Study the Effect of MIG Welding Parameters on Corrosion Behavior, Mechanical Properties, Angular Distortion, and Weld Bead Profile of Duplex Stainless Steel (2205)

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ABSTRACT

In the fabrication industry, welding plays a significant role in the view of the fact that its suppleness to automation, relative simplicity, strong and reliable joints, and ability to weld an immense variety of materials make it globally acceptable in industries like construction, transport, automotive and pressure vessel industry. To regale the requirements of ever-increasing industrial demands a variety of arc welding processes are available. One such arc welding process is MIG which has proved its importance in the industry owing to its versatility and quality of Weld. The physical dimensions and shape of a weld joint not only decide its mechanical strength but also affects its performance during service. Sufficient knowledge of various bead parameters such as penetration, reinforcement, width, etc. becomes imperative along with their dependence on various welding parameters. The Most influencing parameters of MIG Welding are Welding Speed, Voltage, Wire Feed Rate, Nosal Plate Distance & Gas Flow Rate. Appropriately controlling these input factors, the quality of the weld can be controlled. This work presents the influence of MIG welding parameters on duplex stainless steel 2205. By using Taguchi's L9 orthogonal array, the MIG welding parameters were optimized to achieve the better quality of DSS 2205. The quality of the MIG welding of DSS has been evaluated in terms of corrosion test using the weight loss method, Mechanical Properties like Tensile test, Vickers Micro-Hardness test, Charpy Impact test, Angular Distortion and Weld Bead Profile. Analysis of Variance (ANOVA) the statistical tool has appertained to estimate the individual factor's significance on the desired responses like corrosion, ultimate tensile strength, hardness etc. The Corrosion rate, Mechanical Properties, Angular Distortion and Weld Bead Profile are selected as Decision Variables to employ the Multi-Criteria Decision-Making method the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The Objective Function is to find the optimized value of voltage, welding speed and wire feed rate for Rate of Corrosion, Mechanical Properties like the Tensile test, Vickers Micro-Hardness test, Charpy Impact test, Angular Distortion and Weld Bead Profile. The optimal setting comes out to be Welding Speed 40 cm/min, Wire Feed Rate 6 m/min and Voltage 26 for which Corrosion Rate = 0.0181 mpy, Impact Energy = 60 J, Micro-Hardness = 337 HV, Tensile Strength = 621 MPa, Angular Distortion = 6.62º, Hieght of Reinforcement = 1.500 mm, Depth of Penetration = 2.407 mm and Bead Width = 5.400 mm

Keywords: ANOVA, MINITAB, L9 Orthogonal array, TOPSIS, MIG, WFR, Austenitic Stainless steel, Sulphuric Acid

INTRODUCTION

Stainless-Steels are a significant grade of engineering materials which have found extensive use across numerous sectors and settings. Stainless-Steel is a form of steel that either doesn't corrode or only does sounder very specific circumstances. The occurrence of Crmetal which is more than 11% in Stainless-Steel is the most significant difference between it and carbon steel [1]. When exposed to the open air, normal carbon steel corrodes or rusts quickly (air & moisture). Corrosion happens because of the development of an oxide of iron which covers the surface, and causes formation of flakes and that dwindle in carbon steel. However, in Stainless -Steel, chromium forms a chromium oxide coating that prevents oxygen from diffusing through the steel's surface.Because it contains chromium, Stainless-Steel has high oxidation characteristics at high temperatures. Stainless-Steels have all around applications, including the production of electricity, the processing of chemicals and paper, and in many industrial and commercial products including kitchen appliances and automobiles [2]. Iron makes up between 50 and 88 % of the weight of Stainless- Steel, which is mostly an alloy of iron.

TYPES OF STAINLESS STEEL

1. **Austenitic Stainless Steel** – Highly corrosion-resistant, non-magnetic, widely used (e.g., 304, 316).
2. **Martensitic Stainless Steel** – Strong and durable but less corrosion-resistant; contains high carbon and chromium.
3. **Ferritic Stainless Steel** – Low nickel, moderate corrosion resistance, good mechanical properties.
4. **Duplex Stainless Steel (DSS)** – Balanced ferrite-austenite structure offering high strength and excellent corrosion resistance, especially in chloride and sulphide environments.

MIG Welding (Metal Inert Gas Welding):
MIG welding uses a consumable wire electrode and shielding gas (e.g., argon or CO_2 mix) to protect the weld area. It enables high deposition rates, clean welds (no slag), and automation. Key process parameters such as voltage, wire feed rate, and welding speed significantly influence weld quality.

Corrosion:
Corrosion is the deterioration of metals due to environmental interaction, leading to material loss and structural failure. Even stainless steels can corrode under harsh conditions like chloride or sulphide environments, causing issues like pitting or stress corrosion cracking.

