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Comparison of Failure Rates of Different Types of Arc Welding Joints

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ABSTRACT
The purpose of this study is to investigate the welding joint failure in arc welding and identify the kind of joint that fails the least frequently. The strength and safety of the welded structure can be improved by determining the joint with the lowest failure rate. This study uses experimental methods to assess the failure rate of butt joints, lap joints, edge joints, and T-joints. To replicate the actual conditions of welding in the real world, the specimens are made using arc welding with various parameters. The butt joint, followed by the T-joint and lap joint in that order, has the lowest failure rate, according to the testing results. The greater performance of the butt joint is due to its resilience and consistent stress distribution, which makes it less vulnerable to stress concentrations that can lead to failure. In contrast, the geometry of the lap joint and T-joint, which can result in stress concentration and probable weld flaws, contributes to their greater failure rates.
Keywords: Welding, Joint Failure, Butt joint, Lap joint, T- joint, welding flaws.

1. INTRODUCTION
Olawale et. al., (2012) investigations established the correlation of SMAW and heat treatment on some mechanical properties of carbon steel. The sample is welded together by using AWS E6013 Electrode. During welding, voltage is constant and current is varying, correlating voltage and current. The sample is subjected to heat treatment operation at different temperatures. As it is found that with increase in current increase in hardness and UTS of weld metal. After heat treatment operation impact strength increased while UTS and hardness reduced. Maridurai et.al., (2012) investigated the tensile properties of carbon steel P91 when root pass was carried by using TIG welding and then SMAW and SAW welding. The study of characteristics of fracture, toughness and tensile properties of P91 material in SAW process were performed. The fracture, toughness and tensile properties of base metal were evaluated by using crack tip opening displacement and properties are measured at room temperature, the range of temperature during welding is 400 - 600 degree centigrade. Cho et. al., (2013) analyzed the effect of torch angle and current polarities on the convection heat transfer in single wire submerged arc welding. To develop arc models such as arc heat flux, arc pressure and electromagnetic force, the study adopted the Abel inversion method with CCD camera images for direct and alternating current polarities. The heat transfer by molten slag from the flux consumption was considered as an additional boundary heat source in the numerical simulation. The variation of arc forces, the direction of droplet flight with polarity and the torch angle

