off Distance

Stand-off distance (SOD) has been identified as another crucial parameter affecting cutting quality. Research has examined the impact of stand-off distance on kerf width, kerf taper, and heat-affected zone in various materials [7]. Studies have shown that torch standoff distance, along with cutting speed and arc current, significantly affects response variables like material removal rate and kerf width [15].

In plasma arc piercing, which is performed before plasma arc cutting for thick plates, factors such as stand-off distance play an important role in inducing double arcing, which affects cutting quality [16]. Experimental investigations have confirmed that smaller stand-off distances lead to worse surface quality due to double arcing

[16]. Studies have also shown that spatter formation becomes more prominent near the cut edge or kerf when using a higher stand-off distance [5].

3. Measurement and Evaluation of Cutting Quality Metrics

The experimental evaluation of cutting quality in plasma arc machining relies on several established metrics. These metrics provide quantitative measures to assess and compare cutting performance across different parameter settings and materials.

3.1 Kerf Characteristics

Kerf width and taper are primary quality indicators in PAC. Research has determined kerf geometry using three accuracy parameters: top kerf width, bottom kerf width, and kerf taper angle [3]. Studies have analyzed the effects of cutting parameters such as cutting speed, arc current, and cutting height on kerf width and bevel angle (another term for kerf taper) [17].

Investigations on the effect of speed on kerf width to optimize cutting quality have involved measuring and recording kerf width readings at multiple points along the cutting path, comparing measurement readings, and analyzing them to determine optimal speeds for good cutting quality [10]. Research on AISI304 stainless steel has shown that the lowest average kerf taper value (0.32°) was obtained on 4 mm thick plate with a gas pressure of 0.6 MPa and a cutting speed of 151 mm/min, while the highest average kerf taper value (2.59°) was measured on 8 mm thick plate with a gas pressure of 0.8 MPa and a cutting speed of 217 mm/min [18].

Comparative studies between different cutting methods have noted that 1-3° vertical inclination (conicity) occurs on the cut surface in plasma arc cutting, while this inclination is almost non-existent in laser cutting [19]. This highlights the inherent limitations of PAC regarding kerf taper compared to other methods.

3.2 Surface Roughness

Surface roughness is a critical quality metric frequently examined in PAC research. Studies have determined surface roughness using two main parameters through scanning the surface topography: roughness average and maximum height of the profile [3]. Research on aluminum 5083 has investigated surface roughness and conicity angle as primary response parameters [9].

Experimental work aimed at minimizing surface roughness of stainless-steel plates has employed design of experiment methods with full factorial design. Such studies have found cutting speed to be the most influential factor affecting surface roughness, with contribution values exceeding 90%, and have identified optimal parameter combinations (such as 1 mm torch height, 2400 mm/min cutting speed, and 30 A electric current) [11].

For AISI304 stainless steel plates, research has revealed that as cutting speed increases at constant pressure values, cutting surface roughness values increase. Conversely, at constant cutting speed, surface roughness decreases as gas pressure increases [18]. These findings demonstrate the complex interrelationships between process parameters and their effects on surface roughness.

3.3 Heat Affected Zone (HAZ)

The heat affected zone represents another crucial quality metric in PAC. Research has determined surface properties through microstructure analysis in the heat affected zone [3]. Studies have found that while PAC provides acceptable machining quality and excellent material removal efficiency, it is not suitable for final machining due to metallurgical variations in the HAZ [3].

Investigations of air plasma cutting on structural steel have observed the formation of an amorphous phase on the cut surface within the HAZ. This amorphous phase is characterized by a very high nitrogen content (approximately 1.6%) and a hardness of 750 HV 0.2 [12]. The intense nitration results from the diffusion of nitrogen from the plasma gas, while the effect of air plasma arc gases on the liquid metal is responsible for the carburizing of the cut surface (up to approximately 0.5%) and the burnout of alloying components [12].

Studies on cutting steel plates like Hardox 400 have evaluated the effect of process parameters on the quality of cut in terms of HAZ. Results have indicated that minimum HAZ (0.886 mm) was obtained at maximum cutting speed (700 mm/min), demonstrating the inverse relationship between cutting speed and HAZ size [14].

