Çukurova Üniversitesi Mühendislik Fakültesi Dergisi, 39(1), ss. 261-269, Mart 2024
Cukurova University Journal of the Faculty of Engineering, 39(1), pp. 261-269, March 2024

Vaporizing Foil Actuator Welding Arc Problems and Precautions

Ganime Tuğba ÖNDER[*1] ORCID *0000-0002-7504-7394*
Mustafa Kemal KÜLEKCİ[2] ORCID *0000-0002-5829-3489*

[1]Çukurova University, Adana Vocational School, Department of Electricity and Energy, Air Conditioning and Refrigeration Technology Program, Adana, Turkiye
[2]Tarsus University, Faculty of Engineering, Department of Mechanical Engineering, Mersin, Turkiye

Geliş tarihi: 26.07.2023 *Kabul tarihi: 28.03.2024*

Atıf şekli/ How to cite: ÖNDER, G.T., KÜLEKCİ, M.K., (2024). Vaporizing Foil Actuator Welding Arc Problems and Precautions. Cukurova University, Journal of the Faculty of Engineering, 39(1), 261-269.

Abstract

The management of the "arc" has an important place in welding methods made with electric discharge and in cases where the arc is not managed correctly, important technical and environmental problems may occur. Vaporizing foil actuator welding (VFAW) is a novel welding method developed particularly for joining metals and operates on the principle of electrical discharge. This study describes the welding prototype of vaporizing foil actuator welding and outlines technical changes made during the increase in energy levels. The locations, causes, preventive interventions, and solution proposals for arc problems occurring during the welding process are addressed. Welding operations must be carried out safely and comprehensively. Alongside the welding method, potential safety issues should be identified. Necessary precautions must be taken before, during, and after welding. The safety of the welding method can be ensured by eliminating specific risks.

Keywords: Solid state welding, Vaporizing foil actuator welding, Arc, Welding safety

Buharlaştırılmış Folyo Aktüatör Kaynağı Ark Problemleri ve Önlemleri

Öz

Elektrik deşarjı ile yapılan kaynak metotlarında "ark"ın yönetilmesi önemli bir yere sahiptir ve ark doğru yönetilemediği durumlarda önemli teknik ve çevresel problemler meydana gelmektedir. Buharlaştırılmış folyo aktüatör kaynağı, özellikle metallerin birleştirilmesi için geliştirilmiş yeni bir kaynak yöntemidir ve elektrik deşarjı prensibi ile çalışır. Bu çalışmada, imal edilen buharlaştırılmış folyo aktüatör kaynağının, kaynak prototipi anlatılmakta ve enerji seviyesinde artırıma gidilirken yapılan teknik değişiklikler ortaya konulmaktadır. Kaynak yöntemi uygulanırken meydana gelen ark problemlerinin yerlerine, nedenlerine, önleyici müdahalelere ve çözüm önerilerine yer verilmiştir. Bir kaynak işlemi gerçekleştirilirken güvenle yapılması ve bütüncül olarak ele alınması gerekmektedir. Kaynak yöntemi ile beraber, güvenlik problemlerinin hangi noktalarda oluşabileceği ortaya konulmalıdır. Gereken tedbirler kaynak öncesi,

[*]Sorumlu yazar (Corresponding Author): Ganime Tuğba ÖNDER, *gercoskun@cu.edu.tr*

kaynak sırasında ve kaynak sonrasında mutlaka alınmalıdır. Kaynak yönteminin güvenliği, belirli risklerin ortadan kaldırılması ile mümkün kılınabilir.

Anahtar Kelimeler: Katı hal kaynağı, Buharlaştırılmış folyo aktüatör kaynağı, Ark, Kaynak güvenliği

1. INTRODUCTION

An electric arc occurs when current flows between two conductors, this is especially observed when metals form a short gap [1,2]. A short electrical pulse and simultaneous application of pressure cause high-speed deformation of the contact zone [3]. Magnetic Pulse Welding (MPW) technologies, can create a shaping in the weld area, as well as cause undesirable deformations in a manufacturing process that cannot be carried out correctly.