Taguchi Method:
A statistical design of experiments (DOE) technique using orthogonal arrays to optimize process parameters. It minimizes variability and improves quality with fewer experiments. Performance is evaluated using signal-to-noise (S/N) ratios.

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution):
A multi-criteria decision-making method that selects the best alternative based on its closeness to an ideal solution and distance from a non-ideal one. It ensures balanced optimization across multiple outputs like corrosion resistance, strength, and distortion.

LITERATURE REVIEW

The review explores prior research concerning the effects of welding parameters on the corrosion behavior, mechanical properties, and micro structural evolution of various grades of stainless steels, particularly focusing on MIG, TIG, and SMAW techniques.

CORROSION BEHAVIOR AND WELDING PROCESSES

- **Olaseinde (2021)** studied TIG-welded AISI 316 in 0.5M H_2SO_4, showing that base metal had the lowest corrosion rate (0.01873 mm/yr) compared to HAZ (0.87808 mm/yr) and fusion zone (2.451 mm/yr) [16].
- **Balsaraf et al. (2020)** evaluated 409M FSS welded via SMAW, TIG, and MIG. TIG and MIG showed superior corrosion resistance compared to SMAW, with maximum corrosion rates in 0.1M H_2SO_4 (727.10 MPY) [17].
- **Matew et al.** compared TIG and MIG welds on FSS (AISI 430) in varied acid environments. MIG exhibited higher corrosion resistance in acidic mediums, with corrosion rates escalating with acid concentration, especially in H_2SO_4 [18].
- **Iliysu et al.** found corrosion rates in ASS 304 reduced over time in sulfuric acid, with values remaining below 0.1 mm/yr. Chromium and nickel content aided in resistance [19].
- **Omiogbemi et al.** investigated MIG-welded ASS 304 in HCl using a 2-factor design. Optimal corrosion resistance was observed at 40 mm/s welding speed and 110 A current [20].

2.2 Super Duplex and Microstructure Evaluation

- **Bassiouni (2019)** evaluated localized corrosion and microstructural changes in 2507 Super DSS welds. Results showed pitting resistance could be improved by parameter optimization and that corrosion rates were lower at temperatures below CPT [21].
- **Kumar et al.** studied AISI 304L corrosion under different surface textures from cold rolling. Corrosion resistance was better when the surface was parallel to close-packed crystallographic planes [22].
- **Krzysztof et al.** used SEM to assess the impact of magneto-electrochemical polishing (MEP) on 316L SS. Magnetic fields strongly influenced corrosion during MEP [23].

2.3 Welding Parameter Optimization

- **Ghogale (2018)** optimized MIG parameters on cold-rolled steel using Taguchi L9 and found current and voltage had the most significant impact on penetration depth [24].

- **Magudeswaran et al.** focused on DSS 32205 welded by ATIG, identifying electrode gap as a key parameter affecting weld aspect ratio [25].
- **Ameda & Mrudha** explored sensitization in TIG-welded DSS 1500, showing increased weld zone width with increased heat input [26].
- **Femenia I Nobell** studied DSS 2205 and S32705 corrosion in acidic-chloride solutions using micrometer-resolution analysis. DSS S32705 showed more uniform dissolution than DSS 2205 [27].

MULTI-CRITERIA OPTIMIZATION TECHNIQUES

- **Papavat et al.** used Taguchi L9 for AISI 316L MIG welds, finding current as the most influential factor on tensile strength [28].
- **Mandal et al.** applied PCA on TIG-welded DSS 2205 without filler rods. Welding current had the highest influence on tensile strength, affirming PCA's applicability in weld quality optimization [29].
- **Badwal & Singh** examined angular distortion in submerged arc welded low-carbon steel. Welding speed increased distortion, while voltage and wire feed rate reduced it [30].

EXPERIMENTATION

Preparation of Specimen

Veekay India Hacksaw was used to cut all the 9 specimens of Duplex Stainless Steel and all the specimens were cleaned according to standard procedure.

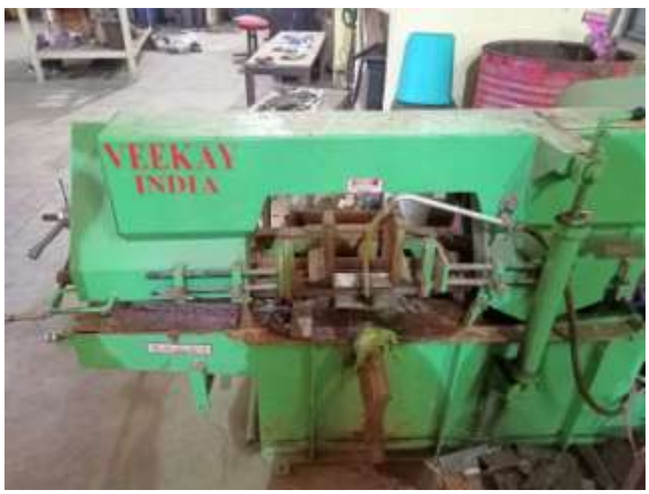

Fig 1.1:Cutting of specimen

Fig 1.2: Cleaning of Specimen

Welding of Specimens
Welding was performed on Semi-automatic MIG welding machine installed in welding workshop of NSUT using Argon gas as shielding gas. Table 4.1 shows its specifications, fig

