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A Review Of Trend Advanced Welding Process And Welding Technology In Industries

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ABSTRACT

This paper reviewed on the current trend advanced welding process and technology used nowadays in various industries. It reveals on the importance of welding, classification of welding process and also selection and application of welding process in industries. Processes of fusion welding and solid-state welding have been discussed in this paper. Conventional welding process such as gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), resistance welding and friction welding are briefly explained. Advanced in welding technique and trend also have been highlighted such as plasma arc welding, laser beam welding, electron beam welding and ultrasonic welding. Main objective for welding process development were determined such as need to improve the total cost effectiveness, concerning over the safety and welding environment and also potential shortage of skilled operators. Advantages and disadvantages of advanced welding also been explained through others researcher discovered in their research

1.0 Introduction

Welding and joining are indispensable procedures in the fabrication of various engineering components, encompassing diverse structures like bridges, ships, buildings, intricate systems such as aircraft engines or miniature components, automotive parts, and micro-electronics applications. Joining techniques encompass welding, brazing, soldering, adhesive bonding, clinching, and mechanical fastening. These techniques constitute integral facets of manufacturing and assembly operations, allowing for the production of individual components that can be easily assembled, rendering the process more convenient and cost-effective. According to Kalpakjian (2001), there are three major categories of joining processes. There are mechanical fastening, adhesive bonding and welding. Mechanical fastening entails the use of standard fasteners such as bolts, nuts, and rivets. Adhesive bonding, as a distinct application, requires the achievement of strength, sealing, thermal and electrical insulation, vibration dampening, and corrosion resistance between dissimilar materials. The welding process encompasses fusion welding, brazing, soldering, and solid-state welding techniques.

Enhancing the cost-effectiveness of joining operations within the fabrication and manufacturing industries is the primary objective of welding process development. Additionally, considerations for safety and the welding environment must be considered. The scarcity of skilled welders and operators in numerous countries significantly influences the necessity for research exploration in this area. According to Norrish et al., the cost of labor, material, power, and reduced capital investment are factors associated with the production cost of a welded joint (Norrish, 2006). In western economies, the labor cost largely covers the total cost of welding operations, accounting for approximately 70% to 80% of the overall expenditure. The efficiency and cost-effectiveness of the welding process directly hinge on the deposition rate. A higher deposition rate results in shorter weld cycle times and reduced labor costs. However, it is important to note that the deposition rate alone can lead to a misleading assessment of effectiveness in terms of cost.

Enhancing the working environment and mitigating operator exposure to hazardous conditions are prominent objectives in the development of welding processes (Sindre et al., 2017). Standard safety measures include the provision of protective clothing, local screening, and effective ventilation. Traditional welding processes demand a high level of operator proficiency, often necessitating substantial training expenses. However, the adoption of newer processes, which incorporate more versatile equipment, can potentially alleviate the skill requirements. Consequently, the investment in training costs can be swiftly offset through heightened productivity and improved quality outcomes.

2.0 Welding Process

There are significant different welding processes have been developed, to be simplified it can be classified in two groups which are fusion and solid-state welding (Figure 1). Fusion welding is described as the melting and connecting of materials using heat. During the welding operation, filler metals were added to the weld region.

Gas welding is grouped under fusion welding. The oxygen-acetylene welding process is the most important in gas welding. It can be used to joint several metals. In this particular process, the liquid air boiled and pure liquid oxygen is left when nitrogen and argon escape. The gas is compressed in cylinder at pressure about 15MPa. Thus, this welding procedure is suitable for practically any workpiece thickness and may be utilized with most ferrous and nonferrous metals.

In addition to that, Gas Metal Arc Welding (GMAW) emerges as a favorable process due to its high productivity and commendable quality. This technique, originating in the mid-1800s, involves the application of a transient heat source to heat, melt, and solidify metals and filler material within a limited fusion zone, facilitating the creation of joints between parent metals (Ibrahim et al., 2012). The quality, productivity, and cost of welding joints are influenced by various factors. Welding parameters, such as arc current, arc voltage, welding speed, torch angle, free wire length, nozzle distance, welding position, and direction, must adhere to specified requirements to establish an optimal arc and achieve superior welding quality.

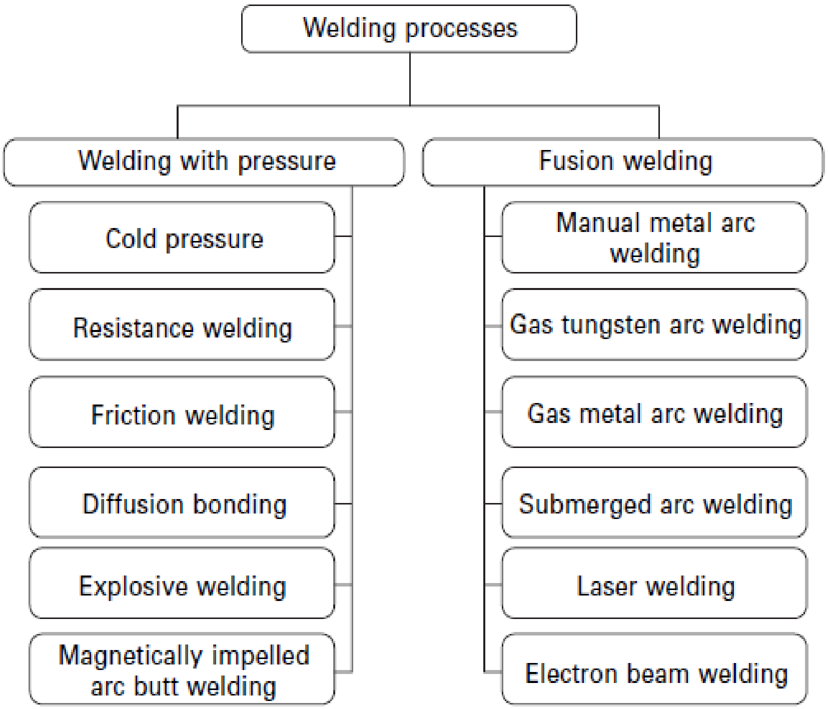

Figure 1: Classification of welding processes *(Norrish, 2006)*.