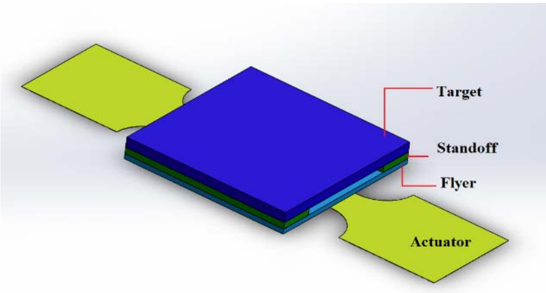

Figure 1. VFAW Basic System Components

Vaporizing foil actuator welding (VFAW) is a new solid-state welding technology making uses the impulse created by the vaporization of the metallic foil or wire by the passage of a high current [4-6]. It belongs to the magnetic pulse source family [7,8]. In this process, an aluminum foil is placed over the flyer sheet to generate the kinetic energy for impact. A pulse of electric current generated by a capacitor bank is applied to the foil. As a result, the active region of the foil evaporates rapidly and the resulting expanding gas hurls the flyer toward the target plate at high speed [9,10]. VFA technology is used to join metals such as Al–Fe, Al–Mg, Al–Cu, Al–Ti and has an open horizon [5,11-14]. Figure 1 shows the basic application stack for the VFAW technique. Each superimposed element also creates the basic system parameters for VFAW.

It is impossible to completely prevent arcing in electrical systems. However, with precise identification of all elements of the system and operating conditions, it can be minimized or kept within a safe range. This study aims to make a welding machine prototype to realize VFAW, a new welding technique in the manufacturing field, and to contribute to the technique through this prototype.

For this, possible locations of arc problems, which is an important event on the prototype, were determined and preventive suggestions were made.

2. EXPERIMENTAL METHOD

In the present study, 0.1 mm thick high-purity aluminum alloy and 0.7 mm thick 1050 aluminum alloy were selected as weld metals. Samples measuring 50 mm x 50 mm for both flyer and target were sanded, cleaned with acetone, and dried before welding. The material used as a standoff is two support elements measuring 10 mm x 50 mm.

A three-phase power unit is used to convert AC current to DC current and transfer energy to a capacitor bank called a capacitor module. Gradual charging is based on the capacitors in order to avoid damage and to have a longer life. Pneumatic switches are switches and fasteners used to convert pneumatic energy into mechanical energy. There are two pistons on the system, these elements are remotely controlled by means of a directional control valve. Pneumatic power was provided by a 2.5 HP-8 bar air compressor. To control the discharge process between the capacitor bank of a double-acting pneumatic piston with a diameter of 40 mm and a stroke length of 300 mm and the fixture terminals (piston 1); On the other hand, the pneumatic piston (piston 2) with a stroke length of 25 diameters 100 mm was used to control the process of directing the energy remaining on the system to the grounding line after the welding process. Capacitors are connected to the grounding line via the second pneumatic switch after discharge (Figure 2).

The fixture is a protection and support zone that holds the basic system elements together. It also minimizes workpiece deformation due to clamping and cutting forces [15]. Fixtures have been specially designed and manufactured for this study. While designing the fixture, attention was paid to allowing different sizes of materials to be welded and to remain balanced on the pedestal. Here, a preliminary design suitable for the welding method, geometric and strength analysis, project design, and then manufacturing comes [16-18].

In order to protect the welding process, system elements, welding personnel, and the environment from dangerous voltages, grounding is performed. This stage is one of the most important steps for the operation of electrical systems [19,20].

