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Comparative Evaluation of Shielded Metal Arc Welding and Gas Tungsten Arc Welding on Stainless Steel Joints

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Abstract

In the present study, Shielded Metal Arc Welding (SMAW) and Gas Tungsten Arc Welding (GTAW) were investigated comparatively in the joining of AISI 304 stainless steel. A detailed analysis of tensile strength, hardness profile, microstructure features, quality of weld, and cost analysis was carried out. The experimental work included tensile testing, Vickers hardness test, and microscopic evaluation under controlled welding parameters. Statistical analysis by ANOVA was carried out to find the significant difference between the two welding processes. The results indicate that GTAW welded joints have higher tensile strength (590-600 MPa) than SMAW welded joints (470-480 MPa), high hardness, and fine microstructure. Analysis of Variance results (F = 288) show that there is a statistically significant difference between the two welding processes. Fine equiaxed structure and fewer defects were observed in GTAW joints, and coarse-grained and slag inclusions were present in the SMAW welded joint. Although SMAW has relatively low initial and carrying cost, GTAW shows good economic benefits and high weld quality. The conclusion is GTAW welding process is best suited for applications where the quality of the weld and mechanical properties are significant, and SMAW is for less significant applications with portability and low cost.

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Introduction

Stainless steels are central to the design and engineering applications in many parts of our modern world today; their importance is attributed to their high corrosion resistance, strength, and durability properties, the latter being largely attributed to a passivating, stable, and dense Cr rich oxide film. The most used of all the Austenitic grades is the AISI 304 due to its outstanding weldability, workability, and acceptable mechanical properties. AISI 304 is most extensively employed in applications involving the chemical and petrochemical industries, food and beverage plants, pharmaceutical process equipment, pressure vessels and pipes, power generation plants, as well as general construction work, which demand reliable and enduring service lives, which are largely dependent on the mechanical integrity and corrosion resistance of the material in question. Since welding is a fundamental method by which stainless steel components are constructed and joined, structural reliability, durability, and safe serviceability are directly linked to the performance of the welded joints, and as such, the welding of AISI 304 stainless steels remains a problem of continued interest both to industry and academia.

The mechanical integrity of stainless-steel joints used in high-stress environments where corrosion resistance and high durability are required depends on the welding process used. Many welding processes have been researched, notably among them are the Shielded Metal Arc Welding (SMAW) and the Gas Tungsten Arc Welding (GTAW), processes which are widely applied in dissimilar- and similar-metal welding. Recent work on similar steel joining between SMAW and GTAW has focused on comparative mechanical and microstructural behavior, and their sensitivity to process parameters.

Shridhar et al. (2025) studied multipass SMAW and GTAW joints of AISI 304 SS to AISI 1018 Mild Steel and found that post-weld heat treatment (PWHT) greatly increased the overall weld performance of the joints by reducing residual stress to almost 48.5% in both processes and improving the impact toughness in both SMAW (17.3%) and GTAW (21.4%). PWHT, however, slightly reduced tensile strength due to material softening, thus illustrating the trade-off between strength and toughness, further suggesting that appropriate post-weld treatments are essential in improving the performance of both SMAW and GTAW joints.

Similarly, Awad et al. (2025) studied S275JR low-carbon manganese steel using SMAW and GTAW with differing heat inputs and observed that GTAW joints produced high hardness in the HAZ, whereas SMAW joints offered higher tensile strength and joint efficiency than GTAW joints. They also found both joints failed in the HAZ, reaffirming that this region is the weakest part of welded structures. These results suggest the appropriate heat input will significantly influence the resultant mechanical properties.

Comparative study by Li et al. (2022) of DSS 2205 again demonstrated that GTAW joints performed better than the hybrid GTAW + SMAW joints concerning mechanical strength and corrosion properties. The addition of SMAW slightly increased the percentage of ferrite at the weld region but adversely affected impact toughness and corrosion behavior at the root region. These results highlight that complete automatic GTAW can provide more dependable quality for sensitive applications.

