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Optimization of Flux Composition for Enhanced Penetration Depth in F-GTAW Processes Using the Taguchi Method

Syed Mohiuddin [1], R S Kiran [2]

[1,2] Department of Mechanical Engineering, S V P Engineering COLLEGE- Andhra University, Visakhapatnam, India.

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Abstract:
The Taguchi technique is used to investigate how oxide fluxes effect arc constriction, current density, and weld depth. Researchers can improve TIG welding efficiency, pass count, and weld quality for precise applications by optimising flux formulations. The optimal parameter combinations for penetration depth & structural integrity assist TIG welding overcome its drawbacks, such as limited productivity and material composition sensitivity. Tungsten Inert Gas or TIG welding optimisation relies on the Taguchi approach, especially when studying multi-component fluxes' impacts on weld properties. Weld penetration impacts TIG welding joint quality and integrity, affecting depth-to-width ratio, which dictates pass count. To evaluate the impact of flux composition on weld penetration, morphology, along with δ-ferrite content in 6mm solid AISI 316L austenitic stainless-steel plates, the Taguchi method can be used to create an experimental design. The Taguchi method lets you thoroughly study control factors like flux makeup, current, and welding speed. The goal is to find the best conditions for improving weld quality and penetration. Because orthogonal groups are used, the method makes sure that only a few experiments are needed to see how these factors affect each other. Signal-to-Noise (S/N) ratio research can also be used to find the best choices for a process that will always produce high-quality results with little variation.
Keywords: Taguchi Technique, Signal to Noise, Penetration, Depth-to-Width Ratio, Flux makeup.

1. Introduction:

The main purpose of the research in this thesis is to find out if the stimulated flux tungsten gas arc welding (A-GTAW) procedure could be used as an alternative way to weld high strength low alloy (HSLA) naval metal DMR-249A and to see how the different arc welding processes change the properties of DMR-249A joints that have been welded. Researcher looked at whether A-GTAW could be used as an alternative way to weld DMR-249A steel by looking at the thermomechanical behaviour, microstructure, and mechanical features of weld joints made with this method. We used FEM to model the temperature gradients along with remaining stress profiles of safeguarded metal arc welding (the SMAW) along with A-GTAW processes and then compared the results with those from experiments. It was looked at how different arc welding methods, such as SMAW, FCAW, SAW, and A-GTAW, affected the microstructure, mechanical characteristics, residual stresses, and rust features of DMR-249A welded joints.

1.1. High Strength Low Alloy Steels:

Mn alloy grades containing 0.3% C & grain-refining elements like V, Nb, and Ti increase brittle fracture resistance in HSLA steels. With alloying elements like Si, Ni, Cu, Cr, and Mo, yield strength is achieved. Equiaxed fine-grained ferritic alloys like HSLA have high yield strength & weldability. High-strength, low-alloy (HSLA) steels are often used in building, pipeline, and ship construction. These materials' strength, toughness, and weldability are their main benefits. Thus, 4 HSLA steel is ideal for large-scale welded steel constructions [3-5]. Its high weldability and absence of preheat make large-scale construction easier and minimise processing costs. Depending on how fast the steel cools and what kind of steel it is, base material close to the fusion area will change into austenite, martensite, ferrite, and/or bainite during the welding temperature cycle. The dynamic features of these distinct phase micro structures are different. Most HSLA steels have a HAZ that is between 2 and 6 mm wide. The base plate has grains that are about 3 to 7 µm in size and is made of an equiaxed ferritic structure via a small amount of pearlite [6-10]. The weld metallic in the welding spheres has a normal microstructure that includes wafer-shaped ferrite, acicular ferrite, and hexagonal Widmanstatten. It also has microphases of bainite along with martensite. The proeutectoid ferrite possesses an even shape or thin lines that show where the austenite grain borders were. On the other side of plate Widmanstatten ferrite, you can see the straight ferrite laths that come from the edges of the austenite grains. Between the bodies of the austenite grains is the acicular ferrite, which is thought to be a toughening process that makes the weld metal stronger and more durable. A fine "basket-weave" microstructure is made when acicular ferrite nucleates intragranular in non-metallic particles. This makes the material very hard for cracks to spread. Choosing the right welding process factors is very important for controlling the intricate method of acicular ferrite nucleation.

1.2. Taguchi method:

Robust design distinguishes Taguchi method from other methods by making goods and processes less vulnerable to uncontrolled elements like environmental changes and production errors. The technique proposes making systems immune to noise (uncontrollable impacts) rather than just meeting targets. Taguchi proposed the Signal-to-Noise (S/N) ratio for a robustness metric, where "signal" indicates intended effect and "noise" unwanted variability. A larger S/N ratio indicates system robustness, ensuring reliable performance under diverse situations. By optimising performance and stability, engineers can ensure goods work effectively in real-world settings, not just ideal ones. The Taguchi approach uses orthogonal arrays for efficient experimental designs. While evaluating all potential combinations of variables and levels may be costly and time-consuming, orthogonal arrays provide valuable insights with fewer tests. Selecting the right input elements allows engineers to optimise the process with least work and resources, identifying those having the greatest influence on output. The Taguchi approach helps companies and architects create high-performing, cost-effective, and dependable products. Reducing variability and enhancing resilience improves quality, defect rates, and process efficiency. The Taguchi approach is frequently used in sectors including automotive, electronics, and aerospace to improve product performance and optimise manufacturing processes, where quality and dependability are crucial.