3.4 Dross and Spatter Formation

Dross (resolidified material attached to the bottom of the cut) and spatter are important quality concerns in PAC. Experimental investigations on spatter and dross formation on S275JR mild carbon steel have involved observation and measurement using digital microscopy. Results have shown that spatter formation is more prominent near the cut edge when using higher stand-off distances, while dross formation can reach a maximum length of 1.741 mm and minimum height of 1.192 mm [5].

ANOVA analysis has revealed that cutting speed and stand-off distance are the most statistically significant factors affecting dross formation. For minimizing dross formation, low arc current, higher levels of cutting speed, and stand-off distance should be utilized [5]. Research has also examined bottom surface burr formations and top surface spatter formations in PAC of stainless steel [18].

4. Material-Specific Considerations in PAC

Experimental studies have investigated cutting quality across a wide range of materials, highlighting the need for material-specific parameter optimization in PAC.

4.1 Nickel-Based Superalloys

Nickel-based superalloys, which are widely used in industries requiring high-temperature resistance, present particular challenges for machining. These alloys withstand high thermal debility conditions, provide better strength to machine parts in aviation, biomechanical, marine, and vehicle industries, and offer high quality, corrosion resistance, and high heat refusal. Inconel 718, in particular, is extensively utilized in demanding loading conditions due to its chemical stability, mechanical friction resistance, high thermal corrosion resistance, and high stability [7].
Research on Monel 400™ and other nickel-based alloys has noted their significance in diverse applications due to superior mechanical properties and high corrosion resistance. Traditional manufacturing processes struggle with these materials due to their affinity to rapid work hardening and poor thermal conductivity. Plasma arc cutting has proven effective for cutting sheet metals with intricate profiles from these challenging materials [20].
Studies on Inconel 625 alloy using plasma arc machining have noted that factors like burr height, kerf ratio, and material removal rate significantly influence performance and quality of plasma cut surfaces. Research has focused on the effect of PAC parameters such as gases used, cutting speed, current, arc voltage, and gas pressure on cut quality characteristics [21].

4.2 Steel Alloys

Various steel alloys have been extensively studied in PAC research. Experimental investigations have examined the influence of laser beam and plasma arc cutting parameters on edge quality across a range of steel grades and thicknesses. Based on experimental results, researchers have analyzed how cutting parameters affect quality and mechanical properties of cut edges on high-strength low-alloy (HSLA) strips and plates [22].
Research on structural steel S235JR has found that optimized parameters enable the obtainment of cut surfaces representing quality class I in accordance with the ISO 9013 standard, while surfaces processed using maximum cutting rates represented quality class II [12]. Studies on Hardox 400, an abrasion and wear-resistant steel plate with a hardness of 400 HBW intended for high-demand abrasion and wear applications, have utilized non-conventional cutting methods to avoid defects that occur with conventional cutting. Such research has evaluated cutting parameters for Hardox 400 using plasma arc cutting technology [14].
Work on Mild Steel E350 grade sheets has analyzed process parameters influencing cut quality in terms of bevel angle. Parameters like current, cutting speed, and arc gap have been identified as important factors, with cutting speed exerting the most significant influence (62.18% contribution to bevel angle variation) [2].

4.3 Aluminum Alloys

Aluminum alloys present unique challenges for PAC due to their high thermal conductivity. Aluminum is recognized as a highly thermally conductive and sensitive material, leading to uncertainties in defining process parameters that produce optimal cut quality. Comprehensive analysis of process responses and defining optimal cutting conditions are therefore necessary [17].
Research has noted that plasma arc cutting has emerged as a versatile and efficient method for precision cutting of materials including commercial-grade aluminum plates. Optimization of process parameters is crucial for achieving high-quality cuts, minimizing material wastage, and enhancing overall productivity [8]. Studies at companies like

CV Kurnia Abadi CNC Plasma Cutting, engaged in CNC plasma cutting based metal cutting services, have addressed quality issues in cutting aluminum [9].
ANOVA analyses have identified that arc current is the most significant parameter affecting surface roughness in aluminum cutting, while material thickness is the most significant parameter affecting burr height. Interestingly, no parameters were found to be significant in altering material removal rate [8].