Kumar et al. (2024) also researched GTAW behavior in Super Duplex Stainless Steel (SDSS) and found that well-controlled parameter selection could effectively increase tensile strength, hardness, and corrosion resistance. It was also verified that appropriate control of current and filler material could effectively increase the stability of microstructure and ultimately, the weld. Therefore, it is verified that GTAW is suitable for highly performing stainless steel in a particularly corrosive environment.

According to Mishra & Dakkili (2020), when comparing SMAW and GTAW processes for welding 304 and 310 grades of stainless steel in different joint designs, it was noted that higher tensile strength was achieved by the SMAW method in a double V-joint configuration. Both processes, SMAW and GTAW, produced defect-free welds in appropriately controlled parameter values. It is worthy of note that the joint designs proved to be important to achieve excellent results regardless of the welding process applied.

The studies performed by Afriansyah et al. (2024) and Haider et al. (2019) emphasize that welding parameters such as current, welding speed, and protection conditions have a high influence on weld quality in both SMAW and GTAW. If not properly selected, the welding parameters lead to defects such as porosity, cracking, and decreased corrosion resistance of stainless-steel welds exposed to corrosive media.

The study performed by Randhawa and Kumar (2018) on combined GTAW root pass and SMAW filler passes in AISI 304L stainless steel indicated that the smaller heat input resulted in fine microstructures and higher hardness, while higher heat input in the weld provided higher toughness and impact strength. Hence, there exists a correlation between toughness and hardness depending on the thermal cycle of both processes.

A review of studies from Sirohi et al. (2022) for the dissimilar welding of Inconel 718 and 304L stainless steel utilizing GTAW and SMAW and nickel-based

filler wires reported a complex microstructural arrangement composed of an unmixed zone and the precipitation of carbide, which in turn deteriorated the impact toughness. Nevertheless, when tested at high temperature the failure mode transitioned to the base metal, indicating the influence of operating service conditions on the joint properties.

Baghel (2022) and Ary et al. (2023) performed reviews for the applications of SMAW, reporting on its low cost and wide usage in industrial applications, despite its weakness and lack of consistency. Research gap identified for this method included optimization of welding parameters and dissimilar welding of components, suggesting that this area warrants further development.

Optimization of GTAW parameters was explored in Elfallah (2022), reporting that current, welding speed, and material thickness have a significant impact on the tensile strength and hardness, as well as for dissimilar welding application of Monel 400 and stainless steel by Mohamed et al. (2023) to develop a complex microstructure strongly influencing the mechanical properties of the joint.

Other comparisons between SMAW and GTAW by Ajenifuja et al. (2025) and Ekpemogu et al. (2021) report that both welding processes showed different responses in the various material systems with distinct welding parameter selection and shielding environment, as well as different properties being achieved, where GTAW obtained better tensile strength and surface finish in comparison to SMAW, although the latter often produced higher hardness and impact strength. Studies investigating process variations, such as electrogas welding by Abbas et al. (2024) and oxyacetylene welding by Kesse (2021), confirmed that both GTAW and SMAW are indeed common industrial welding processes.

In general, most literature indicates that GTAW provides better controllability, corrosion resistance, and microstructural stability, whereas SMAW usually offers better productivity and economic performance, and even better tensile and/or impact properties under specific conditions. However, both GTAW and SMAW are highly sensitive to heat input, shielding environment, and joint configuration, so parameter optimization is critical to achieving satisfactory weld performance in stainless-steel welding.

Henceforth, this work would comprehensively analyze and compare the use of SMAW and GTAW processes for welding AISI 304 stainless steel on tensile strength, hardness distribution, microstructure characterization, weld quality, distortion behavior, corrosion performance, and economic analysis. The study scope is confined to the use of 5mm thick AISI 304 stainless steel plates; the weld would be produced using E308L and filler ER308L. It would then provide multi-criteria, application-specific technical guidance for selecting the welding process in both academic and industrial settings. The importance of this work would be in balancing technical benefits against practical considerations of economic value and performance requirements when resources are limited or reliability is of utmost importance.