1.3. Procedures of Welding:

Traditional welding with arcs (fusion welding) is often employed in building structures such as bridges, nuclear power plants, ships, machines, and space spacecraft. Submerged Arc Welding (SAW) along with Flux cored Arc Welding (FCAW) are popular automated welding processes, while Shielded Metal Arc Welding (SMAW) is utilised for on-site manual welding and repairs. The activated flux Tungsten Inert Gas (A-GTAW) provides a cost-effective non-conventional automated welding method that boosts productivity Activation flux, an inorganic particle, is applied to the steel plate before welding in A-GTAW welding. When switching from GTAW to A-GTAW, the penetration depth increased by 1.6 to 4 depending on the metals being welded. The process of Welding is shown in

Figure 1.

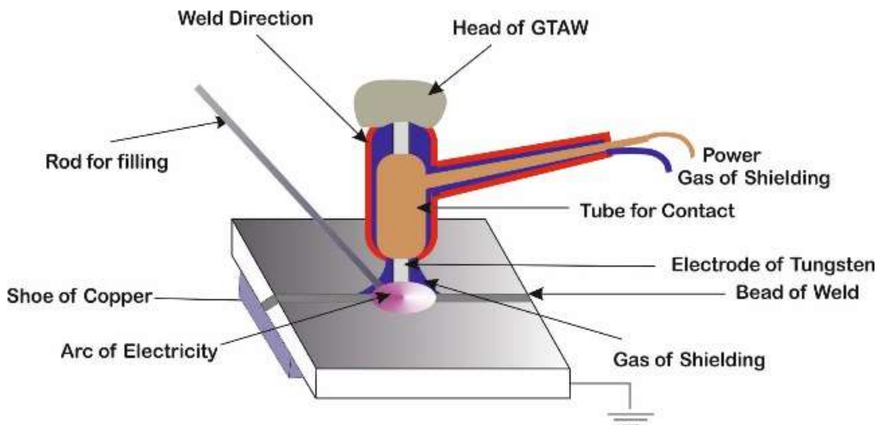

Figure 1. Process of Welding

1.4. Modelling and simulating with finite elements:

Researchers have developed numerical models to explain how welding process factors affect weld characteristics. The welding source of heat must be changed to imitate welding. Major heat source features include mobility over time and space. An analytic heat source approach, the double ellipsoidal model, was suggested by researchers. Researchers discussed the thermo-mechanical model and simulation methods for multi-pass welding. A researcher used several finite-element (FE) models to demonstrate the impact of various modelling methodologies on the computer simulation of the thermo-elasto-plastic phases of welding. Several scholars have reported on thermo mechanical modelling of naval construction arc welding. FEM analysis has been shown effective for predicting thermal and stress residual trends in welding operations using SYSWELD software, as confirmed by experimental findings.

2. Study of Methods and Simulations:

2.1. Ansys Study on Simulation:

A lot of people use ANSYS FEA, or finite element analysis, software because it can help engineers in many fields figure out and solve difficult problems. At its fundamental level, finite element analysis provides a way to use numbers to break down a big, complicated system into smaller, easier-to-handle pieces called elements. It's up to the user to decide how small or thorough these parts should be, which lets them look at the system in great depth. There are scientific models that describe how each part of the system acts and how the whole system reacts to different situations. ANSYS solves these equations and gives information about stress, strain, temperature impacts, fluid dynamics, among other important things in the system. The results are usually shown both in graphical and tabular forms, which makes them simple to understand and useful for improving designs. The versatile program is ideal for complex systems with complex geometry, size, or governing equations that are difficult to analyse manually. ANSYS enables engineers and scientists to simulate real-world variables, including temperature, pressure, and structural stresses, to analyse their impact on the system. ANSYS is essential for exact design and optimisation, allowing users to forecast performance difficulties before creating physical prototypes. This FEA tool significantly reduces development costs and improves design correctness, making it beneficial in sectors including aerospace, automotive, electronics, and materials research.

Many mechanical engineering departments worldwide use ANSYS as their major FEA teaching tool. As engineering students' model and solve real-world issues, ANSYS imparts FEA concepts, providing practical skills for industry. Besides the mechanical engineering field, ANSYS is widely utilised in civil, electrical, physics, and chemical departments. For instance, civil engineers may use ANSYS to assess the structural integrity of bridges and other structures under different loads. Electrical professionals may use it to analyse electromagnetic field behaviour in complicated systems. Applying ANSYS across disciplines highlights its value as a practical and instructional tool in STEM professions. ANSYS is highly adaptable, providing modules and tools for a wide range of engineering applications. The software package offers specialised abilities for structural evaluation, fluid dynamics, thermodynamics, electromagnetics, and crash simulations. ANSYS' versatility enables researchers and engineers to customise it for unique applications, such as heat distribution analysis, airflow simulation, or electromagnetic interference analysis. As an industry-standard FEA tool, the program is trusted for crucial analysis and innovation because to its flexibility and depth.