Shielded metal arc welding (SMAW), alternatively referred to as manual metal arc welding (MMA), stands as a time-honored fusion welding technique that holds its place as one of the oldest welding technologies. It is not only widely practiced but also regarded as one of the simplest and most versatile joining processes. The electrical energy necessary for welding is generated by establishing an arc through the controlled contact of a coated electrode with the workpiece, followed by promptly retracting it to a suitable distance. Because of its portable fuel-powered generator that can be readily utilized and flexible in distant areas, SMAW is often used in general construction, ship building, pipeline, and maintenance work.

Besides, Gas tungsten arc welding (GTAW), commonly known as TIG welding, falls within the category of fusion welding techniques. This process utilizes a non-consumable tungsten electrode, while inert gases like argon or helium provide shielding. TIG welding offers the capability to join dissimilar metals, yielding welds of exceptional quality. It is particularly favored for welding aluminum and stainless-steel pipes. In a study conducted by *Lu et al. (2013)*, focusing on Cr13Ni5Mo martensitic stainless steel, it was observed that the TIG process offers greater precision due to independent control over arc heat and filler metal additions. However, it is worth noting that the TIG process tends to be relatively slow in terms of speed.

In other hand, welding with pressure have been classified under solid-state welding process (Figure 1). These include resistance welding, friction welding, diffusion bonding, cold pressure and various process. Resistance welding is a welding process that harnesses electrical resistance between two components to generate the necessary heat for welding. According to *Han et.al. (2010)* stated that in their research, resistance welding can produce high quality weld and can be produced rapidly. It also often applied using robots welding.

Friction stir welding (FSW) is classified as a solid-state welding technique, as depicted in Figure 2. This welding process is versatile, enabling the joining of a wide range of materials, including components with rotational symmetry. The heat required for welding is generated through friction at the interface between the two connected components in friction welding (Akinlabi et al. 2020) & (Uzkut et al., 2010). FSW has demonstrated effectiveness in joining challenging-to-weld metals, as well as plates of varying thicknesses and dissimilar materials (Muhammad. W et al., 2021). It is particularly favored for joining not only aluminum alloys (El-

Danaf et al., 2013) & (Sonne et al., 2013), but also other difficult-to-weld metals like magnesium alloys (Cao et al.,2011) & (Chowdhury et al., 2010), titanium alloys (Buffa et al., 2012) & (Kitamura et al., 2013), and metal-matrix composites (Bozkurt et al., 2011) & (Sharifitabar et al., 2011). This welding technology has gained widespread adoption across various industrial sectors, including maritime, aircraft, railway, land transportation, and more. FSW is a highly intricate process involving interconnected (non-linear) physical phenomena (Akinlabi et al. 2020) & (He et al.,2014). These phenomena encompass large plastic deformation, material flow, mechanical stirring, tool-workpiece surface interaction, dynamic structural evolution, and heat generation resulting from friction and plastic deformation. Several parameters, such as tool rotation speed, force, and distance, significantly influence the quality of FSW joints.

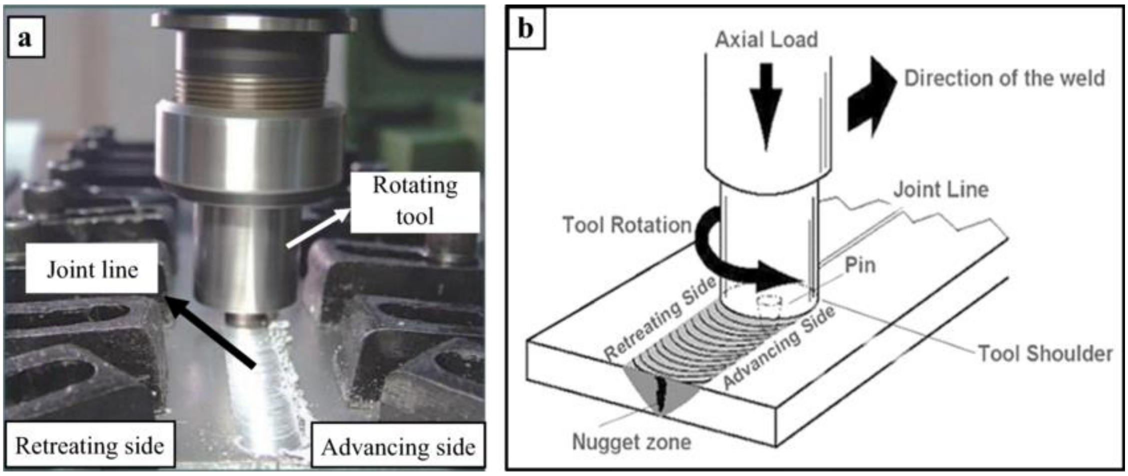

Figure 2: Friction stir welding setup; (a) Physical picture, and (b) Schematic diagram *(Muhammad. W et al.,2021)*.

3.0 Application of Advanced Welding Technology

The application of advanced welding technology continues to evolve rapidly, transforming various industries with its capabilities. In aerospace engineering, for example, advancements in welding technology such as electron beam welding and laser beam welding are being extensively utilized for the fabrication of critical components in aircraft structures. According to a recent study by Zhang et al. (2023), laser beam welding has demonstrated exceptional performance in joining lightweight materials like aluminum alloys and titanium, offering significant advantages in terms of weight reduction and structural integrity.