Materials and Methods

Materials

AISI 304 austenitic stainless steel was chosen as the base material due to its common use in industries, weldability, and corrosion resistance. Plates of 5 mm thickness were chosen to get an indication of the weld penetration, heat input, and the overall weld integrity realistically.

For SMAW, E308L low-carbon stainless steel electrodes were chosen to minimize carbide precipitation, while ensuring the required metallurgical characteristics and compatibility with the base material. For GTAW, ER308L filler wire was used to ensure the correct chemical composition (similar to the base material) and also to achieve ductile welds. The use of pure Argon gas (99.9%) was employed as the shield gas to prevent atmospheric contamination of the molten weld pool for GTAW.

Welding Equipment and Set-up

A conventional AC/DC arc welding power source with a current up to 200 A was used for SMAW. For GTAW, a TIG welding machine was used, which included high-frequency arc initiation and controlled supply of Argon. The horizontal position (2G) was used for all the welding operations, so that all the welds were prepared under the same conditions.

A qualified welder prepared all the welds so that the effect of the operator variability is minimal. All the samples were allowed to cool in free air (ambient temperature) to mimic common fabrication practices.

Specimen Preparation and Welding Procedure

AISI 304 stainless steel plates of 150 mm by 50 mm dimensions were cut using CNC plasma cutting to attain dimensional accuracy. A single V-groove joint was prepared on each of the plates.

The plate edges were beveled at an included angle of 60 degrees to achieve complete penetration of the joint. Before welding, joint surfaces were cleaned with acetone and brushed using a stainless-steel wire brush to remove grease, oxides, and contaminants that could lead to porosity or slag entrapment.

Plates were divided equally for SMAW and GTAW operations. Welding parameters were selected based on preliminary trials and standard welding practice and are summarized in Table 1.

Table 1: Parameters employed in the research for the welding procedure

Parameter	SMAW	GTAW
Current (A)	110–120	90–100
Voltage (V)	22–25	10–14
Travel speed (mm/s)	3–5	2–4
Electrode/filler	E308L (2.5 mm)	ER308L (2.4 mm)
Shielding gas	None	Argon (12–15 L/min)
Welding position	2G	2G
Number of passes	Single/multi-pass	Single/multi-pass

Mechanical Testing

Tensile Testing

Test specimens were machined from welded plates to ASTM E8 specification. The gauge length was positioned at the center of the weld region to ensure the specimen fractured either within the weld or the HAZ (heat-affected zone). All test pieces were tested in tension on a Universal Testing Machine under monotonic axial loading until failure with constant crosshead speed. UTS was calculated from the maximum load sustained and the original cross-sectional area. Fracture locations were recorded, and fracture location and type were also recorded as either ductile or brittle.

Ultimate tensile strength (UTS) was calculated using:

$$UTS = \frac{Maximum\ Load}{Original\ Cross-sectional\ Area} \quad (1)$$

Fracture location (e.g., in weld metal, HAZ, or base material) and fracture type were recorded.

Hardness measurement

Vickers hardness tests were taken across the weld metal, HAZ, and the base metal with a 500 g load applied and a dwell time of 15 seconds. This was performed multiple times at each location to ensure statistical reliability, and the averages of the 3 readings taken for each location were compared using equation (2) for both SMAW and GTAW weld joints.

$$HV = \frac{1.854 \times F}{d^2} \quad (2)$$

where HV is the Vickers Hardness Number, F is the Applied load in kgf, and d is the average diagonal length of the indentation in mm.

Multiple readings were taken to allow for inaccuracies in measuring diagonal length.

Microstructural Characterization

The microstructural investigation was carried out on transverse cross-sections of the welded joints. These samples were prepared by sectioning the samples using an abrasive cutter, then sequentially ground by silicon carbide papers (180 to 1200 grit) and polished with alumina slurry, so a mirror finish could be achieved. Chemical etching was carried out by Aqua Regia (HCl: HNO_3 = 3:1) to reveal grain boundaries and phase morphology.