ANSYS is a crucial tool for industrial design and testing. It reduces physical testing and speeds time to market by offering accurate, reliable simulations to optimise goods. Before manufacturing a product, engineers may use ANSYS simulations to discover flaws or inefficiencies and make educated design choices. This proactive method of solving issues has rendered ANSYS a leader in engineering innovation and design, advancing technology in many sectors.

2.2. Details about what ANSYS can do:

2.2.1. Structural:

Civil engineering (buildings and bridges), military and aviation engineering (ship frames and aeroplanes frames), along with engineering for machines (machine housings, pistons, and tools) all use the finite element method for structural analysis. It involves evaluating stresses and displacements under various conditions:

Static Analysis: Measures steady-load displacements, strains, etc. ANSYS performs both linear and nonlinear static studies, including plasticity, stress stiffening, high deflection, big strain, high elasticity, contact surfaces, and creep.

TDA: Assesses structural response to time-dependent stresses. It includes nonlinearities from Static Analysis. Mode forms and buckling loads are calculated. ANSYS examines linear (Eigen value) & nonlinear buckling. Additionally, ANSYS provides specialised features such as fracture mechanics, composite material evaluation, fatigue analysis, and p-Method and beam studies.

2.2.2. Thermal:

ANSYS can perform steady state & transient thermal studies for any kind of material with defined boundary conditions. Steady-state thermal analysis evaluates the effects of continuous heat load on a system or component. Engineers usually start with steady-state analysis.

Circumstances before transient thermal analysis. Alternatively, steady-state analysis may finish transient thermal analysis after dealing with all transient impacts. ANSYS calculates temperatures, gradients, flow rates, and heat fluxes from constant thermal loads such convection, radiation, heat fluxes per unit of area, heat production rates per unit volume, along with constant temperature bounds. Steady-state thermal analysis can be either linear or nonlinear, depending on where the material characteristics fluctuate with temperature. The thermal behaviour of most materials is nonlinear owing to temperature-dependent characteristics. Radiation boundary circumstances complicate the analysis significantly, making it nonlinear. Time-dependent transient thermal calculations enable ANSYS to calculate distributions and provide visual model representations using incremental time displays.

2.3. Simulation: Conditions at the edges:

The border parameters are defined within an Ansys static structure simulation in the picture given. Based on what you can see, here's a full explanation:

2.3.1. Unchangeable Support:

The blue square in the picture, which is from the far-left edge of the building, shows the stable support. There are no degrees of freedom for movement or rotation in the supported area because of this border condition. In other words, the set part can't turn or move in any way (X, Y, or Z). In real life, this kind of border condition is often used to make it look like an element of the building is firmly linked or fixed and can't move.

2.3.2. The welded region (the green area):

The green region in the middle of both rectangular pieces may be the weld or joint area. This area is crucial for structural analysis because to substantial stress and deformation under loading. Although the figure lacks specifics on boundary conditions, it is likely that thermal or mechanical loads are used to represent tensions in the welded area.

2.3.3. Other Assumptions and Symmetry:

There may be ideas about symmetrical or other limits on the right side (grey part), even though they are not shown directly. The only side that has a stable support is the left side. This means that the right side could have a border condition that lets it move or shift when it's loaded.

2.3.4. Conditions of Loading and Other Things:

Load application sites are not shown in the figure, however static structural models often apply forces, pressures, or temperatures to assess material response. These loads might cause deformation or stress on open surfaces or other elements of the structure, which is analysed under the fixed support. Key boundary condition in image: fixed support on left side prevents movement or rotation. Although not visible in the photograph, the weld site may undergo loading-induced strains or deformation. One portion is anchored in this configuration to test the material's structural reaction to loading.

2.4. A single pass:

A single-pass condition involves just one movement of fluid or thermal power through the system. Modelling and analysing this configuration are easier due to its consistent temperature gradient, particularly compared to multi-pass systems. For homogenous heat transfer or stress and deformation analysis under stable thermal or mechanical loads, ANSYS may employ single-pass conditions. As the fluid / heat moves once, this configuration has fewer variables & is easier to mimic. Single pass is particularly useful for estimating structural and thermal response during preliminary design and optimisation.

2.5. Double pass:

The double-pass condition permits fluid or heat to flow twice through the system. This configuration enhances heat transfer efficiency by exposing materials to thermal stresses twice, resulting in more equal temperature distribution over the structure. Simulating a double-pass situation in ANSYS requires setting boundary conditions of the second circulation of fluid or heat, affecting steady-state and transient studies. Structural analysis should account cumulative thermal contraction or expansion from multiple heating cycles, that may create stresses do not present in single-pass situations. Double-pass simulations help designs with Improved heat transmission without several circulations, as seen in compact heat exchangers.

2.6. Triple pass:

In a three-pass system, fluid as well thermal energy cycles three times, enhancing heat dispersion and efficiency. It maximises heat source-material contact, which is ideal for confined areas and high heat-transfer rates. A three-pass condition in ANSYS necessitates sophisticated boundary conditions to accommodate numerous circulations and probable temperature gradients. As materials undergo repeated heat loading and unloading, structural analysis must account cumulative stress, deformation, and fatigue. Three-pass conditions are often used for temperature consistency and heat enhancement. Transfer is important in chemical reactors and multi-phase heat exchangers.