significantly affected the molten pool flow and the resultant weld beads. The simulated weld pool profiles are validated with corresponding experimental results and found to be in good agreement. Singh et. al., (2014) Finite element method based, ANSYS software was used to develop coupled thermal mechanical three-dimension finite element model. To understand the behavior of residual stresses, two 90 mm thick ASTM A516 Grade 70 rolled thick plate cylinder are butt welded using the Shield Metal Arc welding (SMAW) and Submerged Arc welded (SAW) process. Numerical analysis (finite element analysis) was then carried out to calculate the residual stress values in the welded plates. Three types of V-butt weld joint – two-pass, three pass and four-pass were considered in this study. In multi-pass welding operation the residual stress pattern developed in the material changes with each weld pass. The finite element model was evaluated for the transient temperatures and residual stresses during welding. Variations of the physical and mechanical properties of material with the temperature were taken into account. Dutta et.al. (2014) investigated the variation of temperature in the heat effect zone in weld joints; these properties depend on material properties. Temperature is measured by experiment at predefined location of the plate during welding by mounting of the thermocouple. The heat transfers in heat-affected zones are carried out. Convection, radiation, and radiation heat transfer are the main ways of heat losses due to moving plate heat source. The variation of temperature in heat effect zone is 300 °C to 600 °C. Jha and Jha (2014) investigated the effect of process parameter like welding current on tensile strength of mild steel weldment by using welding current as varying parameter. In the work, mild steel alloy plates were joined by Shielded Metal Arc Welding (SMAW) process which is also known as manual metal arc welding used to examine optimum welding current. Welding specimen tensile strength was investigated using a Tensile Testing Machine to characterize weld strength by determining ultimate tensile strength. The experimental results have shown that the optimum current out of the four-welding current used (100amp, 110amp, 120amp, 130amp & 140amp) is 120amp. Culha et.al. (2014) focused on predicting the design parameters such as distortion analysis, thermal stress, temperature gradient, and nodal displacement on the plate during the SAW process. The residual stress and distortion occur near the HAZ by heating during the welding process. The design parameter value is achieved by the analysis of thermal elastic-plastic by using FEA. It also shows the stress-temperature distribution. During the SAW process, T-beam profiles are used in welding. Kchaou et. al., (2014) in this paper measures the mechanical properties and microstructure of base metal of welded joints. The SMAW was performing on joining two stainless steel plates. The measurement of mechanical properties and analysis of fracture profile are show that these two materials are ductile but ductility is less in the weld metal. The hardness of base metal is indicated as micro hardness measurement as the hardness Increases in the weld bead due to rapid cooling of weld material. In ductile material the fracture surface are observed after tensile test of material . All the test of mechanical properties such as micro hardness ,yield strength, tensile strength are in good agreement. Deogade, et. al., (2015) carried out the analysis of residual stress in the heat effect zone and welded zone. The temperature and residual stress were simulated by ANSYS. The finite element model was to predict the value of temperature and residual stress distribution SMAW welding in ferrite stainless steel. Shielded metal arc welding (SMAW), also known as manual metal arc welding (MMAW), flux shielded arc welding, or informally as stick welding, is a manual arc welding process that uses a consumable electrode covered with a flux to lay the weld (Sayed et al. 2021). An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. The workpiece and the electrode melt to form a pool of molten metal (weld pool) that cools to form a joint. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination. Because of the versatility of the process and the simplicity of its equipment and operation, shielded metal arc welding is one of the world's first and most popular welding processes. It dominates other welding processes in the maintenance and repair industry, and though flux-cored arc welding is growing in popularity, SMAW continues to be used extensively in the construction of heavy steel structures and in industrial fabrication. The process is used primarily to weld iron and steel (including stainless steel) but aluminum, nickel, and copper alloys can also be welded with this method (Sayed et al. 2021). Joining elements with a consumable electrode in arc welding Metal Inert Gas (MIG) or a consumable electrode in active gas Metal Active Gas (MAG) are leading methods in production processes. These methods enable high welding performance, easy inspection of the arc weld, the possibility of careful observation of the weld pool, the possibility of combining a wide range of materials, obtaining good mechanical properties of connections, and ease of mechanization and robotization of the welding process (Madavi, et al., 2022). The traditional methods of MIG/MAG welding of steel materials with a thickness of less than 3 mm cause many technological problems. These are mainly related to the introduction of a large amount of heat to the welded joint, which can cause numerous welding deformations and distortions. Moreover, they can also lead to the formation of numerous welding spatters, thus lowering the aesthetics of manufactured products and increasing the laboriousness of finish machining of the detail after welding (Gapontsev, et al., 2022). Today, more often in various industries, e.g., automotive, household appliances, or fencing systems, there is a necessity to make permanent joints of thin-walled steel elements, either without or with various coatings. Due to the above, in order to eliminate the previously described issues that arise when welding thin-walled elements, new variants of MIG/MAG welding have been developed, such as Cold Metal Transfer (CMT), Cold Arc, or Surface Tension Transfer (STT) (Srinivasan, et al., 2022). In comparison to classic methods, the low-energy welding process MIG/MAG lends itself to welding defects reduction, a significant reduction in the number of welding spatters, a reduction in the amount of total energy implemented to the joint during welding, and a reduction in harmful pollutants emission and thereby the improvement of the working conditions. As a result, they shorten the time and labour consumption of the production process and reduce cost-consuming technological procedures (Bologna, et al., 2022). In addition, currently, the quality, precision, and aesthetics of welded joint designing are becoming more and more relevant for customers, which are essential, for example, during fence system production, door joinery, or the broadly understood furniture industry. Furthermore, the present trend observed is focused on solutions for the privacy of use, which can be obtained by reducing the translucency of fillings, for example, in fence systems. However, the use of classic components would result in a significant increase in the weight of the product, which, in turn, would necessitate the use of special fittings and more powerful drives. Therefore, it is necessary to reduce the cross-sections of the profiles used and the thickness of the sheets in order to minimize the weight of the product, as well as the operating and assembly costs. However, the aesthetics of individual products depends not only on the welding method used, but also on the process parameters, experience and knowledge of employees, the use of additional technological procedures, and even the sequence of connections. Another method of joining materials that is more often used in the industry is the laser welding process, with or without additional material. It should be noticed that due to the specific heat source, which is the laser beam, the welding process itself and the metallurgical processes taking place during welding are significantly different from the processes taking place in arc welding methods. As a consequence, the properties of welded joints will be different from those obtained when using conventional technologies (Vishev, et al., 2021). One of the latest solutions in the field of laser welding is the dynamically developing devices for manual welding in recent years, which use a beam of laser radiation generated by sources with a power of 1kW to 2kW (Danielewski, et al., 2020). But, at the moment there is a lack of precise information regarding the safety of employees in the workplace equipped with this type of equipment. The processes of joining thin-walled steel materials can also be carried out using various resistance welding technologies [Bamberg, et al., 2022). This method is characterized by low operating costs and no need to use additional materials. As a result, welding does not cause significant changes in the chemical composition and metallurgical properties, while maintaining the mechanical properties. Additional advantages of the resistance welding processes are the speed of making connections, the simplicity of the course, and the possibility of remote control. It should be remembered that when welding thin-walled elements, there are great difficulties with ensuring dimensional tolerances of the structures made, which are related to the need to select an appropriate technological allowance and the upset speed of the joined elements. The appropriate selection of process parameters, such as current intensity and welding pressure force, enables the minimization of welding deformations and deformations. In addition, welding allows the connection of two elements with a large variation in the thickness of the materials to be joined, which is very difficult or sometimes even impossible to achieve based on the MIG/MAG arc welding processes. Determining the failure rate for different types of welded joints has been investigated for many years. Accurate design of welded joints is very crucial in cases where special safety regulations must be followed. Generally, it has been found that by employing various destructive and non-destructive testing methods, the strength of welded joints which would reduce the failure rate and increase the longevity of the usage of the material can determined. Therefore, this research aims to analyze the various welded joints and in turn, evaluate the maximum strength that would be reached to cause failure and investigate the effect of the rate of failure of different welded joints using arc welding.