Observations of the weld metal morphology, grain size, fusion line structure, width of the HAZ, and any defect present, like porosity or slag inclusion, were conducted by optical microscopy at magnifications 100x and 1000x. Comparison of microstructure in SMAW and GTAW welded joints was systematically evaluated.

Cost and Energy Analysis

The cost of SMAW and GTAW processes was investigated through a comparison. The consumable costs were calculated by the consumed electrode (SMAW) and filler wire (GTAW) mass for one weld. Argon gas consumption was calculated from the flow rate and welding time for GTAW.

The electrical energy consumption per weld was calculated from observed voltage, current, and welding time values. Labor costs were based on welding time and the typical rate associated with the skill required to perform both welding processes. Extra cost related to post-weld operations, like removing slag and surface grinding, was also included. SMAW joints were typically more labor-intensive for post-weld cleaning than GTAW joints. The comparative cost matrix for consumables, energy, labor, and post-weld operations was established and utilized to facilitate quantitative comparison between SMAW and GTAW processes.

Data Analysis

The mechanical, microstructural, and cost data were evaluated through a comparison to correlate the two welding processes' performance. Average values were reported, and a comparison to investigate trends in performance relative to welding heat input, microstructure formation, and efficiency of the process was carried out.

Results and Discussion

In this section, experimental results from Shielded Metal Arc Welding (SMAW) and Gas Tungsten Arc Welding (GTAW) on AISI 304 stainless steel are presented and discussed in detail. A comparison of tensile strength, hardness distribution, microstructural features, and costs will be made in order to evaluate the welding performance of both welding processes and assess their industrial applicability.

Tensile Strength Behavior

The outcome of the tensile test, as indicated in Table 2, shows that the GTAW joint consistently exhibits higher tensile strength than the SMAW joint. GTAW joint specimens (A2 and A4) gave ultimate tensile strength values of 590 MPa and 600 MPa, respectively, while SMAW joint specimens (A1 and A3) gave significantly lower tensile strength values of 480 MPa and 470 MPa. The values demonstrate an increase of about 20-25% in GTAW with regard to SMAW.

This increase in tensile strength for the GTAW joints can be attributed to the controlled heat input and the inert atmosphere protection by argon to prevent excessive oxidation, porosity, and non-metallic inclusions within the weld. In addition to these, the filler wire used in GTAW (ER308L) had higher metallurgical stability with the AISI 304 base material to make the microstructure homogeneous.

Another indication of a well-performed weld is the location of the fracture, which can be observed in Figure 1. GTAW specimens (A2 and A4) failed in the base metal, indicating that the strength of the weld and heat-affected zone is higher than that of the base metal. For

SMAW specimens, the fracture was found to take place in the weld metal or in the HAZ (shown in Figure 2), showing the weakness that is present in the weld or in the HAZ of SMAW (usually due to inclusions of slag, incomplete fusion, and lack of full penetration, as indicated in the discussion of welding methods).

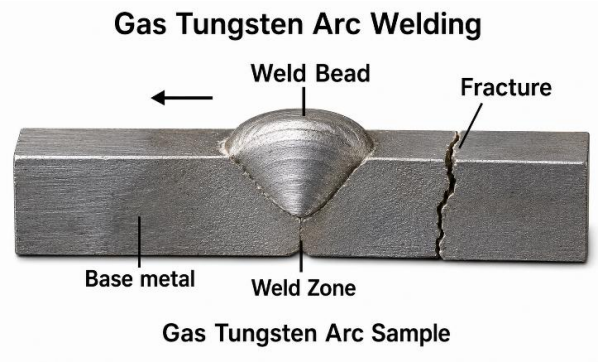

Figure. 1: GTAW samples fractured at the base metal

Figure 2: SMAW samples fractured in the weld zone and heat-affected zone (HAZ)

Table 2: The Ultimate Tensile Strength and Fracture Location of Welded Samples

Sample	Welding Method	Ultimate Tensile Strength (MPa)	Fracture Location
A1	SMAW	480	Weld Zone
A2	GTAW	590	Base Metal
A3	SMAW	470	Heat-Affected Zone (HAZ)
A4	GTAW	600	Base Metal

It has been found that GTAW samples had higher tensile strength than SMAW samples. Figure 3 shows a comparison of the tensile results graphically, making it evident that the difference in performance between the two welding methods.