Similarly, in the automotive sector, the adoption of advanced welding techniques has become increasingly prevalent, particularly in the production of electric vehicles (EVs) with lightweight materials like aluminum and advanced high-strength steel. Recent research by Li et al. (2022) highlights the effectiveness of advanced welding processes, such as friction stir welding and laser welding, in achieving strong and reliable joints for EV battery enclosures and body-in-white structures, contributing to improved vehicle performance and safety.

Furthermore, the application of advanced welding technology extends beyond traditional manufacturing industries into emerging fields such as additive manufacturing and robotics. In additive manufacturing, advanced welding-based processes like direct energy deposition and laser metal deposition are enabling the fabrication of complex metal parts with enhanced geometrical accuracy and material properties (Zhao et al., 2021). Moreover, advancements in robotic welding systems equipped with artificial intelligence (AI) and machine learning algorithms are revolutionizing production lines by enhancing welding accuracy, productivity, and adaptability to dynamic manufacturing environments (Singh et al., 2023). As evidenced by these recent studies, the application of advanced welding technology continues to drive innovation and efficiency across various industries, paving the way for enhanced product performance, sustainability, and competitiveness in the global market.

To enhance conventional welding processes, several advanced techniques have been introduced, including plasma arc welding, laser beam welding, electron beam welding, and ultrasonic welding. Plasma arc welding (PAW), as illustrated in Figure 3, closely resembles gas tungsten arc welding (GTAW) or TIG welding. It utilizes a non-consumable tungsten electrode and shielding gas, such as argon, similar to GTAW (Baskoro et al.,2011). PAW has been developed to increase productivity by leveraging the concept of GTAW, enabling faster welding speeds and higher efficiency compared to GTAW. Wu et al., (2014) found in their study that PAW also prolongs electrode service life, eliminating the need for frequent regrinding throughout the entire production shift. PAW offers a significant tolerance for joint gaps. Moreover, it is a high-power density welding approach, comparable to laser welding (LW), but at a considerably lower cost (Piccini & Svoboda, 2012). In PAW, the electric arc is collimated through a calibrated exit in the gas nozzle, resulting in a slightly extended arc length (A, R. R. S., 2007). One notable advantage of PAW over GTAW is its ability to perform welding in the majority of cases without the need for filler metal. It also exhibits greater tolerance for variations in the distance between the plate and torch, along with higher thermal efficiency of fusion welds compared to LW. Consequently, PAW enables welded connections with reduced volume, lower levels of residual stress or distortion, and smaller heat-affected zones (HAZs). However, the collimated arc in PAW requires tighter tolerances in the welded joint gap and introduces a greater number of variables, demanding a deeper understanding to achieve proper welds (A, R. R. S., 2007). Therefore, the PAW process offers an intriguing alternative due to its higher power density, resulting in smaller joints with minimal thermal effects on the base material.

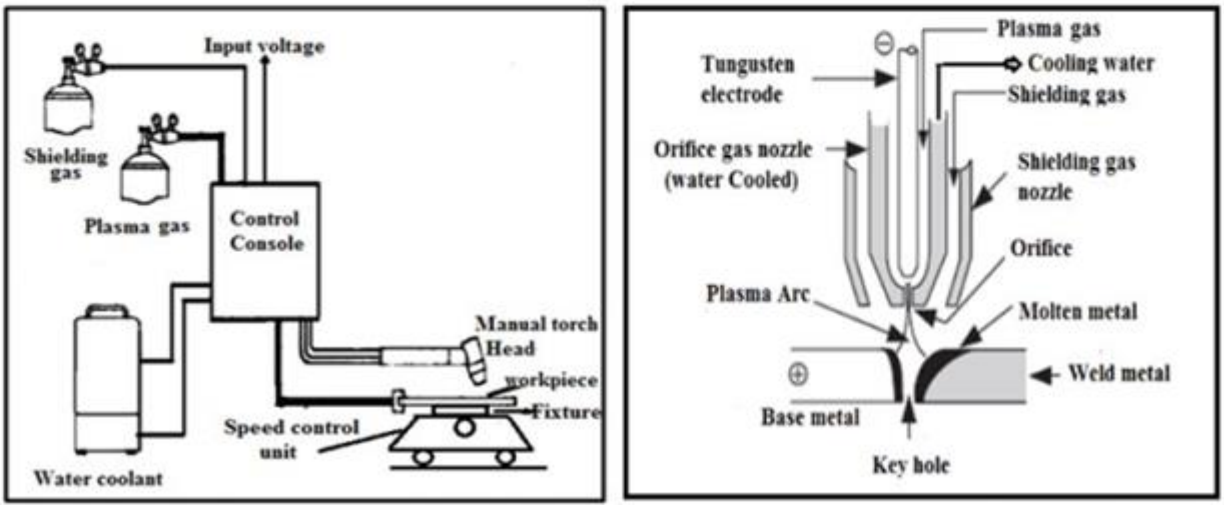

Figure 3: Schematic of keyhole plasma arc welding (*Srikant Prasad, 2019)*.

Laser beam welding (LBW) has gained widespread adoption in various industries for its ability to produce high-quality welds with minimal shrinkage, utilizing the heat generated by a high-power laser beam to achieve fusion welding. The laser beam can be optically shaped, manipulated, and focused onto the workpiece, with spot diameters as small as 0.2mm. This process is suitable for welding materials such as aluminum, ferrous metals, copper, and titanium. Laser welding eliminates the need for direct tool contact, thanks to its unobstructed narrow and straight line of sight *(Prabakaran et al., 2019).*

To further improve efficiency and cleanliness in welding, modern techniques have focused on nickel superalloys using fibre laser beams. Laser welding, being rapid and precise, finds extensive application in industrial welding systems *(Jager et al., 2008)*. However, the complexity of laser welding often poses challenges in its management and control *(Alippi et al., 2001) & (Günther et al., 2016)*. Recent research has explored cognitive laser welding systems, which effectively operate on designated workpieces after setup, addressing control issues *(Paul et al., 2020)*. Despite its widespread industrial use, precise and consistent monitoring and management of the laser welding process remain crucial *(Prabakaran et al., 2019).*