2. MATERIALS AND METHODS

This section focuses on the steps that will be carried out in other to achieve the set objectives.

2.1 Materials

2.1.1 Material Used

The materials used is low carbon steel/mild steel.

2.1.2 Electrode-holder

It is a clamping device used to grip and manipulate the electrode during arc welding. It is made of copper/copper alloy for better electrical conductivity. It is either partially or fully insulated holders made in various sizes ranging 200 – 300 – 500 amps. The electrode-holder is connected to welding machine by a welding cable.

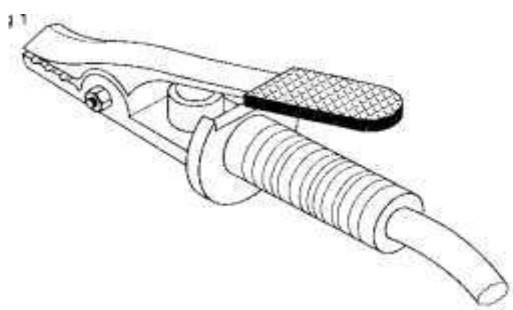

Figure 1: Electrode Holder (Handbook on Welding Techniques)

2.1.3 Earth Clamp

This is used to connect the earth cables firmly to the job or welding table. It is also made of copper/copper alloys. Screw or spring-loaded earth clamps are made in various sizes i.e. 200 – 300 – 500 amps.

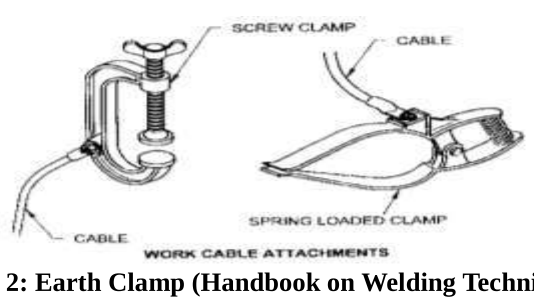

Figure 2: Earth Clamp (Handbook on Welding Techniques)

2.1.4 Cables/ Leads

These are used to carry the welding current from the welding machine to the work and back. The lead from the welding machine to the electrode-holder is called electrode cable and the lead from the work or job through the earth clamp to the welding machine is called earth (ground) cable. Cables are made of super flexible rubber insulation, having fine copper wires and woven fabric reinforcing layers. Welding cables are made in various sizes (cross-sections) i.e. 300, 400, 600 amps etc. The same size welding cables must be used for the electrode and the job. The cable connection must be made with suitable cable attachments (lugs). Loose joints or bad contacts cause overheating of the cables.