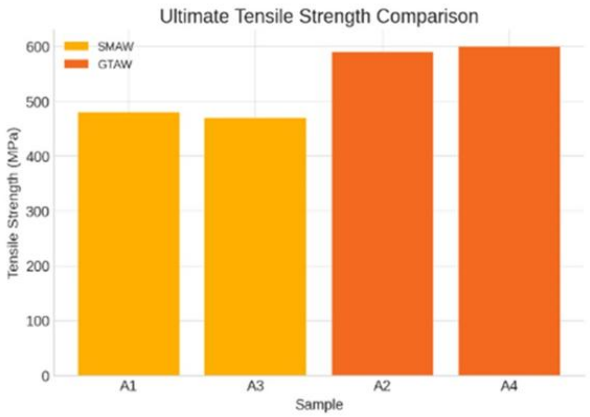

Figure 3. Ultimate Tensile Strength comparison

Hardness Distribution

Table 3 further supports the improved mechanical performance characteristics of the GTAW welds. It was noted that the Vickers hardness of the weld zones for GTAW joints was in the range of 220-230HV, while for SMAW joints, values were found in the range of 175-180HV. This pattern was also repeated across the HAZ, with GTAW samples consistently having higher hardness values.

The high hardness of the GTAW welds is attributed to the fine grain size achieved as a result of the controlled heat input during welding. Higher hardness is beneficial as it indicates greater resistance to plastic deformation and thus increases wear resistance. Low hardness for SMAW joints would correlate with coarser grain structures and less efficient load-carrying capacity due to features such as slag inclusions and micro-porosity.

As the hardness value can provide an indication of a joint's longevity and resistance to wear during service, particularly in abrasive or cyclically loaded conditions, one would expect the GTAW joints to outlast the SMAW joints over the duration of service life.

Table 3: Vickers Hardness Values in Weld Zones and Heat-Affected Zones.

Sample	Welding Method	Weld Zone Hardness (HV)	HAZ Hardness (HV)
A1	SMAW	180	160
A2	GTAW	220	200
A3	SMAW	175	155
A4	GTAW	230	210

It can be observed that there is a systematic trend toward higher hardness values in the GTAW welds as compared to the SMAW welds. In Figures 4 and 5, representative microphotographs depicting the differences in microstructure associated with hardness are shown. Figure 6 shows a comparison of the hardness profile using both methods of welding.