2.7. Coupled terrain:

Coupled-field analysis examines the relationship between engineering disciplines. In piezoelectric analysis, the voltage distribution induced by applied displacements and vice versa is utilised to analyse the interaction between structural & electric fields. Various domains, such as thermal-stress, thermal-electric, and fluid-structure analysis, collaborate to give a complete knowledge of system behaviour. There are many situations that need coupled-field analysis, such as: Researcher look at thermal stress in pressure tanks, fluid structure in flow restrictions, magnetic-thermal study in induction heating, and piezoelectric analysis in micro-electromechanical systems (MEMS), magneto structural analysis in magnetic making, and ultrasound actuators.

2.8. Analysis of Modal:

Typically, a formal study is needed to establish the inherent frequencies & mode shapes of a machine or structure during operation. Additionally, it may serve as a first step for more complicated investigations like harmonic response or complete transient dynamic analysis. Although essential in ANSYS, modal analysis might be more computationally demanding than static analyses. To decrease complexity and speed up solution time, a reduced solvers is used to pick important degrees of freedom automatically or manually.

2.9. Analysis of harmonics:

ANSYS harmonic analysis is widely used by rotating equipment makers to predict the dynamic reaction of structures under recurrent cyclic stresses. This specialised examination validates machine designs' capacity to reduce resonance, fatigue, and additional negative impacts from forced vibrations. To optimise designs for durability and operational dependability under cyclic loading circumstances, engineers may simulate and analyse harmonic frequencies and their influence on structural integrity and performance.

2.10. ANSYS Simulation Application:

ANSYS simulations use single, double, as well as three-pass conditions based on system needs and design limitations. By controlling heat flows and temperature limits in steady-state thermal analysis, engineers may better simulate operational performance. When doing transient thermal investigation, the total number of passes impacts the pace of thermal equilibrium & helps visualise time-dependent temperature and stress distributions. Multi-pass simulations enhance structural effectiveness by analysing the effects of multiple thermal loading cycles, enhancing design durability, dependability, and integrity.

2.11. Importance in a Wide Range of Engineering Settings:

Understanding pass circumstances in thermal & structural studies is essential for accurate modelling and design in several engineering domains, including mechanical, civil, and chemical. Engineers can optimise thermal management & structural robustness in high-performance settings such as exchangers for heat, pressure vessels, and pipe systems using single, double, & three-pass conditions. ANSYS correctly simulates pass circumstances, enabling engineers to make dependable, optimised designs that enhance functionality and longevity in complicated systems.

3. FLUXES and GTAW:

3.1. Welding:

In welding, two metals are joined by applying pressure and heat using an electric arc. Arc weld is a fusion method of welding that uses electrical arcs to liquefy metals and create a strong bond.

3.1.1. Parameters of TIG Welding:

Power: 331w
Torch type: Button torch
Shielding Gas: Argon (Ar)
Pre Heating: None
Welding Current: 41 Amps
Welding Voltage: 13V
Gas flow limit:13 L/min
Cup size: 9 mm

3.2. SMAW (Shielded metal arc welding):

The "stick welding" method uses a flux-coated electrode to shield the hot metal (Fig 4.8). During melting, the electrode holder firmly holds the electrode. Slag protects the hot weld from contaminants in the air. Metal shielded SMAW creates heat by producing an electrical current between a flux-covered electrode tip & the base metal surface. Electrode contains a mineral & metallic compound around a tiny metal core. Coating composition depends on electrode type and welding polarity. It protects the weld pool, removes impurities by fluxing, and adjusts chemical composition for optimal mechanical properties. SMAW is a welding technique that may be used in tight places and any orientation. The joining process is practical for most metals and alloys, using portable and affordable equipment.

3.2.1. Benefits and Drawbacks of SMAW:

Advantages of SMAW include simplicity, mobility, and cost-effectiveness compared to other arc welding methods. Reason being, SMAW is usually used for repair, maintenance, and field construction. However, shielded metal arc welding (a SMAW) gas shields lack the necessary purity for welding metals that react like aluminium. Using high welding currents might cause electrode coverings to overheat and detach, limiting deposition rate. Regular electrode replacement is necessary due to the electrode's limited length of 36 cm, which reduces manufacturing rate.

3.3. Arc welding with gas tungsten:

GTAW, also known as TIG, uses a tungsten electrode that is not consumable to create welds (Fig 4.9). To prevent contamination of the weld area, an inert shielding gas like Argon or Helium is employed. GTAW fuses metals by delivering heat via an electric arc among a tungsten electrode and the workpiece. Pressure while filler metals are optional, while welding flames provide shielding. Using a tungsten electrode that is not consumable & inert shielding gas results in better open arc welding quality than other approaches. Welds are polished and leave little residue or spatter, requiring minimum or no cleaning. While Gas Tungsten Arc Welding (the GTAW) is suitable for all welding circumstances, it requires operator experience, especially for delicate and intricate components. It is often used in industries such as aerospace, aviation, energy, chemicals, & oil & gas.