4.4 Copper and Other Materials

Copper presents its own set of challenges in PAC. Research has investigated the influence of cutting feed rate on hardness and microstructure of copper machined using plasma arc, examining changes and their impact on cut surface quality. Studies have employed various constant cutting feed rates and amperage values as parameters to measure cutting performance, with pre- and post-cut hardness measurements and scanning electron microscope (SEM) images for analysis [23].
Findings have indicated that the hardness of copper surfaces remains unchanged before and after plasma arc cutting. PAC does not affect copper's hardness or the microstructure of the thermally affected cutting zone. While the copper from the cut surface is melted by the plasma arc operation near the edge, no change in microstructure occurs, and the quality of the cutting surface remains unaffected [23].
Similar results were found in studies on 1 mm thickness copper plates, where hardness measurements before and after cutting showed minimal differences that could be neglected. The quality of the cutting surface was not affected, and the microstructure of the thermally affected cutting zone of copper was not altered after PAC [24].

5. Optimization Approaches for Enhancing Cut Quality

Researchers have employed various optimization techniques to enhance cutting quality in plasma arc machining. These approaches range from statistical methods to advanced computational techniques.

5.1 Taguchi Method and Design of Experiments

The Taguchi method has been widely employed for parameter optimization in PAC. Research has focused on finding optimal process parameter combinations for plasma arc cutting systems, examining how parameters like cutting speed, arc current, and torch standoff distance affect response variables such as material removal rate and kerf width. Taguchi's L9 orthogonal array has been utilized as a design of experiments approach, with data analyzed through Analysis of Mean (ANOM) and Signal to Noise graphical approaches [15].
Studies on mild steel have utilized Taguchi Design of Experiments with analysis performed using Minitab software. After conducting Analysis of Means (ANOM), researchers have identified optimum parameters, determined percentage contributions of parameters on the bevel angle using Analysis of Variance (ANOVA), computed regression equations, and generated surface plots to understand parameter interactions [2].
Research on Inconel 625 alloy has employed design of experiments techniques to develop Taguchi designs with L18 orthogonal arrays. Grey relational analysis has been used for optimization of cutting conditions, leading to the identification of the most suitable gas and optimal PAC parameters [21].

5.2 Response Surface Methodology

Response Surface Methodology (RSM) has proven effective for optimization in PAC. Studies have focused on intelligent modelling of the PAC process and investigation of multi-quality characteristics using approaches like fuzzy logic. Box-Behnken response surface methodology has been incorporated to design and conduct experiments, establishing relationships between PAC parameters (cutting speed, gas pressure, arc current, stand-off distance) and responses (material removal rate, kerf taper, heat affected zone). Quadratic regression models have been developed and assessed using analysis of variance [20].

Research on aluminum EN AW-5083 has employed a novel hybrid approach combining response surface methodology with desirability analysis to model relations between input parameters and process responses and to conduct optimization. Prediction accuracy of regression models has been verified by comparing experimental and predicted data, while ANOVA has been used to check the significance of process parameters and their interactions. Desirability analysis has proven effective for multi-response optimization and defining optimal cutting areas [17].
Studies on D3 tool steel have applied RSM for optimization of plasma arc cutting parameters, focusing on gas pressure, arc current, and cutting speed to maximize material removal rate. ANOVA has been used to evaluate the contribution of each parameter to the response [25].

5.3 Multi-Objective Optimization Techniques

Multi-objective optimization has addressed the complexity of simultaneously optimizing multiple quality metrics in PAC. Research has noted that plasma arc machining parameter optimization is a typical multi-objective problem, with surface roughness, kerf ratio, and material removal rate serving as evaluation targets, while parameters like arc voltage, standoff distance, cutting speed, and plasma offset serve as inputs. The employment of rational multi-objective approaches is considered crucial for parameter optimization [26].

Studies on SS 304 alloy have utilized probabilistic multi-objective optimization for parameter design based on L18 orthogonal arrays. This approach has identified optimal parameters for different nozzle types, such as arc voltage at 136V, cutting speed of 2000mm/min, standoff distance of 2mm, and plasma offset of 2.25mm for a 130A nozzle [26].

Research using cryogenically treated nozzles has employed grey relational analysis to find optimal machining settings. This approach has identified parameters such as 6 bar of gas pressure, 120 amperes of arc current, and 1800 mm/min cutting speed as optimal for cryogenically treated nozzles, resulting in reduced surface roughness and kerf width [27].

6. Equipment Design and Technological Advancements

Beyond process parameters, equipment design significantly influences cutting quality in plasma arc machining.