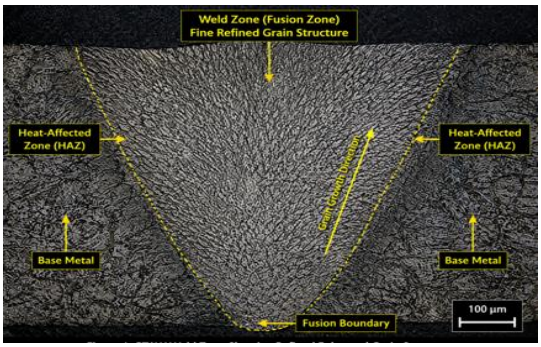

Figure 4: GTAW Weld Zone: Refined Enhanced Grain Structure

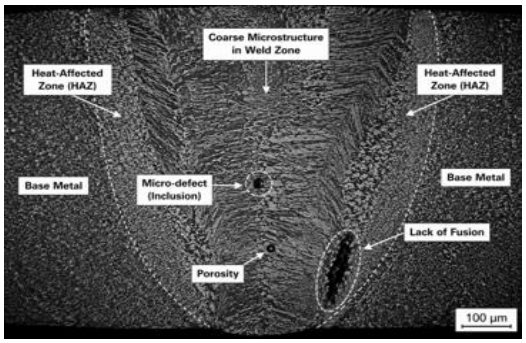

Figure 5: SMAW Weld Zone: Coarse Microstructure, Micro- defect, Lower

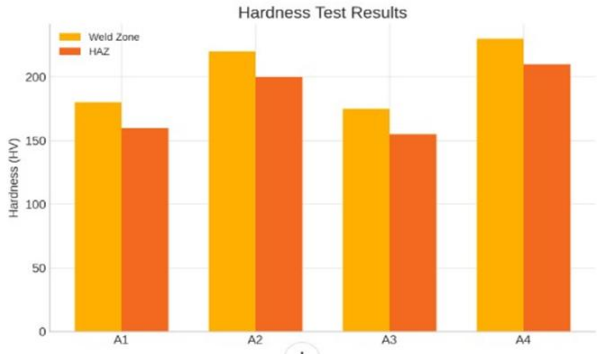

Figure 6: Results of the hardness test

Mean Tensile Strength

SMAW Mean = 475 MPa

GTAW Mean = 595 MPa

This gives a value of roughly a 25% increase in tensile strength for GTAW compared to SMAW.

Values for Mean Hardness

Table 4: The Mean Hardness Distribution

Welding Method	Mean Weld Hardness (HV)	Mean HAZ Hardness (HV)
SMAW	177.5	157.5
GTAW	225	205

These results show GTAW produced much higher hardness in the weld metal and HAZ regions.

ANOVA (Inferential Statistical Analysis)

ANOVA model:

$$F = \frac{MSW}{MSB} \qquad (3)$$

Table 5: ANOVA Table for Tensile Strength

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value
Between Groups	14400	1	14400	288
Within Groups	100	2	50	
Total	14500	3		

Decision Rule:

If the F calculated value is larger than the F critical value, then the null hypothesis should be rejected.

The table below indicates at a 5% significance level:

F critical value ($df_1 = 1$, $df_2 = 2$) ≈ 18.51

F calculated value = 288

Because the F calculated value is so much greater than the F critical value, the null hypothesis is rejected.

The results indicated that there is a statistically significant difference between the tensile strength of SMAW and GTAW welding joints. Such variation due to the welding process is not likely to be the result of an experimental error.

Microstructural Implications

Significant differences were found between SMAW and GTAW welded joint structures. (See Table 6). It can be concluded that variations in the mechanical properties result directly from variations in the microstructural changes brought about by each welding process. While GTAW shows fine and equiaxed austenitic grain structure, a small HAZ is also observed. SMAW shows coarse columnar grains and a large HAZ, as mentioned earlier in microstructures.

The resistance to deformation due to the grain boundary in the case of fine-grain structures is much larger than that in the case of coarse-grain structures or structures with inclusions, which result in stress concentration points and premature failure.

Table 6: Microstructural Characteristics

Welding Method	**Grain Structure**	**Slag Inclusion**	**HAZ Width**
SMAW	Coarse columnar grains	Present	Wide
GTAW	Fine austenitic grains	Absent	Narrow

From a metallurgical aspect, the refined microstructure achieved by GTAW is the direct reason for the increased tensile strength and hardness properties obtained.

Economic Analysis.

The cost comparison between SMAW and GTAW in Table 7 explains the economic advantages and disadvantages of the two welding methods. SMAW is economically favorable over GTAW in terms of acquisition cost of the welding equipment and welding electrodes, and the consumables are relatively cheaper than in GTAW. No gas is required for SMAW; thus, it is inexpensive when fabricating at low cost and on-site.

On the negative side, a higher rejection rate due to cleaning of slag and other defect rectification at the weld, which takes extra man-hours, hence higher cost. On the other hand, the high cost of investment is primarily due to the cost of inert gas required in the GTAW process and non-consumable tungsten electrodes, and the high capital cost of the equipment. High consumption of energy and relatively slow speed are other disadvantages of the GTAW process. But considering the superior quality of the weld, no post-weld cleaning required, and less rework required, it makes it economically favorable for highly reliable applications like chemical, food processing, and aviation industries over the life span of components.