2.1.5 110/220volt Arc Welder Machine

The arc welding machine is a device used for fusing metals. The machine emits an electrical arc from an electrode which melts metal or supplies filler into a joint between two pieces of metal. The arc welding machines consume significant quantities of energy in order to produce the temperatures up to 3,600 ºC needed to fuse metals.

Figure 3: Arc Welder 110/220volts (Practical Arc Welding (Chaffee, W.J)

2.1.6 Rockwell Hardness Testing Machine

This Hardness Testing Machine uses a direct reading instrument based on the principle of differential depth measurement. It is a fast non-destructive way to determine if the heat treatment process being done was successful. The procedure of Rockwell Hardness Test:- The surface area to be measured is positioned close to the indenter, the major load is applied for a specified time period (dwell time) beyond zero, the major load is released leaving the minor load applied.

Figure 4: Rockwell Hardness Testing

2.1.7 Charpy Impact Testing Machine

Impact Testing is for testing impact load on materials. Materials behave quite differently when they are loaded suddenly than when they are loaded more slowly as in tensile testing. Because of this fact, impact test is considered to be one of the basic mechanical tests (especially for ferrous metals). The brittle fracture is used to describe rapid propagation of cracks without any excessive plastic deformation at a stress level below the yield stress of the material. Metals that show ductile behavior usually can, under certain circumstances, behave in a brittle fashion. At very low temperatures, fracture occurs before yielding.

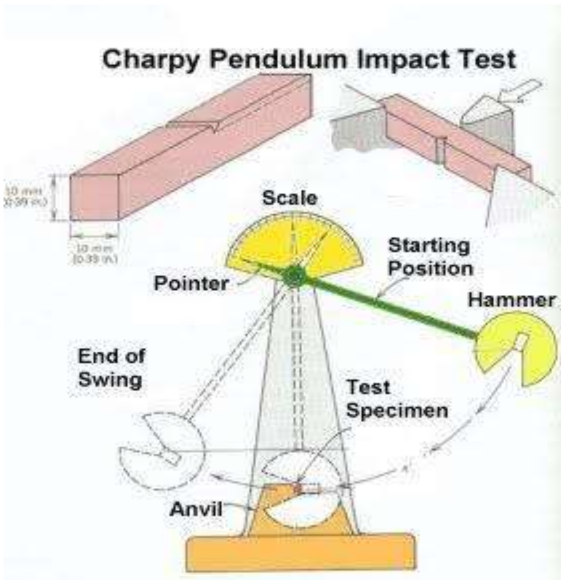

Figure 5: Charpy Pendulum (matest.com)

2.1.8 Digital Readout Welding Gauge

Weld gauge with a digital display is used for measuring throat depths at corners or heights above flat weld joints. With an LCD display, differential measurements can be made while holding either the zero setting or the measured value in any position. It enables rapid and simple precise inspection of welds of various diameters.

Figure 6: Digital Readout Welding Gauge

2.1.9 Biting Edge Stainless Steel Welding Gauge

It rapidly and easily verifies conformity with the four crucial parameters needed to meet NRC Visual Weld Acceptance Criteria. Undercut depth, porosity comparison, porosity per linear inch, and crown height are all examined.

Figure 7: Biting Edge Stainless Steel Welding Gauge

2.2 Methods

2.2.1 Methodology employed in the present study

Two mild steel specimens were prepared for welding. Welding was carried out at 105 A current of and 220 V. The specimen is welded with electrodes. The filling of specimen was carried out with proper joining and removing impurities on the welded surface. After getting the required welded specimen, the notch was prepared of 2 mm depth by means of shaper machine. The testing of welded joints first carried out in Rockwell Hardness Testing Machine and secondly, it is carried out in Charpy Impact testing machine.