6.1 Torch Design and Components

Torch design plays a crucial role in determining cutting quality. Studies using optical interferometry and metallographic analysis have examined the structure of cutting seams obtained after steel cutting with plasma torches featuring various design elements in the gas-dynamic stabilization system. Research has demonstrated that new plasma torch designs can achieve higher quality and lower energy costs when cutting medium-thick steel [28].

Investigations have shown that using additional methods of gas-dynamic stabilization in plasma torches (such as feed symmetry with a double swirl system of plasma-forming gas) can achieve advantages in terms of surface quality [28]. Research has demonstrated how the inner geometry of the torch can affect cut quality, noting that one side of the kerf is typically much more oblique and sensitive to factor variations than the other. Theories based on computational fluid dynamics models have been proposed to investigate the causes of these phenomena [29].

6.2 Nozzle Treatments and Materials

Innovative approaches to nozzle treatments have shown promise for improving cutting quality. Research has investigated wear analysis in relation to cryogenically treated nozzles used in plasma arc machining. Key output characteristics like kerf width and surface roughness have been examined while machining S235 steel, along with the impact of nozzle treatment on quality metrics. Experiments have involved cryogenic treatment of nozzle material using liquid nitrogen at -194°C to increase nozzle life [27].

Studies have demonstrated that cryogenic treatment can reduce surface roughness by 0.4670 µm and narrow kerf width by 0.96 mm. SEM analysis has confirmed that thermal distortion and wear in the nozzle tip area are minimized to a greater extent in treated nozzles compared to untreated ones [27].

7. Limitations and Future Research Directions

Despite significant advances in plasma arc machining, several limitations and research gaps remain.

7.1 Current Limitations

PAC still faces challenges in achieving the precision offered by some alternative methods. Comparative studies have noted that plasma arc cutting produces a 1-3° vertical inclination (conicity) on the cut surface, while this inclination is almost non-existent in laser cutting [19]. Research has concluded that while PAC provides acceptable machining quality and excellent material removal efficiency, it is not suitable for final machining due to metallurgical variations in the heat affected zone [3].

During the cutting procedure, material properties such as high quality, corrosion resistance, and heat refusal can cause processing issues including surface roughness, machining efficiency, and tool wear [7]. Problems in plasma arc machining include large burr formation due to heat, resulting in surface roughness on the workpiece [11].

7.2 Future Research Directions

Several promising directions for future research can be identified:

Advanced modelling approaches: Research using fuzzy logic and other modelling approaches has shown promise, with comparative evaluations predicting very low average errors (0.04% for MRR, 0.48% for KT, and 0.46% for HAZ). Further refinement of these modelling techniques could improve prediction accuracy [20].

Integration of artificial intelligence: Building on current modelling approaches, machine learning and AI could enhance parameter optimization and quality prediction.

Novel materials and specialized applications: As new materials like Inconel 718 find expanded applications, more research is needed to address specific cutting challenges these materials present [7].

Equipment innovations: Research has shown that new plasma torch designs can achieve higher quality and lower energy costs. Further innovations in equipment design could address current limitations [28].

Sustainability considerations: Recent reviews have noted that minimization of energy consumption in thermal-based non-conventional machining methods is not extensively studied, suggesting an important area for future research [30].

8. Conclusion

This literature review has examined experimental approaches to analyzing cutting quality in plasma arc machining, highlighting the complex interplay between process parameters, material properties, equipment design, and quality outcomes. The reviewed research demonstrates that PAC has established itself as a versatile and effective method for cutting a wide range of conductive materials, particularly when dealing with hard-to-machine materials or complex profiles.

Key process parameters including arc current, cutting speed, gas pressure, and stand-off distance have been extensively studied across various materials, with researchers consistently finding that these parameters significantly influence quality metrics such as kerf width, surface roughness, heat affected zone, and dross formation. The relative importance of these parameters varies by material and application, underscoring the need for material-specific optimization approaches.

Optimization techniques ranging from Taguchi method and response surface methodology to multi-objective optimization have proven effective for enhancing cutting quality. Equipment innovations, particularly in torch design and nozzle treatments, represent promising avenues for further quality improvements. Despite these advances, limitations persist in terms of precision and metallurgical effects, pointing to opportunities for continued research and development.

As industrial demands for precision cutting of advanced materials continue to grow, the ongoing refinement of plasma arc machining through experimental analysis will remain essential for expanding its capabilities and applications.