SHOWS THE WELDING SETUP

Table 1.1 Specification of MIG Welding Apparatus

Model	KH-400
Maximum Current	400A
Minimum Current	50A
Open Circuit Voltage	18-54V
Frequency	50Hz

Fig 1.3 MIG Welding Machine Setup

Fig 1.4: Welding in NSUT Workshop

Fig 1.5: All Welded Specimens

Weight Loss Measurement Method

All the weight loss Measurement method samples were prepared according to ASTM G1 recommended procedures. All 9 welded samples are cut into square pieces of size 90mm X 60mm X 3mm with surface area 1500mm2 as depicted in fig 4.6 and using emery paper of series 150 and 200 were mechanically abrased and then all the specimens were drenched in acetone and water which is distilled to remove oil and dirt and possible product which may be there on surface of plate. Samples will be placed in 0.25M H2 SO4 for 56 days as depicted in fig 4.8 & 4.9 and each sample will be taken after 14 days interval time and every time taken out to measure weight loss these were cleaned using $CH3$ $COCH3$ and distilled water and dried in sun. The weights were measured using digital weight balance of machine sensitivity of 0.001g as depicted in fig 4.7. The observations were tabulated and corrosion rate is calculated in miles per year using mass loss data equation (4.1).

- Mpy = mile per year
- W=Loss of weight (gm)
- D=Sample density (g/cubic cm)
- A=Sample area (sq. in)
- T=Time kept (hr)

$$Corrosion\ rate(mpy) = 534\frac{W}{DAT} \qquad \text{Eq (4.1)}$$

Fig 1.6: Samples preparation for Wt. loss method

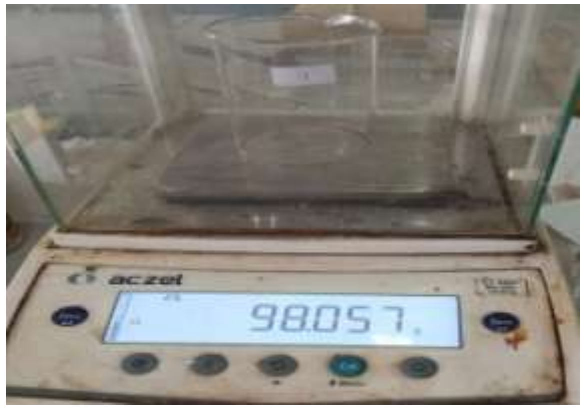

Fig 1.7: Digital Weighing Machine

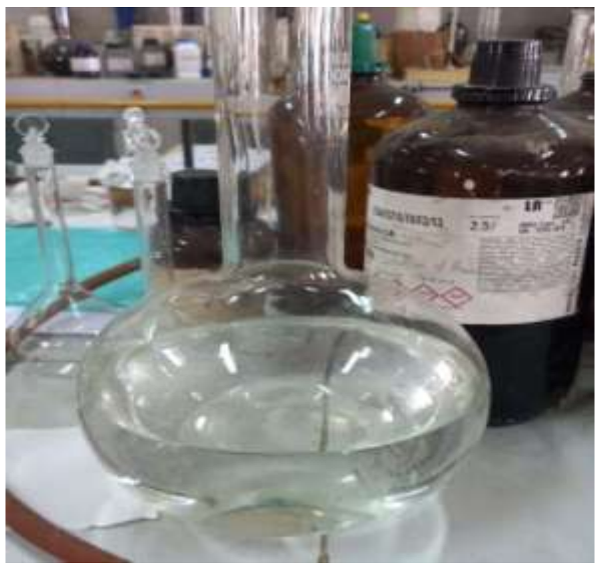

Fig 1.8: 0.25M H_2SO^4

Angular Distortion

The angular distortion of the welding specimens was seen by taking into consideration the instrument depicted in fig. 4.12. As we seen it comprises of a surface plate which is levelled according to the testing standards, a calibrated Vernier gauge used for height and load. The welded samples were kept with some weights present on one of the edges at the surface plate. The Vernier height gauge gave the starting reading A1 noted at this position. When the other edge gets raised to some height the final reading A2 is noted down at this position. The angular distortioncan becalculated by using the equation, sin θ=(A2-A1)/l,where *l* depicts breadth oftheplate0.75cm for these specimens. On implementing the plan of action explained above, distortion in all the specimens was known.