3.3.1. Benefits and Drawbacks of GTAW:

Gas tungsten welding with arcs is ideal for attaching thin components owing to its lower heat input. The welding current has little impact on how much is fed of filler metal, allowing for freedom in altering the fusion ratio among the base metal & filler metal. It is able to adjust the dilution and energy input without changing the weld size. It may also fuse thin sheets altogether without filler metals, called autogenous welding. GTAW is ideal for welding metals that react such as titanium, zirconium, aluminium, and magnesium due to its high degree of purity. GTAW deposition is low. Using high welding currents may melt the tungsten electrode, causing brittle inclusions within the weld metals. Utilising warmed filler metals helps accelerate material deposit. Hot-wire GTAW involves direct contact between the wire and the weld pool. Resistance heating occurs when an electric current is supplied via the wire.

3.4. GMAW (Gas metal arc welding):

GMAW, often known as MIG, uses a wire feeding gun to deliver wire at a variable pace. A shielding gas, such as argon or argon and CO_2, protects the weld puddle from environmental contaminants (Fig 4.10). GMAW welding utilises automatic feeding of a solid, consumable electrode. This electrode is shielded by external gas. The method is used to fuse commercial metals such steel, aluminium, stainless steel, and copper. This welding method may be used in any direction with the right settings and equipment. GMAW uses positive DCEP polarity. Welders only need to manually modify gun placement, guidance, and travel speed since the equipment has automated arc control. The technology of flux-cored arc welding (the FCAW) is comparable to MIG welding. Unlike others, it uses a flux-filled tubular wire. You may apply this procedure with or without shielding gas, according to the filler material. FCAW electrical arc welding is designed for carbon, stainless, and low-alloy steels. A continuously tubular filler metal electrodes is fused to the base material using an electric arc, with or without a protecting gas. In gas protected flux-cored wire, a flux-filled tubular electrodes provides shielding. Externally supplied gas enhances electrode core components, preventing molten metal contamination from the environment. The use of voltage-detecting feeders enables high-quality flux-cored welding with a constant current welding power source. Apply this method to all welding spots, selecting the suitable filler metal and circumstances. Shielding gas utilisation results in similar process equipment to GMAW.

3.5. SAW (Submerged arc welding):

A consumable electrode is automatically supplied with granular fusible flux in submerged arc welding (SAW). Fully

coated by the flux blanket, the molten weld and arc zone are protected from air contamination. In Submerged Arc Welding (SAW), an electrical arc is created between an electrode and the material, shielded by a flux substance. A continuous, solid wire electrode is used in this process, shielded by flux. When welding, flux stabilises the arc by shielding the molten pool with the atmosphere. Moreover, it protects and covers the weld during cooling, possibly impacting its composition and quality. Although SAW is predominantly mechanised, semi-automated methods are also available. Current may be AC or DC. Automated systems may use electrodes from a single wire to many solid and tubular wire or strips.
Granular flux & the molten welding pool's flow confine welding to flat or parallel placements. This method enables rapid deposition rates and versatile welding of materials from thick to thin. Submerged Arc Welding or (SAW), advantages from the protective & refining impact of slag, resulting in clean welds. The arc is submerged, preventing spatter and heat loss, even with high welding currents. Incorporating alloying ingredients and metal powders into granular flux helps adjust weld metal composition and increase deposition rate. Using many electrodes sequentially improves deposition rate. Compared to GTAW and GMAW, SAW (Submerged Arc Welding) can fuse thicker workpieces because to its faster deposition rate. Large amounts of molten slag & metal pool may limit the use of SAW for flat position & circumferential welded pipes. Increased heat input may impact weld quality and increase distortion.

3.6. Things that affect the penetration of a weld:

Influences on penetration depth Different welding settings affect the depth of weld penetration. The following points, in no particular order, highlight how welding process factors affect penetration depth, assuming constant variables.

3.6.1. Current:

The current, determined by amperage or amps, is the most important welding parameter affecting weld penetration. Increasing welding current (amperage) will also enhance the quantity of weld penetration. When using constant current (CC) outputs in arc welding, the major variable is the current. When using constant voltage (CV) the output, main welding variables are voltage & wire feed speed (WFS), with current being a consequence of WFS. Rising water flow rate (the WFS) leads to higher current levels for particular electrode types and diameters.

3.6.2. Polarity:

The depth of penetrating depends on welding polarity. In most welding methods, DC+ polarity leads to better weld penetration by concentrating arc energy on the base plate. Conversely, DC-polarity leads to less weld penetration since more arc power is directed to the electrode's surface instead of the base plate. SMAW, GMAW, FCAW, and SAW processes are instances of this phenomena. When using gas tungsten arc welding (the GTAW), polarisation has the opposite impact on penetration comparing to other welding processes. Gas Tungsten Arc Welding (GTAW) often enhances weld penetration using DC- polarity, whereas DC+ polarity is seldom used. Superior arc stability & accurate control throughout weld deposition rates along with penetration levels are achieved with advanced power sources using Waveform Control Technology & AC. Additionally, they may manage the alternating current wave's balance, current deviation, and frequency to affect welding characteristics more.

3.7. A-GTAW welding:

A-GTAW welding will be covered in this overview. To improve the penetration of an arc in GTAW welding, add a flux coating with particular inorganic compounds to the joint surface before welding. Fluxes reduce the impact of material composition changes on penetration from one casting to other. Additionally, they guarantee constant penetration across base metal compositions throughout heats. Oxide particles are mixed with acetone & binder to form a paste. The flux paste is manually applied to the plate bead surface using a brush preceding welding (Fig2.12). The acetone evaporates, leaving surface flux deposition. Next, autogenous GTAW the welding process is done.