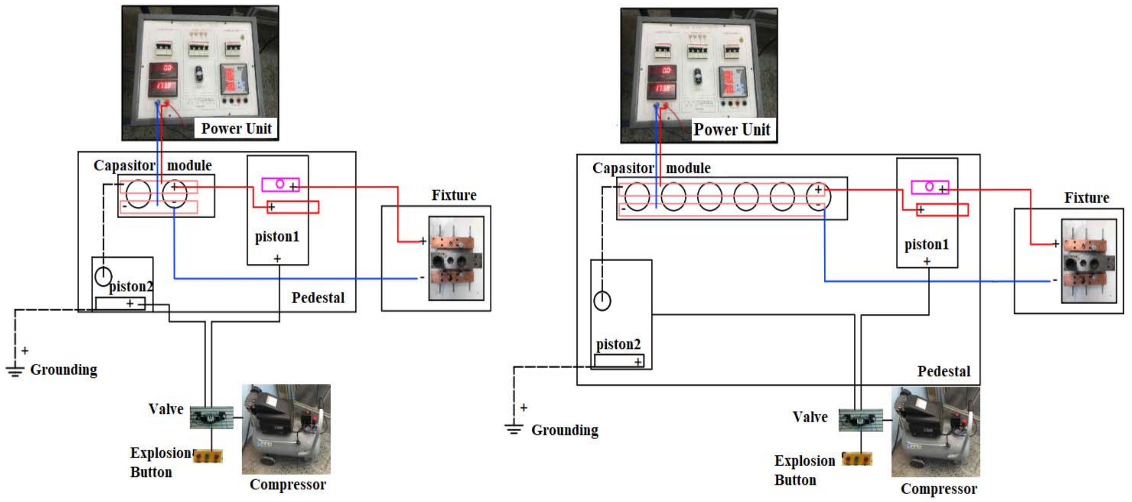

Figure 2. Reinforcement of the VFAW prototype

Table 1. Capacitor specifications

Capacitor	R	L	C	Nominal short circuit current rise time (us)	Max charge voltage (kV)	Max charge energy (kJ)
	Impedance (Ω)	Internal inductance (H)	Capacitance (F)			
	0.01	0.00000002	0.010	6.55	0.045	1.0125

The number of capacitors has been increased in order to increase the efficiency of the aluminum foil used as the actuator on the materials to perform the welding and to work in a wider range. By adding 4 more DC capacitors, which were used 2 at the beginning, the number was increased to 6, thus strengthening the input energy conditions of the welding prototype (Figure 2). The characteristics of the capacitors used during the experiments are given in Table 1.

Metal samples were welded at variable power settings at an energy input ranging between 2 kJ and 6 kJ. Welded samples were examined in SEM analysis.

3. RESULTS AND DISCUSSIONS

An arc can occur when one piece of metal collides with or makes electrical contact with another. Arc problems that may occur during applications include negative aspects for all components, especially welding metals and capacitors, as well as for the environment. Due to arc formation and splashes, the entire system and its physical environment should be kept at a safe distance, and materials (cloth, plastic, chemical liquids, cleaning fluids, oil, cleaning cotton/cloths, etc.) that are at risk of burning and explosion should never be kept in the same environment as the test area. Both capacitors and all other components carrying electricity should be physically and electrically avoided.

As a result of the risk analysis, it is clear that the VFAW technique is in the dangerous risk group, especially due to electrical phenomena [21]. At the point where an arc occurs, it causes both energy loss and material damage and burning. For this reason, arc formation is an undesirable and problematic situation in the VFAW process [22]. The measure taken for each port is different from the other. Below are the six regions where arcing occurs most frequently on the prototype created for VFAW, and the causes, preventive interventions, and solution suggestions for these situations. These regions will be detailed over the technical changes made when the number of capacitors is increased from two to six

Figure 3. 1st Arc-Zone

The 1st region; these are the connection points of the capacitor + and – terminals with the copper busbar. It is important that the detachable connection is not loose in the use of screws and washers that connect the capacitor terminals with the busbar. It is necessary to pay attention to the fact that the connection points are properly tightened so as not to cause arcing [23,24].

The copper busbars, which are 20 mm x 3 mm for two 450 V capacitors on the prototype (Figure 3a), which collect and distribute the electrical energy, are strengthened with 40 mm x 4 mm wide and thick copper bars (Figure 3b) when the number of capacitors is increased to 6. The strengthening process should be done according to the current carrying capacity of copper busbars. In addition, a plastic insulation material is used vertically in order to solve the arc jump problem between the + - terminals that are close to each other (Figure 3b). The + and - terminals, which are in the case of two conductor ends, the electric current transition that occurs spontaneously with the ionization of the air, is thus prevented.