Weld Bead Profile Measurement

The samples were cut using power hacksaw from every of the welded specimens. These samples were mechanically abrased using series of emery papers then polished by using 2000 number emery paper on polisher. Carpenter etchant was prepared in chemistry lab according to the weights mentioned in the paper [23]. This etchant is widely used to get profile of weld bead profile as depicted by Fig 4.13. The images of profiles of welded specimens' bead were forecasted on the screen of an outline projector and their values were calculated employing IMAGE J Software.

Tensile Test

The ASTM (E8) standard was taken into consideration for the preparation of the tensile specimens. Tensile testing, is a material science test in which administered tension is equipped to specimen until it breaks [22]. Tensile testing can directly measure maximum elongation, ultimate tensile strength. These values can be in charged to compute Young's modulus, Poisson's ratio, strain-hardening properties & yield strength. When tested under temperature, humidity, and specific test machine speed conditions, this test method is used to measure the tensile properties of Duplex Stainless Steel as standard dumbbell-shaped test specimen.

Charpy Impact Test

The samples of were prepared by ASTM D255. The impact test is an ASTM standard method for finding the resistance to impact offered by the materials. A strong arm is elevated to a particular zenith (where the potential energy became fixed) and then allowed to leave. Signatures press the drawn pattern and change the pattern. The sample soak up some energy which was determined from the swing level of the arm which hits the sample. The sheared specimen is widely used to find the impact energy.

Vickers Micro Hardness Test

The ASTM (e384-22) standard was followed in the preparation of the micro hardness specimens. This test is done to determine the material hardness basically sections which are very papery and parts which are bijou. It comprehends of indentor which is of shape like diamond and small load to get the material indented.

RESULTS

The study investigated the effects of MIG welding parameters—welding speed, wire feed rate, and voltage—on the corrosion behavior, mechanical properties, angular distortion, and weld bead profile of Duplex Stainless Steel (DSS) 2205. Using Taguchi's L9 orthogonal array and TOPSIS for multi-response optimization, the following results were achieved:

- **Optimal Parameters**: Welding speed = 40 cm/min, Wire feed rate = 6 m/min, Voltage = 26 V.
- **Corrosion Rate**: Minimized to 0.0181 mpy at optimal settings.
- **Mechanical Properties**:
    - Tensile Strength = 621 MPa
    - Impact Energy = 60 J
    - Micro-Hardness = 337 HV
- **Weld Geometry**:
    - Angular Distortion = 6.62°
    - Height of Reinforcement = 1.5 mm
    - Depth of Penetration = 2.407 mm
    - Bead Width = 5.4 mm
- **ANOVA Analysis** showed welding speed had the most significant influence on corrosion rate and reinforcement height, while wire feed rate significantly affected angular distortion.
- **Conclusion**: Welding speed was the most influential parameter across most responses, with voltage having the least impact. TOPSIS effectively optimized multi-response variables simultaneously.

CONCLUSIONS

This study evaluated the influence of MIG welding parameters—welding speed, wire feed rate (WFR), and voltage—on the corrosion behavior, mechanical properties, angular distortion, and weld bead profile of DSS 2205. Key findings include:

- **Corrosion Rate**: Welding speed had the most impact. The lowest corrosion rate (0.0181 mpy) was achieved at 40 cm/min, 6 m/min WFR, and 24 V.
- **Bead Width**: Most influenced by voltage. It ranged from 3.68 mm to 6.85 mm.
- **Depth of Penetration**: Dominated by WFR. Maximum depth was 2.845 mm.
- **Height of Reinforcement**: Primarily affected by welding speed. It ranged from 1.127 mm to 2.010 mm.
- **Angular Distortion**: Most affected by WFR. Values ranged from 5.36° to 8.10°.
- **Impact Energy**: Welding speed was the main factor. It varied from 40 J to 60 J.
- **Micro-Hardness**: Influenced mainly by welding speed, with values between 310.16 HV and 396.66 HV.
- **Tensile Strength**: Also mainly influenced by welding speed. It ranged from 558 MPa to 621 MPa.
- **TOPSIS Optimization**: Sample 9 (40 cm/min, 6 m/min, 24 V) was found to be optimal, offering the best combined performance across all tested parameters.

FUTURE SCOPE

- Further Studies can be conducted using different green corrosion inhibitors as a factor to study their effect on corrosion rate.
- Comparative study for corrosion rate can be conducted using different acidic Environment like chloride as well as alkaline environment.
- The other SS grades may be also be investigated to study the effect of welding parameters on their corrosion behavior.

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