4. Results:

4.1. Simulation: Conditions at the edges:

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Structural Boundary Condition:

The border constraints are defined within an Ansys static structure simulation in the picture given. Based on what you can see, here's a full explanation:

4.1.1. Stable Help:

The blue square marking on the left side of the construction represents the permanent support. The boundary condition limits translation and rotation degrees of freedom in the supported zone. A stationary component will not move within any way (X, Y, or as Z) or rotate. Boundary conditions are often used to represent real-world scenarios when a structure is solidly attached or fastened, restricting movement.

4.1.2. Region that Welded:

The centre green region of these two rectangular pieces may be the weld or joint area. In structural analysis, this region is crucial due to substantial stress and deformation under loading. The picture does not provide specifics on the boundary circumstances for the weld location, however thermal or mechanical loads may be used to model stresses.

4.1.3. Other Assumptions and Symmetry:

The right-hand side (grey half) may include assumptions about symmetrical or additional constraints, which are not immediately presented. The right side might possess a boundary condition that allows movement or displacement under stress, since just that side has a permanent support.

4.1.4. Conditions of Loading and Other Things:

Load application sites are not shown in the figure, however static structural models often apply forces, pressures, or temperatures to assess material response. These loads might cause deformation or stress on unsupported surfaces or other elements of the structure, which is analysed under the fixed support. Key boundary condition in image: fixed support on left side prevents movement or rotation. Although not visible in the photograph, the weld site may undergo loading-induced strains or deformation. One portion is anchored in this configuration to test the material's structural reaction to loading.

4.2. Results of the thermal study simulation:

A look at temperature Playing Games Representation in Graphics This paper's thermal analysis is mostly about two things: how the temperature and heat move through the material when it goes through single, double, along with triple runs. Figure 2 shows how temperature and heat flow are distributed using thermal analysis.

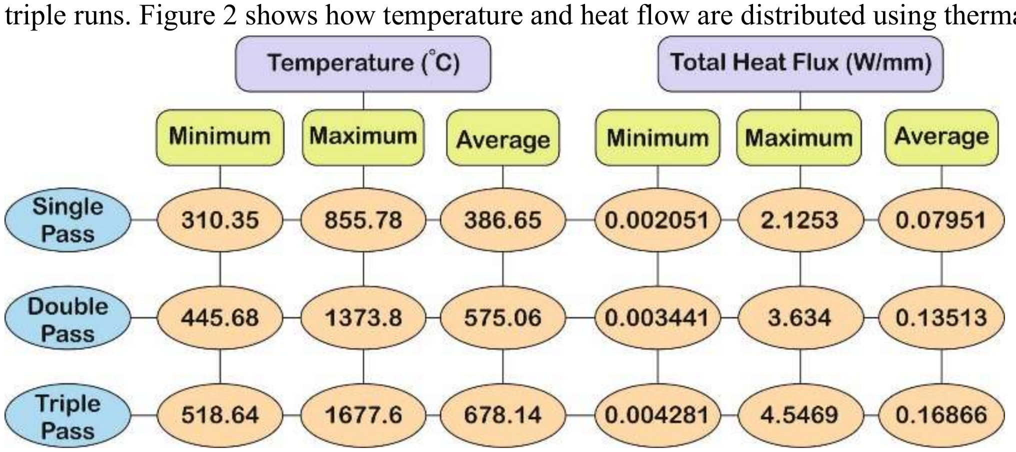

Figure 2. Diagram of how temperature and heat flow are distributed using thermal analysis

4.2.1. Spread of Temperatures:

Temperature distribution graphs (Figure 3) show a gradual rise in material maximum temperature with many passes. The temperature rise is significant, ranging from 855.78°C in single-pass configuration to 1373.8°C in double-pass and 1677.6°C in triple-pass. Each pass increases the maximum temperature significantly, illustrating the cumulative impact of thermal cycles. Heat builds up as more pass are made, adding thermal energy to the material. The cumulative heating effect raises the total temperature, possibly causing thermal strains, expansion, or deterioration if the material's temperature threshold is exceeded.

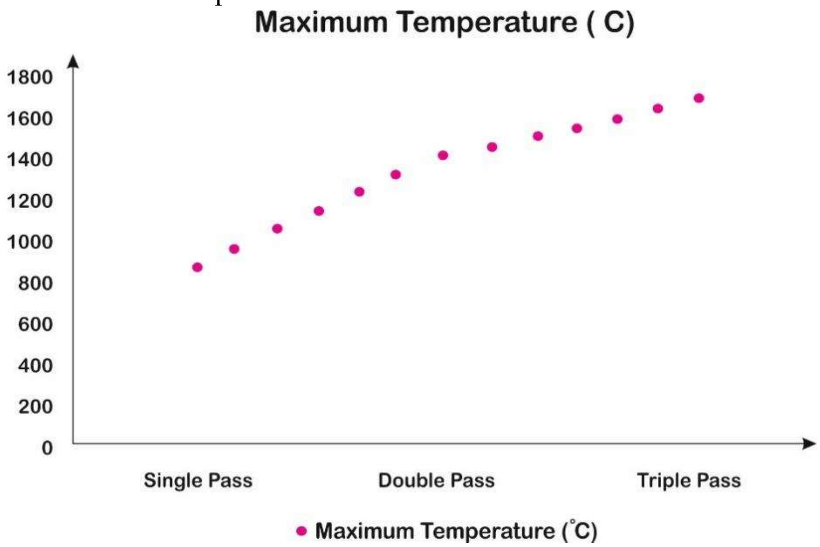

Figure 3. Maximum Temperature (℃)