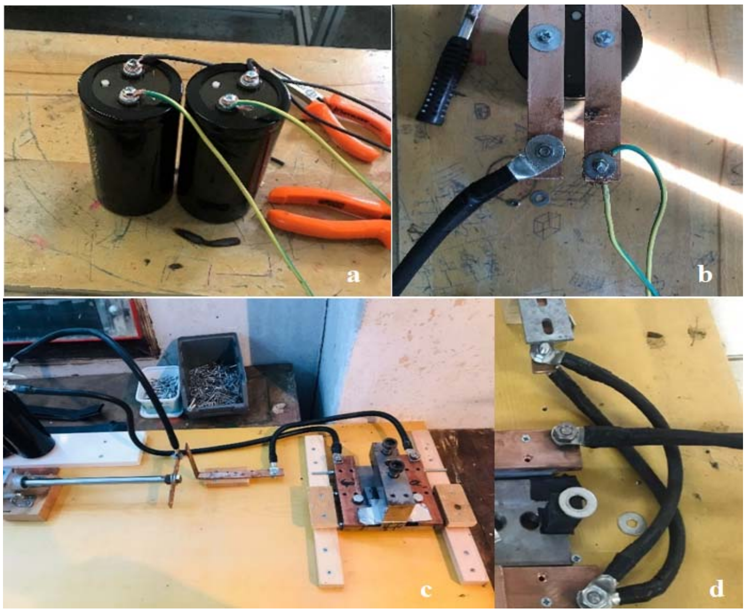

Figure 4. 2nd Arc-Zone

The 2nd region; copper busbar and cable connection points. Thin-section transmission cables used for the two-capacitor prototype were replaced with thick voltage cables in the six-capacitor application (Figure 4a,b). In addition, the energy load carrying area has been increased by laying all single-line voltage cables in the copper busbar-terminal connection points in the double-line form. All connection points were checked more frequently to prevent dissolution (Figure 4c,d). Proper grounding on a system is critical for the safe and sound operation of the system [22,25,26]. The system and basic elements are secured by grounding.

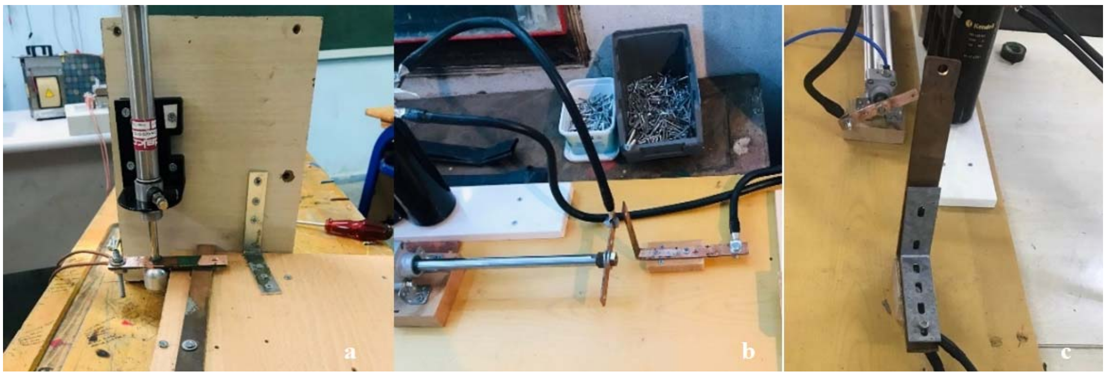

Figure 5. 3rd Arc-Zone

The 3rd region; is the switch connection between the movable copper busbar on the piston and the fixed busbar. The copper bar at this point has been replaced with a thick and wide one (Figure 5a,b). The fixed copper piece is protected from flexing during impact by an L-shaped support plate (Figure 5c). In addition, if there is a need for contact points between each experiment, they were mechanically leveled and the surface was cleaned with liquid chemicals to be free from the oxide layer [27-29].

Acetone was used for all surface cleaning processes. In this way, surface irregularities that may occur due to deformation are prevented from creating arcing problems.

The 4th region; is at the point where the foil inlets and outlets are in the fixture area. Here the distance from the terminal is made as protected as possible [30-33]. The importance of insulation is obvious during the experiments with both two capacitors and six capacitors. The tape used for this situation; should be usable in electrical and thermal insulation [6]. In order to protect the welding materials, which may be affected by the arc heat and the instantaneous pressure of the jet formed during VFAW, the insulating tape was used in a wider area not only between the fixtures (Figure 6a) but also in the area between the fixture and the copper terminals (Figure 6b).