On the other hand, the implementation of hybrid welding processes offers improvements in welding quality. Laser hybrid welding combines the principles of laser beam welding and arc welding *(Liu et al., 2020) & (Desmaison et al., 2014)*. Laser arc hybrid welding (LAHW) has gained popularity as a replacement for traditional welding techniques like gas metal arc welding (GMAW). LAHW harnesses the advantages and complexities of both laser and GMAW processes *(Alam et al., 2012).* The combination of arc and laser procedures offers benefits such as high welding speed, deep penetration due to the laser, and effective bridging of joint gaps by the melting electrode wire *(Lamas et al., 2015).*

Electron beam welding (EBW) stands out in comparison to laser beam welding (LBW) due to its versatility in welding nearly all types of metals, spanning from foil to plate thicknesses. The electron beam guns utilized in this process can achieve power capacities of up to 100 kW. Similar to LBW, EBW yields desirable characteristics such as deep penetration, low heat input, minimal weld size, and a narrow heat-affected zone, resulting in enhanced efficiency and clean welding outcomes *(Naffakh et al., 2014)*. The application of EBW extends to various industries, including aerospace (e.g., aircraft), nuclear, electronics, as well as automotive components like gears and shafts.

Ultrasonic welding (shown in *Figure 4*) emerges as a rapid and cost-effective welding method extensively employed in contemporary applications. By converting friction into heat, ultrasonic welding achieves the melting of plastic or metal components. This welding process finds utility in joining thermoplastic materials, synthetic fabrics, and films. Notably, ultrasonic welding represents a sustainable and eco-friendly technology, eliminating the need for glue or solvents in the joining process. Its origins trace back to the early 1950s when it was first introduced as ultrasonic metal welding for wire bonding, tube sealing, and joining thin metal foils (Shakil et al., 2014). Ultrasonic has a capability in producing clean surface oxides and contaminants welding. It is also able to weld large area using minimal energy with low cost per weld.

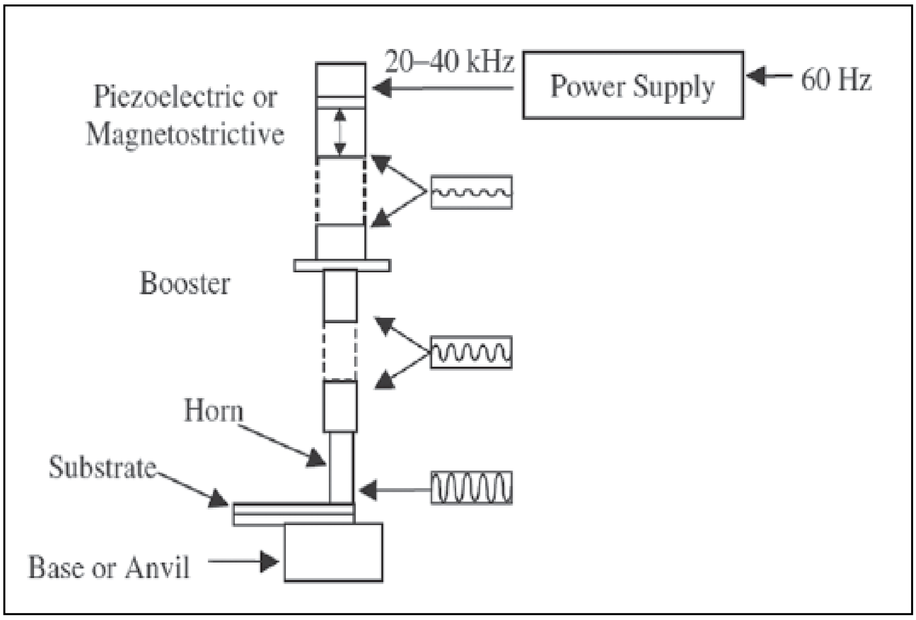

Figure 4: Diagram of an ultrasonic welding machine *(Pereira da Costa et al., 2012)*.

4.0 A Trend of Advanced Welding Technology in Industries

4.1 Vision System in Welding Process

Welding process is one of the famous joining methods which used in various industries for example in pipe welding. A study on monitoring molten pool using the machine vision in pipe welding has been carried out (Baskoro et al., 2011). The aim is monitoring the molten pool image using machine vision as sensor during pipe welding. The vision system captured image of the molten pool width and neural network system is used to simulate the weld bead width. The sensor will interact to the system and reduced the welding process complexity and also the time processing. Thus, the vision system will obtain information on what goes on in the environment and the process monitored at possible distances and also capable to analyze the entire work environment (Ryberg et al., 2010). In other hand, this particular system has some issues where the image obtain is 2D image and also the pixel resolutions of the images obtained is low.

4.2 Consumable Guide Enclosed Arc Welding (CGEAW)

The Paton Electric Welding Institute, National Academy of Science, Ukraine, has pioneered an advanced welding technique known as Consumable Guide Enclosed Arc Welding (CGEAW). This innovative method involves the use of self-shielded flux-cored wire, which is delivered through a longitudinal slot within a specially prepared plated consumable electrode (Bajic et al., 2013).

Formerly, rails joined by riveting method. As the new method of welding introduced, it is suitable for weld rails. An advantage of using CGEAW methods is the weld joints are extremely high quality. Moreover, the parts joined are very stable. Other advantages are shielding gases or fluxes are not required in this welding method and there is no preheating or heat treatment welds. CGEAW equipment are easily adopted to weld rails in different sizes and shapes. Joining rails using welding method has several disadvantages. Some of them are expensive equipment of large dimension and quality of weld products depends on the competence of welder.