4.2.2. Spreading out the heat flux:

Additionally, heat flux distributions graphs (Figure 4) demonstrate that the highest heat flow rises with more passes. For instance, maximal heat flux is at. The single-pass configuration produces 2.1253 W/mm2, whereas the double-pass configuration produces 3.634 W/mm2 and the triple-pass configuration reaches 4.5469 W/mm2. Heat flow as the material traverses more cycles, it retains more heat and suffers a greater rate of heat exchange per unit area, increasing with each pass. This is critical for applications requiring steady heat distribution, since each pass increases the material's thermal burden. Increased heat flow in the triple-pass instance indicates material thermal management capacity stress, potentially causing fatigue or overheating difficulties if not adequately handled.

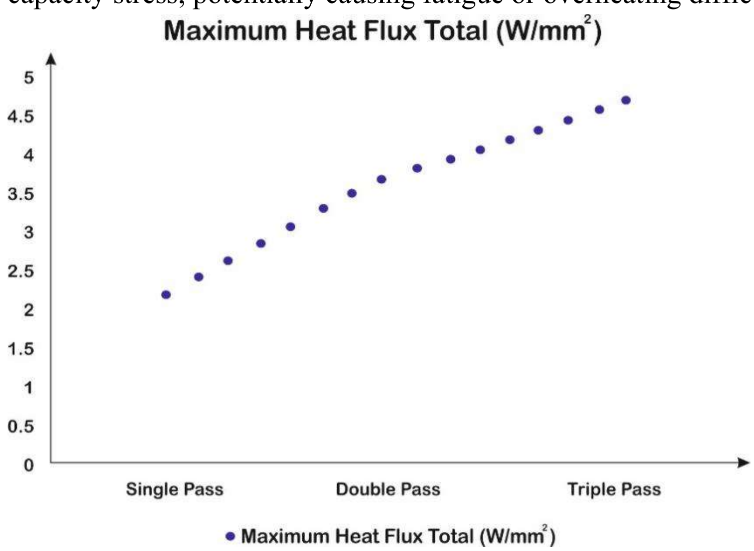

Figure 4. Maximum Heat Flux Total (W/mm^2)

4.3. Results of the Structural Analysis Simulation:

Structure Simulation Visualisation the part on structural analysis examines how numerous passes impact the material's physical structure, including total deformation, equivalent elasticity strain, and von-Mises stress.

4.3.1. Deformation in Total:

Total deformation indicate a rise in average deformation with more passes. The single-pass arrangement has an average deformation about 0.10076 mm, whereas the double-pass climbs to 0.15224 mm and the triple-pass to 0.18088 mm. Deformation refers to the physical displacement or shape change of a substance under heat or mechanical stress. As passes increase, the material deforms due to accumulated heat and thermal pressures. This gradual deformation reflects the material's reaction to heat expansion and stress redistribution, intensifying with each pass. In the triple-pass instance, increased deformation indicates structural changes that may compromise mechanical integrity, particularly in applications requiring exact dimensional stability.

4.3.2. Similar Stretching:

As passes rise, so does comparable elastic strain. The strain increases from 6.06E-03 during the single pass to 9.08E-03 during the double pass and 1.08E-02 during the triple pass. The equivalent elastic strain indicates a material's ability to stretch or compress without permanent deformation under stress. Increased strain with repeated heating indicates increased internal tensions, causing material to stretch or compress farther. The increasing strain indicates that each temperature cycle stretches the material's atomic structure, bringing it closer to its limit of elasticity. If strain increases with successive passes, the substance could exceed its limit of elasticity, causing plastic deformation and irreparable damage.

4.4. The Effect of Si & O Concentration on DOP and Activated Fluxes:

The concentration of components like Silicon (Si) and Oxygen (O) within the flux mix affects activated flux welding processes. Deep Penetration (DOP) during welding is influenced by concentrations. Understanding these correlations may optimise flux compositions. This paper examines how differing Si & O concentrations impact DOP in activated flux mixtures.

4.4.1. Depth of Penetration vs. Si Concentration:

Figure 5 shows how the proportion of Silicon (Si) in active flux affects Depth of Penetration (DOP). By analysing this connection, we can determine whether Si concentration directly affects DOP.