The 5th region; is the distance between the fixture bodies and the copper bars. Here, the frontal surfaces of the fixtures, especially those facing the copper bars, should be protected with insulation tape (Figure 7). Especially since the efficiency increases at the voltage value where six capacitors are used, arc jump problems are more common. For this reason, distance and insulation are also important at these points.

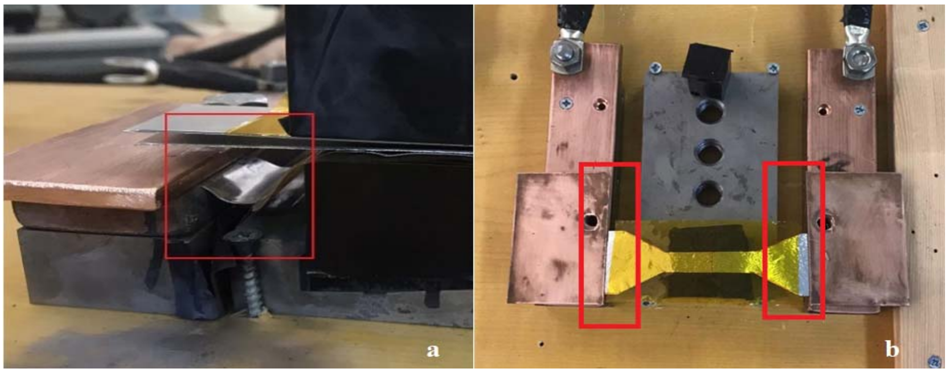

Figure 6. 4th Arc-Zone

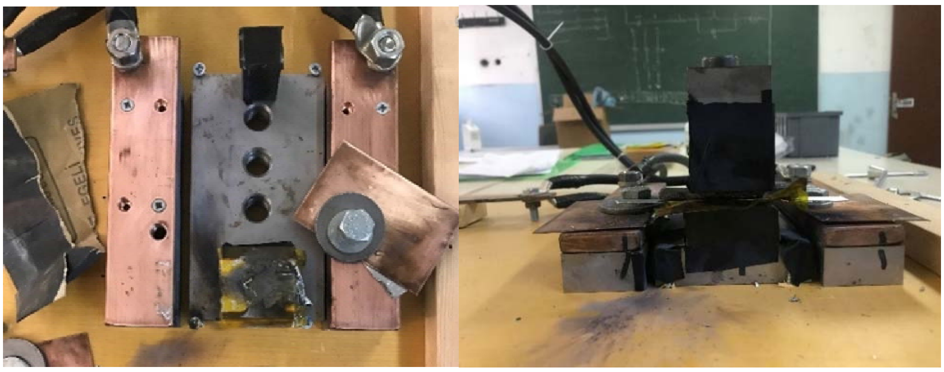

Figure 7. 5th Arc-Zone

The 6th zone; is the contact point of the foil actuator with the copper busbar. In this region, thin copper pressure plates have been replaced with thick ones to ensure full and gapless contact with the foil actuator (Figure 8). In this way, full contact with the aluminum foil, which is a thin conductor, can be ensured and arcing is prevented by creating a gap between the two metals during electrical energy transmission.

Figure 8. 6th Arc-Zone

4. CONCLUSION

Arc problems are inevitable if necessary precautions are not taken at the six arc points determined on the DC capacitor prototype manufactured to improve the VFAW welding technique. Each case was determined as a result of many trials on the prototype. In addition to the stated precautions of the six arc points, it is also important that all connections are dry and clean, and that the surface roughness, if any, is leveled in order to prevent arc problems. Surface roughness, which may occur during the energy transfer between the contact surfaces, will lead to the unexpected conclusion of the welding process. As with all welding technologies, it is essential to keep the entire system under surveillance before, during, and after the experiment.

All of the above-mentioned arrangements must be taken into account in order for the detonation event to occur in the active region on the foil actuator, which is the weakest point, as it should be. Otherwise, the discharge process will take place at the weakest point and this will damage the system components and the environment. In addition, it will cause the loss of stored energy and the deformation of consumables. Safe and accident-free welding is possible for VFAW. For this, all possible safety measures must be taken in a timely manner for each hardware and installation material.

5. ACKNOWLEDGEMENT

This study was supported within the scope of TÜBİTAK "1002-A Rapid Support Module" within the scope of the project numbered 222M455 and the project numbered INSTITU.21.001 of the Tarsus

University Scientific Research Projects (BAP) Coordination Unit.