4.3 Improvement in Arc Welding Processes

Conventional welding methods were developed to meets the needs of rapid technology expand. Innovations of welding method is one of the ways to produce better products at lower cost and it is a challenge to industries gives a friendly environment to the workers (Rosado et al., 2008). Both TIG and MIG have been put innovation into them.

Tandem welding is one of welding method using two electrode wires initially apply in the submerged arc welding. During the process, two electrodes use which called leading electrode and followings electrode which there are placed one after another. The leading electrode placed first and followed by the following electrode. Automation and robotize Tandem welding method will increase the speed of weld parts. However, the speed is depending on the thickness of the welded elements and joints. Another welding method to improve the welding productivity is TIME (Transferred Ionized Molten Energy) welding. TIME welding is one of new variant of metal active gas welding.

4.3 Pipeline welding

The growth in pipeline industries has driven Cranfield University's Welding Engineering Research Centre to develop Tandem GMAW (Gas Metal Arc Welding) process which use two tandem torches on a single carriage. This particular process allows high welding speed and reduction of welding time. In a comparison of Tandem GMAW with traditional GMAW, there is about 25% saving in girth welding costs. The major advantage in this particular process is the weld bevel and profile similar to conventional welding process and it can use conventional radiography and automated ultrasonic testing to detect (Yapp & Blackman, 2004).

4.4 Welding Technologies for Thermoplastic Composite

Welding serves as a joining method not only for metals but also for thermoplastic composites, which find extensive use in aerospace applications and automotive industries (Pereira da Costa et al., 2012) & (Bilici, 2012). Thermoplastic materials are favored in numerous industrial and engineering sectors due to their ability to reduce product weight, enhance thermal conductivity, and improve toughness and stress-to-weight ratio (Paoletti et al., 2015). The utilization of thermoplastic composites has gained significance as they offer a viable alternative to metallic and thermoset composites. The efficacy of ultrasonic welding in joining two or more components relies on various factors, including the material's physical properties, frequency and amplitude of ultrasonic waves, and joint design (Pereira da Costa et al., 2012). Ultrasonic welding has found applications in diverse industries such as electrical, aerospace, energy, medical, and packaging. These welding techniques are particularly relevant in the aerospace industry, as they are compatible with lightweight thermoplastic matrix composite materials.

Other than that, microwave welding also used to weld thermoplastic composite. The advantage of using microwave welding for aerospace industry is the capability to irradiate the whole components and it can produce three dimensional (3D) joints with less than one minute needed to weld. However, it comes with a drawback which the homogenous material heating only possible for simple geometries. On the other hand, there is one more popular welding method for thermoplastic composite which is the hot plate welding. This particular welding process is widespread as it is simple, reliable and economical to produce strong welds joints. Besides, IR welding is one of the new techniques in welding process which it gives several advantages such as able to fast heating and it allows high productivity rates in automated system to produce tough joints. In addition, IR welding has a great flexibility and capable to joint large flat and curved areas.

Welding process have been used widely in aerospace industries. Aeronautical industry nature of welding is characterized by low production, high unit cost, extreme reliability and severe operation conditions (Mendez & Eager, 2002). Friction Stir Welding (FSW) was used to replace others welding processes such as plasma arc welding and electron beam welding in special application of aluminum and titanium in aircraft industry, friction welding process used to joint components with simple cross section for example to joint aluminum landing gear components. Boeing has invested in the usage of FSW to weld the booster core tanks. Besides, flash welding used in aeronautics as it produces strong welds as the base material and flash welding can joint section with complicated cross section. Major used in aeronautics industries is the Diffusion Welding because it has proven useful when combined with super plastic forming (SPF) of titanium alloys. Application of diffusion welding reduces the original riveted aluminum design with cost savings around 30% (Mendez & Eager, 2002). In addition, FSW welding of thermoplastic materials is a promising approach for the automobile industry since it has some advantages over other joining technologies, such as reduced machine and tooling costs (Paoletti et al., 2015).

4.5 Welding Procedure for Auto Manufacturing for Vehicle

The production process in the weld shop commences with the creation of subgroups or smaller units of the automobile body, such as doors, floor components, or roof elements. Subgroup production involves an automation ratio of approximately 50%. The assembly of larger units and the final car body is accomplished through a fully automated process that operates with precision to one-tenth of a millimeter (Malik, 1986). An automobile body can feature nearly 3000 welds across its structure, encompassing areas such as the engine compartment, seat rails, and doors. These welds are meticulously numbered in the building blueprints, and the results of ultrasonic examinations must be accurately linked to these specific spots and numbers (Klein, 2010). This establishes a foundation for quality assurance across all joints in automotive body components. Initially, robots are employed to weld the front and back sections of the floor together. The completed floor is then transferred to a distinct production line, known as the global body line, where other components, including chassis sidewalls, dashboard, and roof, are welded (Kim et al., 2003). The weld shop houses more than 200 different types of robots. During the welding process, a total of 2220 welds are performed on the car, utilizing spot and arc welding techniques within a protective atmosphere. When welds performed by suppliers on smaller parts are considered, a single car can have a total of 3300 welds. Once the automobile body is finalized and modified, it proceeds to the main welding line, where powerful robotic welds strengthen the entire structure of the car body (Boekholt, 2000).

4.6 Issues of Intelligence Welding Technology

The field of intelligent welding manufacturing technology encompasses crucial intelligent technical elements, including the sensing of the welding process to replicate the welder's sensory functions, the extraction and modelling of knowledge about the welding process to simulate the welder's reasoning capabilities, and the intelligent control of the welding process to imitate the welder's decision-making operations. With the ongoing advancements in production technologies, the realization of autonomous, robotic, flexible, and intelligent welding manufacturing is anticipated as a future trend. Welding technology, widely recognized for its evolution from manual craftsmanship to a systematic technical science, is intricately linked to various technological disciplines such as material science, mechanical engineering, electrical engineering, control systems, and computer science (Chen & Lv, 2014). Figure 5 showing a main problems of intelligent welding technology.