Table 7: Comparison of Costs

Parameter	SMAW	GTAW
Electrode/Filler Cost	Low	High
Shielding Gas Cost	None	Expensive
Equipment Cost	Affordable	Expensive
Energy Consumption	Medium	High
Welding Speed	Faster	Slower
Weld Repair Rate	High	Low

Comprehensive Comparative Performance:

A summary comparison between the two welding processes is summarized in Table 8. In general, GTAW seems to offer superior tensile strength, hardness, refinement of microstructures, and weld quality compared to SMAW. SMAW is, however, still applicable for mass and cost-critical applications where portability, high speed, and ease of use outweigh the requirements for higher accuracy.

Table 8. Summary Comparison Table of the performances

Parameter	SMAW	GTAW
Tensile Strength	Lower; fracture in weld/HAZ	Higher fracture in the base metal
Microstructure	Coarse grains; slag present	Fine grains; clean weld
Hardness	Lower due to inclusions	Higher due to refined grains
Weld Quality	Defect-prone	Superior and defect-free
Cost	Low initial; high rework	High initial; low rework
Welding Speed	Faster, less precise	Slower, highly controlled
Post-Weld Cleanup	Significant	Minimal

These results have demonstrated that although SMAW can be applied to general-purpose and inexpensive fabrication processes, GTAW is better utilized for applications that require the best mechanical, metallurgical, and durable performance.

Discussion

It is concluded that the welding process plays an important role in the mechanical properties, microstructure, and integrity of the welds of AISI 304 stainless steel joints. Improved mechanical performance of GTAW joints over SMAW can primarily be attributed to a different level of heat input, shielding quality, and weld pool dynamics, which are all governing factors for the solidification mechanism and the resultant microstructure.

The resultant values for the tensile strength of GTAW welds varied from 590 to 600 MPa and were significantly higher than those of SMAW weld joints, which varied from 470 to 480 MPa. The significant increment in the tensile strength of GTAW weldments suggests that it was able to deliver a stronger weld free of significant defects. One crucial observation during the tensile testing was the location of fracture, which took place in the base metal for GTAW weld joints instead of in the weld and HAZ of the welded joint, meaning that the weld region possessed similar strength or even higher strength than the base metal. Conversely, during SMAW testing, fracture took place within the weld and HAZ, indicating that they represent the weakest regions within the joint, a common feature with weld discontinuities and concentrated localized stress.

The observed tensile strength results are in good agreement with the metallurgical characteristics of the GTAW process. The high purity argon used during the GTAW welding protects the molten weld pool against external contamination thereby eliminating the possibilities of oxidization, absorption of nitrogen and formation of inclusions. Also, a stabilized arc used during GTAW process allows accurate control of heat input. Hence this process produces more controlled solidification and less accumulation of residual stress. Li L., Du, Z., Sheng, X., Zhao, M., Song, L., Han, B., & Li, X. (2022) observed similar outcome where GTAW weld joints provided better mechanical properties and corrosion resistance than the weld obtained by using SMAW operation. Similarly, Kumar et al. (2024) reported that optimum GTAW parameters achieved improvement of tensile strength and microstructural stability in stainless steel weldment.

The values of hardness test results also prove the improved performance of the GTAW process. The hardness of the weld zone in the GTAW process is 225HV, while it is 177.5HV in the SMAW process. The values are higher in the HAZ in a similar pattern. Increased hardness value in GTAW weldments is related to smaller grains within the fusion zone and also the neighboring heat-affected regions. According to the Hall-Petch relation, as the grain size reduces, dislocation mobility becomes difficult to cause movement, thus increasing the hardness and strength. The smaller grains formed during the controlled cooling cycle during the GTAW process resulted in greater tensile strength and hardness values. However, the lower values obtained during the SMAW process indicated the formation of bigger grains with different microstructural phases and inclusions, which would further resist deformation under the applied load.