References

1. Asmael, M.B.A, Çınar, Z., and Zeeshan, Q.. 2018. "Developments in Plasma Arc Cutting (PAC) of Steel Alloys: A Review". Jurnal Kejuruteraan. https://doi.org/10.17576/JKUKM-2018-30(1)-02
2. Raju, D.. 2016. "Optimization of Process Parameters of Plasma Arc Cutting Using Taguchi's Robust Design Methodology". IOSR Journal of Mechanical and Civil Engineering. https://doi.org/10.9790/1684-1605303124128
3. Gostimirović, Marin, Rodić, D., Sekulić, M., and Aleksić, Andjelko. 2020. "An Experimental Analysis of Cutting Quality in Plasma Arc Machining". Advanced Technologies & Materials. https://doi.org/10.24867/atm-2020-1-001
4. Kaushik, Surya Vatsal. 2022. "Analysis of Process Parameters of Plasma Arc Cutting Using Design of Experiment". Journal of University of Shanghai for Science and Technology. https://doi.org/10.51201/jusst/22/0264
5. Azlan, Ira Fatin, Ismail, Mohd Idris Shah, and Samin, R.. 2024. "ANALYSIS OF PROCESS PARAMETERS ON SPATTER AND DROSS IN PLASMA ARC CUTTING". International Journal of Modern Manufacturing Technologies. https://doi.org/10.54684/ijmmt.2024.16.3.68
6. Magid, H. M.. 2021. "Experimental study of mild steel cutting process by using the plasma arc method". Journal of Achievements of Materials and Manufacturing Engineering. https://doi.org/10.5604/01.3001.0015.5066

7. Karthick, M., Anand, P., Meikandan, M., Sekar, S., Natrayan, L., and Bobe, Ketema. 2022. "Optimization of Plasma Arc Cutting Parameters on Machining of Inconel 718 Superalloy". Journal of nanomaterials. https://doi.org/10.1155/2022/7181075
8. Choudhury, M., Dutta, H., Deka, Utpal, Bhavani, B., Saxena, K., and Borah, Anil. 2024. "Optimization of process parameters in plasma arc cutting of commercial-grade aluminium plate". High Temperature Materials and Processes. https://doi.org/10.1515/htmp-2022-0329
9. Hamid, A.. 2019. "OPTIMIZATION OF PROCESS PARAMETERS AND QUALITY RESULTS USING PLASMA ARC CUTTING IN ALUMINUM ALLOY". Journal of Engineering and Management in Industrial System. https://doi.org/10.21776/UB.JEMIS.2019.007.01.2
10. Zeid, Abdulrahman Abu. 2020. "Investigating the Effect of cutting Speed on Roughness & Quality of the Cutting Surface Edge of 1 mm Copper Sheets Using Plasma Arc". International Design Journal. https://doi.org/10.21608/IDJ.2020.113241
11. Ahmaddani, Restiawan and Dwijayanti, Khusna. 2024. "Design of Experiment for Determining Setting Parameter on Plasma Arc Machining for Stainless Steel Plate Cutting with Full Factorial Design". Key Engineering Materials. https://doi.org/10.4028/p-BXul3C
12. Górka, J.. 2023. "The effect of air plasma cutting on the quality, structural transformations and changes in the chemical composition of structural steel". Archives of Civil and Mechanical Engineering. https://doi.org/10.1007/s43452-023-00763-y
13. Pandya, Dakshesh M.. 2019. "A Review Paper on Study and optimization of Process Parameter in Plasma arc Cutting". International Journal for Research in Applied Science and Engineering Technology. https://doi.org/10.22214/IJRASET.2019.1087
14. A.Afifi, Sarah, M.Koura, Omar, Tawfik, M., and S.Mohammed, Samah. 2021. "Experimental Study of Cutting Steel Hardox400 Using Plasma Arc Cutting". Engineering Research Journal - Faculty of Engineering (Shoubra). https://doi.org/10.21608/erjsh.2021.227960
15. Mittal, Shubham and Mahajan, M.. 2018. "Multi-Response Parameter Optimization of CNC Plasma Arc Machining Using Taguchi Methodology". Industrial Engineering Journal. https://doi.org/10.26488/IEJ.11.12.1153
16. Kim, Dong-Hyun, Cho, Dae-Won, Jo, Yeong-Kwan, Suh, J., Choi, Kwang-Deok, Kim, R., and Ahn, Seokyoung. 2021. "Characteristic Analysis of Double Arcing on the Top Surface of STS304 in Plasma Arc Piercing". Journal of Welding and Joining. https://doi.org/10.5781/jwj.2021.39.4.11
17. Peko, Ivan, Marić, D., Nedić, B., and Samardzic, I.. 2021. "Modeling and Optimization of Cut Quality Responses in Plasma Jet Cutting of Aluminium Alloy EN AW-5083". Materials. https://doi.org/10.3390/ma14195559
18. Hırtıslı, Şerafettin and Erdem, Oğuz. 2024. "Investigation of cutting qualities of AISI304 stainless steel using plasma arc cutting method". European Mechanical Science. https://doi.org/10.26701/ems.1573836
19. Irsel, G. and Güzey, B. N.. 2021. "Comparison of laser beam, oxygen and plasma arc cutting methods in terms of their advantages and disadvantages in cutting structural steels". Journal of Physics: Conference Series. https://doi.org/10.1088/1742-6596/2130/1/012022
20. Devaraj, Rajamani, Nasr, Emad S. Abouel, Esakki, B., Kasi, Ananthakumar, and Mohamed, Hussein. 2020. "Prediction and Analysis of Multi-Response Characteristics on Plasma Arc Cutting of Monel 400™ Alloy Using Mamdani-Fuzzy Logic System and Sensitivity Analysis". Materials. https://doi.org/10.3390/ma13163558
21. Pothur, Hema, Ganesan, Ramprasad, and Aruna, K.. 2020. "Experimental Investigations on Inconel 625 Alloy Using Plasma Arc Machining". International Journal of Manufacturing, Materials, and Mechanical Engineering. https://doi.org/10.4018/ijmmme.2020100104
22. Klimpel, A., Cholewa, W., Bannister, A., Luksa, K., Przystałka, P., Rogala, T., Skupnik, Damian, Cicero, S., and Martín-Meizoso, A.. 2017. "Experimental investigations of the influence of laser beam and plasma arc cutting parameters on edge quality of high-strength low-alloy (HSLA) strips and plates". The International Journal of Advanced Manufacturing Technology. https://doi.org/10.1007/s00170-017-0119-2
23. Abouzaid, Abdelrahman and Mousa, S.. 2023. "Influence of the Cutting Feed Rate on the Hardness and Microstructure of Copper Using Plasma Arc Machining (PAM)". Metals. https://doi.org/10.3390/met13020208