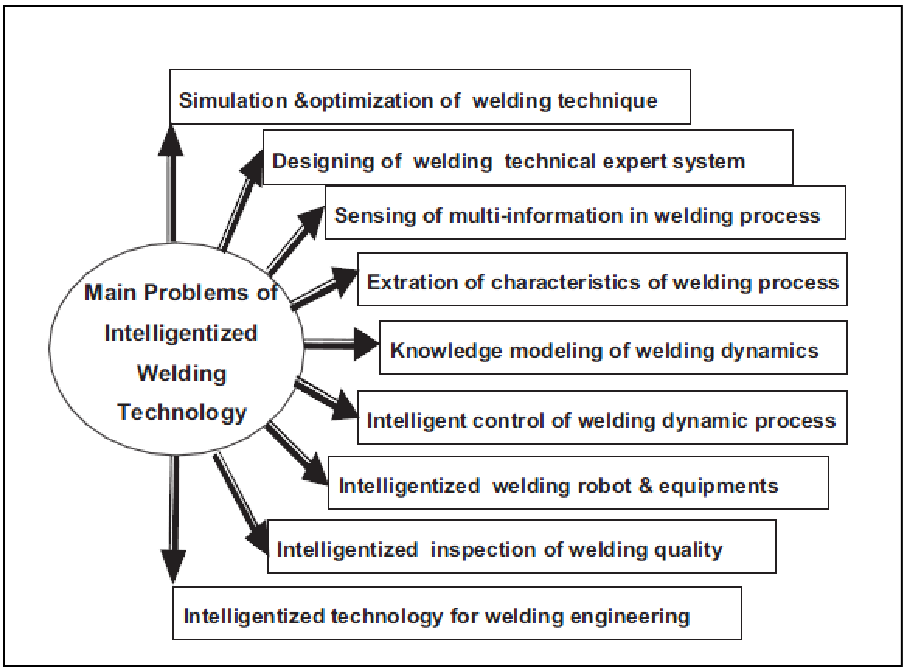

Figure 5: The key scientific and technical problem in Intelligence Welding Manufacturing Technology *(Chen & Lv, 2014).*

5.0 Conclusion

Welding processes and technologies are rapidly growing nowadays and became one the vital element in manufacturing industries. It was developed in several ways to increase productivity of the process and also to reduce manufacturing cost. In addition, welding process nowadays is not limited for metal materials only but also can be used to weld thermoplastic composite and other materials. Begin from the simple welding process until up to the complicated process, it is widely used and utilized to obtain maximum benefits. In future, welding process will continuously develop to meets the industries needs such aeronautic and automotive industries which preferred welding joint than the riveting technique. The same concept can be seen in pipeline industries which some techniques developed to meet the requirements such as curved parts and complex joints.

The evolution of welding processes and technologies continues to be driven by the demand for increased efficiency and cost-effectiveness in manufacturing. From traditional methods to cutting-edge techniques, the goal remains consistent: to optimize production while minimizing expenses. Moreover, the scope of welding applications has expanded beyond conventional metal materials to encompass a diverse range of substrates, including thermoplastics and composites.

This broadening of possibilities underscores the adaptability and versatility of welding as a manufacturing solution.

Looking ahead, the trajectory of welding innovation is poised to align closely with the evolving needs of key industries such as aeronautics and automotive manufacturing. In these sectors, the preference for welding over riveting techniques reflects a strategic shift towards streamlined processes and enhanced structural integrity. Similarly, in pipeline industries, ongoing advancements are targeted at meeting the demands of intricate configurations and challenging joint requirements, including curved sections and complex geometries. As technologies continue to mature and new methodologies emerge, the future of welding promises to be defined by its capacity to address the diverse and evolving demands of modern manufacturing.

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Author Contributions

A.S. Buang: Conceptualization, Methodology, Writing- Original Draft Preparation; **M.S. Abu Bakar**: Data Curation, Validation, Supervision; **M.Z. Rohani**: Writing-Reviewing and Editing.

Conflicts Of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

6.0 References

Akinlabi, E. T., Mahamood, R. M., Akinlabi, E. T., & Mahamood, R. M. (2020). Introduction to friction welding, friction stir welding and friction stir processing. Solid-state welding: friction and friction stir welding processes, 1-12.

Chaturvedi, M., &Vendan, S. A. (2022). Advanced Welding Techniques. Springer Verlag, Singapore.

Mehta, K. (2017). Advanced joining and welding techniques: an overview. Advanced Manufacturing Technologies: Modern Machining, Advanced Joining, Sustainable Manufacturing, 101-136.

Zhang, D., & Chen, Z. (2018). Advanced welding technologies for lightweight vehicle construction: state of the art and future prospects. Journal of Manufacturing Science and Engineering, 140(5)

Sindre, G., &Johnsen, R. (2017). A review of research on welding in the energy sector. Welding in the World, 61(1), 147-157.

Liu, X., Li, M., Wang, Z., & Chen, T. (2020). Application of hybrid laser-arc welding in shipbuilding: A review. Journal of Manufacturing Processes, 56, 272-285.

Tavoosi, M., Azeredo, S., & Rodrigues, D. (2019). Method for laser welding dissimilar materials. U.S. Patent No. 10,272,727

Muhammad, W., Husain, Wilayat, Tauqir, Anjum, Wadood, Abdul, Zaigham, Hamid, Ur Rehman M. A, (2021). Assessment of microstructure and mechanical properties of friction stir welded AA2014-O and AA2014-T6 sheets. The International Journal of Advanced Manufacturing Technology 115(7-8):1-13

Srikant Prasad, (2019). Investigation and Analysis of Micro Plasma Arc welding of SS-3161. A Thesis submitted to Indian Institute of Technology Guwahati India

Prabakaran, MP, Kannan, GR & Lingadurai, K (2019). Microstructure and mechanical properties of laser-welded dissimilar joint of AISI 316 stainless steel and AISI 1018 low alloy steel', Caribbean Journal of Science, vol. 53, pp. 978-998, ISSN: 0008-6452 (Annexure I). IF-0.75.