6. REFERENCES

1. Ayrton, H.M., 2012. The Electric Arc, Cambridge University Press, ISBN 978-1-108-05268-9.
2. Kaymaz, Ö., 2014, Kaynak İşlerinde İş Kazası ve İşe Bağlı Sağlık Problemlerine Neden Olan Faktörler ve KKD Kullanımının Bu Faktörlere Etkileri Üzerine Çevresel ve Teknik Araştırma. İş Sağlığı ve Güvenliği Uzmanlık Tezi/Araştırma. T.C. Çalışma ve Sosyal Güvenlik Bakanlığı İş Sağlığı ve Güvenliği Genel Müdürlüğü, , 3, Ankara.
3. Grigoryev, E.G., 2011. High Voltage Electric Pulse Welding of Titanium with Stainless Steel. Machines, Technologies, Materials, 8, 8-10.
4. Vivek, A., Hansen, S.R., Liu, B.C., Daehn, G., 2013. Vaporizing Foil Actuator: A Tool for Collision Welding. Journal of Materials Processing Technology, 213, 2304-2311.
5. Su, S., Chen, S., Mao, Y., Xiao, J., Vivek, A., Daehn, G., 2019. Joining Aluminium Alloy 5A06 to Stainless Steel 321 by Vaporizing Foil Actuators Welding with an Interlayer. Metals, 9(1), 43.
6. Hahn, M., Weddeling, C., Taber, G., Vivek, A., Daehn, G. S., Tekkaya, A.E., 2016. Vaporizing Foil Actuator Welding As a Competing Technology yo Magnetic Pulse Welding. Journal of Materials Processing Technology, 230, 8-20.
7. Aizawa, T., Kashani, M., 2004. Magnetic Pulse Welding (MPW) Method for Dissimilar Sheet Metal Joints. 57th Annual Assembly of the International Institute of Welding (IIW), 8.
8. Sarvari, M., Abdollah-zadeh, A., Naffakh-Moosavy, H., Rahimi, A., 2019. Investigation of Collision Surfaces and Weld Interface in Magnetic Pulse Welding of Dissimilar Al/Cu Sheets. Journal of Manufacturing Processes, 45, 356-367.
9. Cheng, J., Hu, X., Sun, X., 2020. Molecular Dynamics Study on Interface Formation and Bond Strength of Impact-Welded Mg-Steel Joints. Computational Materials Science, 185.
10. Ren, D., Liu, L. 2014. Interface Microstructure and Mechanical Properties of Arc Spot Welding Mg–Steel Dissimilar Joint with Cu Interlayer. Materials & Design, 59, 369-376.
11. Liu, B., Vivek, A., Presley, M., Daehn, G., 2018. Dissimilar Impact Welding of 6111-T4, 5052-H32 Aluminum Alloys to 22MnB5, Dp980 Steels and the Structure–Property Relationship of a Strongly Bonded Interface. Metallurgical and Materials Transactions A, 49, 899-907.
12. Liu, B., Vivek, A., Daehn, G.S., 2017. Joining Sheet Aluminum AA6061-T4 to Cast Magnesium AM60B by Vaporizing Foil Actuator Welding: Input Energy, Interface and Strength. Journal of Manufacturing Processes 30, 75-82.
13. Nassiri, A., Zhang, S., Lee, T., Abke, T., Vivek, A., Kinsey, B., Daehn, G., 2017. Numerical Investigation of Cp-Ti & Cu110 Impact Welding Using Smoothed Particle Hydrodynamics and Arbitrary Lagrangian-Eulerian Methods. Journal of Manufacturing Processes, 28, 558-564.
14. Chen, S., Huo, X., Guo, C., Wei, X., Huang, J., Yang, J., Lin, S., 2019. Interfacial Characteristics of Ti/Al Joint by Vaporizing Foil Actuator Welding. Journal of Materials Processing Technology, 263, 73-81.
15. Pachbhai, S.S., Raut, L.P., 2014. A Review on Design of Fixtures. International Journal of Engineering Research and General Science, 2(2), 126-146.
16. Eker, B., Türker, M., Tosun, M., 2011. Kaynak Uygulamalarında Kullanılan Fikstür Tasarımında Göz Önüne Alınacak Ana Parametreler, Kaynak Teknolojisi VIII. Ulusal Kongre ve Sergisi, 6.
17. Zhang, Y., Mu, S., 2012. Study of Computer-Aided Design Process and Methods Based on Welding Fixture. Journal of Computers, 7(6), 1421-1428.
18. Kumar, K.S., Dharmaraj, M., Thangavel, P., Srikishore, K.A., Sudharsan, R., Vimal, M., 2021. A Critical Review on Fume Extraction System for Pipe and Plate Welding. In IOP Conference Series: Materials Science and Engineering, 1084(1), 012064.