- DOP seems to fluctuate nonlinearly via respect to Si content, as seen in the data. Although there is no direct correlation between DOP and Si %, a broad trend may be seen. DOP peaks at 4.16 mm with greater Si concentrations (about 0.25%). Si concentration drops to 0.23%, resulting in a moderate DOP reduction to 4.1 mm.
- Si concentration can lead to optimum penetration within a limited range, as shown by this pattern. Insufficient or excessive Si may reduce penetration owing to its impact on flux viscosity, oxidation behaviour, and thermal conductivity.
- Silicon may affect slag production in welding fluxes, causing physical and chemical effects. Slag layers with higher Si concentration may be more solid, trapping more heat & improving penetration depth. Increased Si levels may cause brittleness or modify slag viscosity, slowing energy transmission through the weld pool & lowering DOP.
- Taguchi's orthogonal array enables us to identify the optimal Si value (high or low concentrations) for maximising DOP.
- The S/N ratio indicates whether a greater or lower Si content leads to deeper penetration.
- Taguchi Method Insights: Moderate Si concentration may be the optimal balance between maximising DOP and lowering variability, supporting earlier data. This ideal level guarantees steady arc and constant penetration.

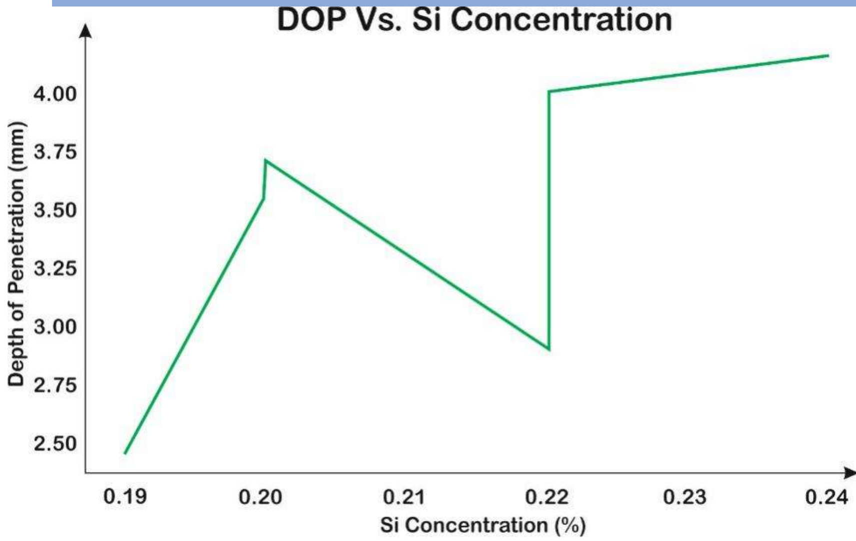

Figure 5. DOP vs. Si Concentration

4.5. Summary of the Taguchi Method:

The Taguchi method can be used on both the heat and structural study data to get the following important things:

- In a Taguchi experiment, control elements like as pass count, material characteristics, and heat input may be optimised. Analysing the impacts of these parameters using an orthogonal array enables optimised layouts that reduce temperature, deformation, strain, & stress.
- The Taguchi approach enables robust design, ensuring constant and dependable material performance despite external disturbances or fluctuating production circumstances. Maximising the S/N ratio reduces variability and ensures solid results.
- Minimising Variability: Taguchi approach effectively identifies process conditions that moderate reactions like temperature, heat flux, and stress. This enables engineers to create designs that are high-performing, repeatable, and dependable for real applications.
- The Taguchi technique may improve production efficiency by optimising pass count and other aspects, decreasing material waste, energy consumption, and time, while also enhancing product performance.

Finally, using the Taguchi technique for thermal and structural study data allows for a statistical approach to design optimisation. This approach improves performance & material integrity throughout several runs by identifying essential elements, decreasing variability, and improving resilience, optimising efficiency and dependability.

5. Conclusion:

The Taguchi technique can optimise thermal along with structural analysis findings for single, double, & triple pass instances. Temperature, heat flow, deformation, elastic strain, & von-Mises stress rise with each pass, indicating intensification. The Taguchi approach, using DoE, orthogonal arrays, and S/N ratio analysis, identifies key factors affecting outcomes. The method optimises thermal analysis by determining the optimal number of passes and heat flux management, decreasing overheating risks and ensuring efficient transfer of heat. It also optimises structural analysis by minimising stress concentration and reducing overall deformation, elastic strain, along with von-Mises stress. The Taguchi method's strong architecture prioritises performance and consistency, reducing variability and improving performance. The Taguchi technique addresses complicated engineering issues by raising efficiency, minimising material stress, and increasing dependability in multi-pass processes. Comprehensive ANSYS software analyses were used to undertake thermal and structural evaluations. For single, double, as well as multiple passes welding situations, temperature, heat flux, deformation, equal elastic stress, along with strain were carefully computed. Researchers found that numerous passes welding resulted in larger strains. For stress reduction, single pass welding with a greater deposition over potential (D.O.P) is suggested. Activation fluxes significantly improve D.O.P. Thus, silicon dioxide was used as an activation flux, enhancing welding performance. To evaluate TIG welding, six workpieces were treated with different active flux compositions and radiographed. The radiographic examination revealed that Mix 1 and Mix 2 had higher D.O.P values. Therefore, these compositions are suitable for additional welding applications.

Using the Taguchi technique to analyse the correlation between Si and O concentrations and DOP offers a statistical optimisation strategy. The Taguchi approach identifies optimal Si and O values for maximising DOP, element contributions to DOP variability, & synergistic effects on welding penetration depth.

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