24. Abouzaid, Abdelrahman and Aly, O.. 2023. "Effect of The Cutting Speed on Hardness and Micro-structure of Copper Using Plasm Arc Machining (PAM)". International Design Journal. https://doi.org/10.21608/idj.2023.226245.1087
25. Venkatesan, S., Mohan, P., Kumar, T. Ranjith, and Artralarasan, E.. 2019. "Experimental Investigation and Optimisation of Treatment Parameters in Plasma Arc Cutting of D3 Tool Steel by Response Surface Modification". Social Science Research Network. https://doi.org/10.2139/ssrn.3430314
26. Zheng, M. and Yu, Jie. 2023. "Parameter Optimization Design of Plasma Arc Machining SS 304 Alloy by Means of Probabilistic Multi – objective Optimization". Materials Plus. https://doi.org/10.37256/mp.2220233132
27. Senthilkumar, N., Jayaprakash, G., Nagaprasad, N., and Ramaswamy, K.. 2023. "Effect of the Cryogenically Treated Copper Nozzle Used in Plasma Arc Machining of S235 Steel". Advances in Materials Science and Engineering. https://doi.org/10.1155/2023/1189042
28. Anakhov, S., Guzanov, B., Matushkin, A., Pugacheva, N., and Pykin, Y.. 2020. "Influence of Plasma Torch Design on Cutting Quality during Precision Air-Plasma Cutting of Metal". Steel in translation. https://doi.org/10.3103/S096709122003002X
29. Chabert, S., Gonzalez, J. J., and Freton, P.. 2023. "Plasma Arc Cutting - Reversed Swirl Ring, Electrode Thread and Cut Direction Effects on Kerf Geometry". Plasma Physics and Technology. https://doi.org/10.14311/ppt.2023.1.1
30. Sawdatkar, Pankaj, Parmar, Vinod, and Singh, Dilpreet. 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. https://doi.org/10.1080/10426914.2024.2362620