Prabakaran, MP & Kannan, GR 2019 'Optimization of laser welding process parameters in dissimilar joint of stainless steel AISI 316/AISI 1018 low carbon steel to attain the maximum level of mechanical properties through PWHT', Optics and Laser Technology vol. 112, pp. 314-322, ISSN: 1879-2545 (Annexure I). IF-3.319.

Paul, S., Duggirala, A. and Mitra, S. (2020), 'Study of Laser Beam Welding of AA 2024 Using Taguchi Methodology.', 2020 IEEE India Council International Subsections Conference (INDISCON), pp. 248-253, Doi: 10.1109/INDISCON50162.2020.00058.

SenthilKumar, G., Natarajan, U and Ananthan, S.S. (2012). Vision inspection system for the identification and classification of defect in MIG welding joints. International Journal of Advanced Manufacturing Technology (IJAMT) Vol 61, pp 923-933

Selvabharathi, R & Thamarai Selvan, A 2021, 'Influence of severe shot peening and Plasma spray FeCr18Ni10Mo3 coating on microstructure and mechanical properties of super austenite stainless steel sheets by laser beam welding', Journal of Materials Research and Technology, vol. 10, pp. 363-375,

Li, H., Wang, Y., & Zhang, L. (2022). Advanced Welding Technology for Electric Vehicle Manufacturing: A Review. Journal of Manufacturing Science and Engineering, 144(4), 040801.

Singh, A., Kansara, K., & Pandey, P. (2023). Robotics in Welding: Recent Advances and Future Perspectives. Robotics, 12(1), 13.

Zhao, Y., Li, M., & Guo, D. (2021). Advances in Additive Manufacturing of Metallic Components Using Welding-Based Processes: A Review. Metals, 11(4), 600.

Zhang, Q., Wang, X., & Liu, Y. (2023). Recent Advances in Laser Beam Welding of Lightweight Materials for Aerospace Applications: A Review. Journal of Materials Processing Technology, 299, 117381.

Kalpakjian, S. (2001). *Manufacturing Engineering and Technology* (Vol. 7): Pearson Education South Asia.

Norrish, J. (2006). *Advanced welding processes Technologies and process control*: Woodhead Publishing Limited.

Ibrahim, I. A., Mohamat, S. A., Amir, A., & Ghalib, A. (2012). The Effect of Gas Metal Arc Welding (GMAW) Processes on Different Welding Parameters. *Procedia Engineering, 41*, 1502-1506.

Lu, S. P., Qin, M. P., & Dong, W. C. (2013). Highly efficient TIG welding of Cr13Ni5Mo martensitic stainless steel. *Journal of Materials Processing Technology, 213*(2), 229-237.

Z. Han, J. Orozco, Indacochea, J. E., & Chen, C. H. (2010). Resistance Spot Welding: A Heat Transfer Study - Real and simulated welds were used to develop a model for predicting temperature distribution *Welding Research Supplement, May*, 363-371.

Uzkut, M., Ünlü, B. S., Yilmaz, S. S., & Akdağ, M. (2010). *Friction Welding And Its Applications In Today's World*. Paper presented at the 2nd International Symposium on Sustainable Development, Sarajevo. Material Science, Corpus ID: 3584266

Thomas, W.M., Nicholas, E.D., Needham, J.C., Murch, M.G., Templesmith, P. and Dawes, C.J. (1991) International Patent Application No. PCT/GB92/02203 and GB Patent Application No. 9125978.8.

El-Danaf, E. A., & El-Rayes, M. M. (2013). Microstructure and mechanical properties of friction stir welded 6082 AA in as welded and post weld heat treated conditions. *Materials & Design, 46*, 561-572.

Sonne, M. R., Tutum, C. C., Hattel, J. H., Simar, A., & de Meester, B. (2013). The effect of hardening laws and thermal softening on modeling residual stresses in FSW of aluminum alloy 2024-T3. *Journal of Materials Processing Technology, 213*(3), 477-486.

Cao, X., & Jahazi, M. (2011). Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy. *Materials & Design, 32*(1), 1-11.

Chowdhury, S. M., Chen, D. L., Bhole, S. D., & Cao, X. (2010). Tensile properties of a friction stir welded magnesium alloy: Effect of pin tool thread orientation and weld pitch. *Materials Science and Engineering: A, 527*(21–22), 6064-6075.

Buffa, G., Fratini, L., & Micari, F. (2012). Mechanical and microstructural properties prediction by artificial neural networks in FSW processes of dual phase titanium alloys. *Journal of Manufacturing Processes, 14*(3), 289-296.

Kitamura, K., Fujii, H., Iwata, Y., Sun, Y. S., & Morisada, Y. (2013). Flexible control of the microstructure and mechanical properties of friction stir welded Ti–6Al–4V joints. *Materials & Design, 46*, 348-354.

Bozkurt, Y., Uzun, H., & Salman, S. (2011). Microstructure and mechanical properties of friction stir welded particulate reinforced AA2124/SiC/25p-T4 composite. *Journal Of Composite Material, 45*, 2237-2245.

Sharifitabar, M., & Nami, H. (2011). Microstructures of dissimilar friction stir welded joints between 2024-T4 aluminum alloy and Al/Mg2Si metal matrix cast composite. *Composites Part B: Engineering, 42*(7), 2004-2012.

He, X., Gu, F., & Ball, A. (2014). A review of numerical analysis of friction stir welding. *Progress in Materials Science, 65*, 1-66.