2.2.2 The Weld Joint

Welding produces solid connection between two pieces, called a weld joint. A weld joint is the edges or surfaces of parts that have been joined by welding.

(a) **Butt joint: -** the metal pieces are placed side by side.

Figure 8: Butt Joint

(b) **Lap joint**: **-** In the lap joint, one sits on the other but not completely

Figure 9: Lap Joint

(c) **Tee joint: -** In the tee joint, one part is perpendicular to the other in the approximate shape of the letter T.

Figure 10: Tee Joint

(d) **Edge joint: -** The parts in an edge joint are parallel with at least one of their edges in common and the joint is made at the common edge(s).

Figure 11: Edge Joint

3. RESULTS AND DISCUSSIONS

3.1 Rockwell Hardness Test Result

The table and the graph of the Rockwell hardness test, shown in **Table 1** and **Figure 12** respectively, displays the Rockwell B hardness values for each welded joint type, with the x-axis showing the joint type and the y-axis showing the hardness value. The Butt joint has the highest hardness value of 92, followed by the T-joint at 82. The lap joint has hardness values of 79, while the edge joint has the lowest hardness value at 70.

Table 1: Hardness Value from Rockwell Hardness Testing

Welded Joint	Rockwell Scale	Dwell Time	Indenter Type	Indenter Size	Minor Load (kg)	Major Load (kg)	Hardness (HRB)
Lap Joint	HRB	15 sec	Diamond	1/16 inch	10	60	79
T-Joint	HRB	15 sec	Diamond	1/16 inch	10	60	82
Edge Joint	HRB	15 sec	Diamond	1/16 inch	10	60	70
Butt Joint	HRB	15 sec	Diamond	1/8 inch	10	100	92

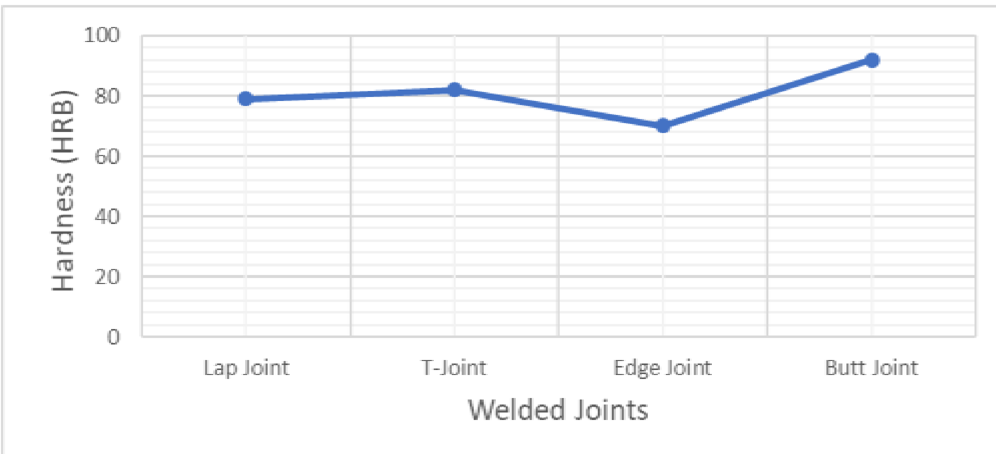

Figure 12: Graph of Hardness (HRB) against Welded Joints

3.1.2 Values for Charpy Impact Test:

Table 2 and **Figure 13** respectively displays the Charpy impact test values for each welded joint type, with the x-axis showing the joint type and the y-axis showing the impact energy (in joules). The Edge joint has the highest impact energy of 23.8 J, followed by the T-Joint at 22.1 J. The butt joint has 21.4 J impact energy while the lap joint has the lowest impact energy value at 18.7J.