Microstructural observations also support the mechanical test results. Figure 4 indicates that the GTAW weld has finer equiaxed austenitic grains and a narrower HAZ compared with the coarser columnar grains in SMAW, a wider HAZ, and inclusions present in SMAW weldments (Figure 5). A fine, equiaxed grain distribution improves mechanical behavior by redistributing stress and preventing crack propagation, whereas coarse grain boundaries weaken overall joint strength by providing an easier path for cracks. The wider HAZ formed in SMAW suggests that the material around the weld zone has been subjected to greater thermal effects, leading to grain growth.

The mechanical test values presented are in reasonable agreement with literature results where lower heat input leads to the formation of finer grains and better mechanical properties. Randhawa and Kumar (2018)

noticed that low heat input welding of AISI 304 resulted in improved hardness and finer microstructure. Similarly, Shridhar J., Janapareddy, P. K., Kumar, G. V., Sahu, S. K., El-Rayyes, A., Giri, J., & Singh, B. (2025) obtained that the distribution of residual stress of stainless-steel joints is highly dependent on the microstructure obtained in the welded region and has a significant affect on the mechanical performance. The mechanical test data are thus consistent with fundamental metallographic principles.

The statistical analysis confirmed that the variation of tensile strength by welding method is statistically significant. The calculated F-value for the ANOVA test ($F = 288$) is greater than the critical F-value (18.51) at a 95% confidence level, meaning that the null hypothesis can be rejected and hence we conclude that the difference in tensile strength for both SMAW and GTAW weld joints is indeed significant.

From the aspect of application, it is noticeable that SMAW is cost-effective as compared to the GTAW welding process. This is due to the expensive welding consumables (electrode, shield gas) in the GTAW process. However, SMAW weld joints have greater inclusion formation (slag inclusions) in the weld metal, a higher degree of distortion, and reduced tensile strength as compared to GTAW welds. Thus, for better mechanical properties of AISI 304 stainless steel weld joints, the use of the GTAW process would be preferred despite its increased cost.

Conclusion and Recommendations

A comparative analysis using mechanical testing, microstructure examination and statistical tests was conducted between the SMAW and GTAW welding procedures on AISI 304 stainless steel. The results demonstrated that GTAW weldments exhibit higher tensile strength, superior hardness, finer microstructure, and generally improved weld quality than SMAW weldments. Statistically, it was concluded that a significant difference exists between the weldments produced by the GTAW and SMAW processes and the welding procedure profoundly influences the mechanical and metallurgical properties of the weldment.

The GTAW process is more advantageous due to its capacity to accurately control the heat input, effectively protect the weld puddle from contamination by the atmosphere (good gas shield), resulting in fine microstructures and reduced defects. Coarse microstructures with extensive heat-affected zones (HAZ) are prevalent in SMAW weldments due to inefficient gas shielding and inappropriate filler metal application. Additionally, these weldments are more susceptible to defects like slag inclusions and porosity compared with GTAW. While the low cost, robustness, and high portability of the SMAW process are appealing, it is best suited for non-critical applications where weldment failure will have negligible impact. However, in engineering applications where high strength and reliability in service are crucial, the GTAW process is recommended to produce weldments with exceptional strength, reliability, corrosion resistance, and integrity.

Based on the observations from this comparative study, the GTAW process is recommended for the food and beverage industry, pharmaceutical industry, chemical plants, pressure vessel fabrication, and other fields where elevated weld quality is required. The SMAW process may continue to be considered for repair tasks, field fabrication, and cost-effective applications, but care must be taken in the selection of the electrode, welding procedure, operation by skilled personnel, and implementing rigorous quality checks, which would include non-destructive testing such as ultrasonic testing and dye penetrant inspection. The welding productivity can be increased by using automatic and semi-automatic GTAW without sacrificing weld quality, which will contribute to the selection of these systems for industrial production. For future work, the long-term service life of SMAW and GTAW weldments should be investigated, especially concerning fatigue life, corrosion resistance, and reliability. Furthermore, the effects of welding parameters, post-weld heat treatments and hybrid welding techniques such as the use of GTAW for root pass welding and SMAW for fill passes should

be thoroughly studied. A sound technical basis has been established which will provide assistance in welding procedure selection, with the weldment properties heavily reliant upon this choice.

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