19. Gürsu, B., İnce, M.C., 2007. Genetik Algoritmalar ile Yüksek Gerilim İstasyonlarında Optimum Topraklama Ağı Tasarımı. Fen ve Mühendislik Bilimleri Dergisi, Fırat Üniversitesi, 19(4), 511-524.
20. Şentürk, E., 2004. Geçici Rejimlerde Topraklama Sistemlerinin Performans Analizi. Doktora Tezi, Yıldız Teknik Üniversitesi, Fen Bilimleri Enstitüsü Elektirk Mühendisliği Anabilim Dalı, İstanbul, 242.
21. Önder, G.T., Külekci, M.K., 2023. Vaporizing Foil Actuator Welding Prototype Manufacturing and Applications Risk Analysis, Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 12(4), 1079-1091.
22. Mao, Y., Thurson, B., Li, J., Vivek, A., Daehn, G., 2020. High Strength Impact Welding of HSLA 340 to Al 5754 and Application Prototype. 9th International Conference on High Speed Forming, 13.
23. Raja, J., Ajay-D-Vimal Raj, P., Rajasekar, S., 2018. Best Practices in Operation and Maintenance of Distribution Substation Equipment and Auxiliaries. Practices in Power System Management in India, 77-107.
24. Matisoff, B., Matisoff, B., 1997. Standard Manufacturing Processes. Handbook of Electronics Manufacturing Engineering, 121-254.
25. Mishra, M., Patnaik, B., Biswal, M., Hasan, S., Bansal, R.C., 2022. A Systematic Review on DC-Microgrid Protection and Grounding Techniques: Issues, Challenges and Future Perspective. Applied Energy, 313, 118810.
26. Pourmirasghariyan, M., Zarei, S.F., Hamzeh, M., 2022. DC-System Grounding: Existing Strategies, Performance Analysis, Functional Characteristics, Technical Challenges, and Selection Criteria-A Review. Electric Power Systems Research, 206, 107769.
27. Kenéz, A.Z., Földes, T., Lublóy, É., 2023. Effect of Surface Cleaning on Seam Quality of Laser Beam Welded Mixed Joints, Case Studies in Construction Materials, 18, e01904.
28. Gaspar, P., Hubbard, C., McPhail, D., Cummings, A., 2003. A Topographical Assessment and Comparison of Conservation Cleaning Treatments. Journal of Cultural Heritage, 4, 294-302.
29. Kambham, K., Sangameswaran, S., Datar, S.R., Kura, B., 2007. Copper Slag: Optimization of Productivity and Consumption for Cleaner Production in Dry Abrasive Blasting. Journal of Cleaner Production, 15(5), 465-473.
30. Ecer, G.M., 1980. Magnetic Deflection of the Pulsed Current Welding Arc. Welding Journal, 59(6), 99-107.
31. Wenji, L., Liangyu, L., Jianfeng, Y., Peiyu, Y., Xiaohui, L., 2017. Research on the “Jump Sidewall” Behavior and its Signal Characteristics in Narrow Gap P-MAG Welding. The International Journal of Advanced Manufacturing Technology, 91, 1189-1196.
32. Kim, R.H., Choi, G.D., Kim, C.H., Cho, D.W., Na, S.J., 2012. Arc Characteristics in Pulse-GMA Welding with Acute Groove Angles, Weld. Journal, 91, 101-104.
33. Reis, R.P., Scotti, A., Norrish, J., Cuiuri, D., 2012. Investigation on Welding Arc Interruptions in the Presence of Magnetic Fields: Welding Current Influence. IEEE Transactions on Plasma Science, 40(3), 870-876.