Table 2: Impact Test result using Charpy Impact Test

Welded Joint	Material Used	Test 1 (Joules)	Test 2 (Joules)	Average Impact Energy (Joules)
Butt Joint	Mild Steel	20.5	22.3	21.4
Lap Joint	Mild Steel	18.2	19.1	18.7
T-Joint	Mild Steel	21.8	22.4	22.1
Edge Joint	Mild Steel	23.6	24.1	23.8

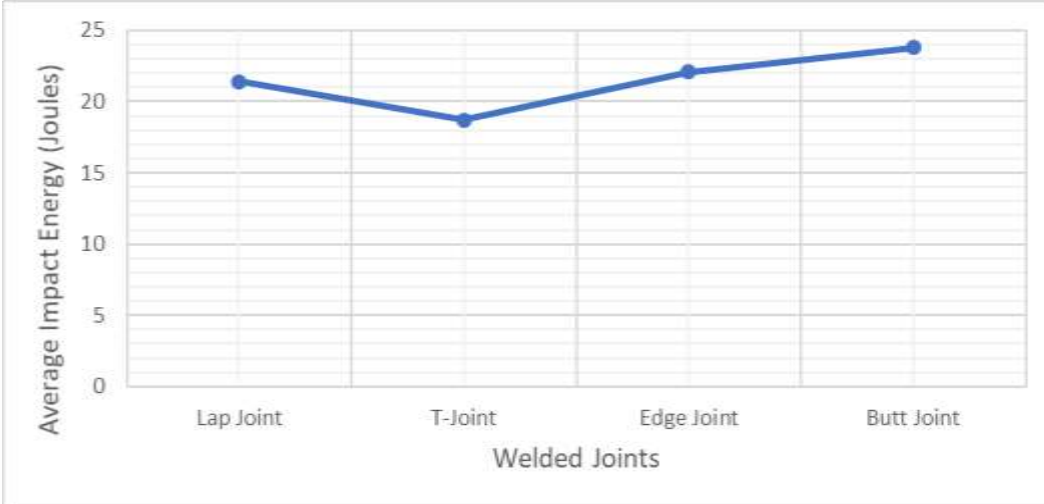

Figure 13: Graph of Average Impact Energy (Joules) against welded joints

4. CONCLUSIONS

Based on the Rockwell hardness test results for mild steel, we can conclude that mild steel has a relatively low hardness. The hardness values obtained for the different welded joints are all within the same range, which indicates that the hardness of mild steel is not significantly affected by the welding process or joint type. The Rockwell hardness test is a useful method for assessing the hardness of materials, including mild steel. However, it is important to note that the results obtained from the test may be affected by other various factors, such as the condition and preparation of the test specimen, the load and indenter type, and the dwell time. Therefore, it is essential to carefully control these parameters to obtain accurate and reliable results. The Charpy impact test is a widely used method to measure the toughness of a material, especially metals. It involves striking a notched specimen with a pendulum hammer and measuring the energy absorbed by the specimen during fracture. For mild steel, the Charpy impact test is commonly used to evaluate its ability to absorb energy in the presence of a notch or defect. The results of the test can provide valuable information on the ductility, brittleness, and fracture toughness of the material. In general, mild steel has good toughness and ductility, which makes it suitable for a wide range of applications. However, the toughness can be affected by factors such as composition, heat treatment, and the presence of defects. Therefore, it is important to carry out Charpy impact tests on mild steel to ensure that it meets the required specifications for a particular application. The results of these tests can help manufacturers to optimize the composition and heat treatment of the steel to achieve the desired toughness and ductility.

From the investigation of failure rate for different types of welding joints using arc welding, the following recommendations can be made: **-** The type of welding joint used should be carefully selected based on the intended application and the expected load on the joint. For example, butt joints are more suitable for applications with high loads and stresses compared to lap joints; The quality of the welding process and the materials used should be strictly monitored to ensure that the welding joint meets the required standards and specifications. This will help to reduce the risk of joint failure due to poor weld quality; Charpy impact testing can be used as a reliable method for evaluating the impact resistance of welding joints. This can help to identify potential weak spots in the joint and guide the selection of suitable joint types for different applications; Rockwell hardness testing can be used to evaluate the hardness and strength of welding joints. This can help to ensure that the joint can withstand the expected loads and stresses. Further research can be conducted to investigate the failure rate of different welding joint types under different loading and environmental conditions. This will help to improve the understanding of welding joint behavior and guide the selection of suitable joint types for specific applications.

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