Baskoro, A. S., Erwanto, E., & Winarto, W. (2011). *Monitoring of molten pool image during pipe welding in gas metal arc welding (GMAW) using machine vision.* In Proceedings of the 2011 International Conference on Advanced Computer Science and Information Systems, Jakarta, Indonesia, 17–18 December 2011; pp. 381–384.

Wu, C. S., Wang, L., Ren, W. J., & Zhang, X. Y. (2014). Plasma arc welding: Process, sensing, control and modeling. *Journal of Manufacturing Processes, 16*(1), 74-85.

Piccini, J., & Svoboda, H. (2012). Effect of the Plasma arc Welding Procedure on Mechanical Properties of DP700 Steel. *Procedia Materials Science, 1*, 50-57.

A, R. R. S. (2007). *Fudamental of Practice of Plasma Arc Welding*: Artilzer San Pablo.

Erdős, G., Kemény, Z., Kovács, A., & Váncza, J. (2013). Planning of Remote Laser Welding Processes. *Procedia CIRP, 7*, 222-227.

Jager, M., Humbert, S., & Hamprecht, F. A. (2008). Sputter Tracking for the Automatic Monitoring of Industrial Laser-Welding Processes. *Industrial Electronics, IEEE Transactions on, 55*(5), 2177-2184.

Alippi, C., Braione, P., Piuri, V., & Scotti, F. (2001). *A methodological approach to multisensor classification for innovative laser material processing units.* Paper presented at the Instrumentation and Measurement Technology Conference, 2001. IMTC 2001. Proceedings of the 18th IEEE.

Günther, J., Pilarski, P. M., Helfrich, G., Shen, H., & Diepold, K. (2016). Intelligent laser welding through representation, prediction, and control learning: An architecture with deep neural networks and reinforcement learning. *Mechatronics*.

Schroth, G., Stork, I., Wersborg, G., & Diepold, K. (2009). *A cognitive system for autonomous robotic welding.* Paper presented at the Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on.

Ancona, A., Spagnolo, V., Lugarà, P. M., & Ferrara, M. (2001). Optical sensor for real-time monitoring of CO2 laser welding process. *Applied Optics, 40*(33), 6019-6025. doi: 10.1364/AO.40.006019

Desmaison, O., Bellet, M., & Guillemot, G. (2014). A level set approach for the simulation of the multipass hybrid laser/GMA welding process. *Computational Materials Science, 91*, 240-250.

Alam, M. M., & Kaplan, A. F. H. (2012). Analysis of the Rapid Central Melt Pool Flow in Hybrid Laser-Arc Welding. *Physics Procedia, 39*, 853-862.

Lamas, J., Frostevarg, J., & Kaplan, A. F. H. (2015). Gap bridging for two modes of laser arc hybrid welding. *Journal of Materials Processing Technology, 224*, 73-79.

Naffakh Moosavy, H., Aboutalebi, M.-R., Seyedein, S. H., Goodarzi, M., Khodabakhshi, M., Mapelli, C., & Barella, S. (2014). Modern fiber laser beam welding of the newly-designed precipitation-strengthened nickel-base superalloys. *Optics & Laser Technology, 57*, 12-20.

Shakil, M., Tariq, N. H., Ahmad, M., Choudhary, M. A., Akhter, J. I., & Babu, S. S. (2014). Effect of ultrasonic welding parameters on microstructure and mechanical properties of dissimilar joints. *Materials & Design, 55*, 263-273.

Pereira da Costa, A., Cocchieri Botelho, E., Leali Costa, M., Eiji Narita, N., & Tarpani, J. R. (2012). A Review of Welding Technologies for Thermoplastic Composites in Aerospace Applications. *Journal of Aerospace Technology and Management, 04*(3), 255-265.

Ryberg, A., Ericsson, M., Christiansson, A. K., Eriksson, K., Nilsson, J., & Larsson, M. (2010). *Stereo vision for path correction in off-line programmed robot welding.* Paper presented at the Industrial Technology (ICIT)

Bajic, D., Kuzmenko, G. V., & Samardzic, I. (2013). Welding of Rails with New Technology of Arc Welding. *Metalurgija, 3*, 399-402.

Rosado, T., Almeida, P., Pires, I., Miranda, R., & Quintino, L. (2008). *Innovations in Arc Welding*. Proceedings of 5. Congresso Luso-Moçambicano de Engenharia, Maputo, 2-4 September 2008

Yapp, D., & Blackman, S. A. (2004). Recent developments in high productivity pipeline welding. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 26*, 89-97.

Bilici, M. K. (2012). Application of Taguchi approach to optimize friction stir spot welding parameters of polypropylene. *Materials & Design, 35*, 113-119.

Paoletti, A., Lambiase, F., & Di Ilio, A. (2015). Optimization of Friction Stir Welding of Thermoplastics. *Procedia CIRP, 33*, 562-567.

Mendez, P. F., & Eager, T. W. (2002). *New Trends in Welding In the Aeronautic Industry*. Paper presented at the New Trends in Welding In the Aeronautic Industry, Bilboa, Spain.

Malik, G. A. K. (1986). *Manufacturing Science*: The University of Michigan.

Klein, R. J. (2010). *Welding: Processes, Quality, and Applications (Mechanical Engineering Theory and Applications)*.

Kim, I.-S., Son, J.-S., & Yarlagadda, P. K. D. V. (2003). A study on the quality improvement of robotic GMA welding process. *Robotics and Computer-Integrated Manufacturing, 19*(6), 567-572.

Boekholt, R. (2000). *the Welding Workplace: Technology Change and Work Management for a Global Welding Industry*: Woodhead Publishing.

Chen, S. B., & Lv, N. (2014). Research evolution on intelligentized technologies for arc welding process. *Journal of Manufacturing Processes, 16*(1), 109-122.