

Journal of Materials and Engineering Structures

To study the metallurgical and mechanical properties of SMAW dissimilar weld joints between AISI 1020 carbon steel and AISI 410 martensitic stainless steel using three distinct fillers

Pankaj Kumar^a, Lochan Sharma^{a,*}, Shahbaz Juneja^b

^a Chandigarh University, Mechanical Engineering Department, Mohali-140413, Punjab, India

^b Chandigarh University, University Center for Research & Development, Mohali-140413, Punjab, India

ARTICLE INFO

Article history :

Received : 22 August 2025

Revised : 12 January 2026

Accepted : 16 January 2026

Keywords:

Dissimilar welds

AISI 1020 carbon steel

AISI 410 martensitic stainless steel

Mechanical properties

Metallurgical behaviour

ABSTRACT

This study investigates the metallurgical and mechanical properties of dissimilar weld joints between AISI 1020 carbon steel and AISI 410 martensitic stainless steel, fabricated using three distinct filler metals: austenitic AWS 309L and AWS 316L, and martensitic AWS 410. The weldments were comprehensively evaluated through tensile testing, Charpy V-notch impact testing, microhardness profiling, and microstructural analysis to determine the optimal consumable for this application. The results demonstrated the superior performance of the AWS 309L filler, which yielded the highest ultimate tensile strength (410.5 MPa) and greatest impact toughness (24.2 J). This enhanced performance was attributed to the formation of a desirable duplex microstructure of austenite and distributed delta ferrite in the fusion zone. Conversely, the weldment made with the matching AWS 410 filler, despite exhibiting the highest hardness (peak 532 HV), showed low impact toughness (18.7 J) and moderate tensile strength (371.3 MPa), indicating a brittle, untempered martensitic structure susceptible to failure. The AWS 316L filler produced the lowest mechanical properties overall. The findings conclude that AWS 309L is the most suitable filler metal, producing a robust and damage-tolerant joint, whereas the AWS 410 filler is inappropriate for this application in the as-welded condition due to its inherent brittleness.

1 Introduction

Dissimilar Metal Welding (DMW) is one of the most important and accepted technologies for joining materials in such industries as nuclear reactors, power plants, petrochemical companies, car manufacturing and even construction industries. The resistance to DMW acceptance has thus far been minimal because it allows integration of dissimilar materials with particular properties that, by themselves cannot be obtained from one material only due to cost effectiveness or engineering design. For example, dissimilar metal welding makes it possible to combine carbon steels which possess high strength with some stainless steels which offer superior corrosion resistance (Economics Merits) [1].

* Corresponding author.

E-mail address: lochan.e9455@cumail.in

A critical and growing need for incredibly strong, long-lasting, and dependable joining solutions is highlighted by the growing demand for DMW applications, especially in settings with high temperatures and aggressive corrosive conditions, like those found in nuclear reactors and advanced power plants. One The long-term structural integrity and operational safety of welded components are crucial because of the extreme operational stresses imposed by these environments. Therefore, it is not only academically but also critically important to conduct in-depth research aimed at fully comprehending and successfully addressing the intricate and multifaceted challenges inherent to DMW. [2]. AISI 1020 is a widely utilized plain carbon steel, distinguished by its excellent weldability, good machinability, and high ductility. These advantageous attributes are primarily derived from its relatively low carbon content, typically around 0.22% Carbon and 0.55% Manganese. Its microstructure at room temperature predominantly comprises a combination of ferrite and pearlite phases. In quenched and tempered conditions, tensile strength can be between 470-650 MPa, while in the normalized state, it is generally ≥ 410 -430 MPa, with specific values influenced by material diameter [3, 4]. While the inherent good weldability of AISI 1020, due in great part to its low carbon composition, is a definite strength for similar metal joining, this same property becomes a major weakness in dissimilar welding with AISI 410. The low carbon percentage in AISI 1020 makes it a vulnerable source for carbon migration to the higher-alloyed stainless steel. This migration may cause the development of a soft, decarburized zone in the AISI 1020 heat-affected zone (HAZ), thus weakening its mechanical properties and even constituting a weak link in the overall joint. It is an indication of how a desirable characteristic in one situation can prove to be a critical issue in another, pointing to the intricate metallurgical interactions in dissimilar welding [5].

AISI 410 is a versatile martensitic stainless steel prized for its balance of moderate corrosion resistance, high hardness (20-45 HRC or 143-331 HB), and high strength (tensile strength 480-700 MPa, or 415-1402.7 MPa with specific heat treatments; yield strength 275-450 MPa; 15-20% elongation). Its composition is primarily 11.5-13.5% chromium and 0.15-0.20% carbon, with minor amounts of silicon, manganese, nickel, phosphorus, and sulphur. Heat treatment significantly influences its mechanical properties [6, 7]. The inherent high hardenability and propensity for martensitic transformation in AISI 410, while highly advantageous for achieving desirable base metal properties like high strength and hardness, paradoxically introduce a significant challenge during welding. The fast cooling inherent in fusion welding processes can cause the formation of untampered, brittle martensite in the weld metal and HAZ, which greatly increases the likelihood of cracking [8].

Experimentally, Chamim et al [9] studied the role of welding thermal cycle (similar to WAAM/GTAW depositions) to control the d-ferrite evolution and morphology of austenitic consumable deposits. Their major finding is that peak temperature and T_{8/5} cooling-window are critical factors that control the transformation of d-ferrite to austenite or leave it as vermicular/skeletal ferrite; deposits that were exposed to higher temperatures had shown ferrite morphologies that enhanced hot cracking resistance but also enhanced local hardness. This paper thus holds that process thermal history (and indirectly the selected heat input in SMAW) is one of the main levers to optimize their beneficial vs. detrimental ferrite in austenitic filler metals. Giudice et al. [10] emphasized that the primary challenges in preventing solidification and cold-cracking in dissimilar joints lie in proper filler-metal chemistry and controlled heat input (to preserve tempered HAZ microstructures in the martensitic side with a limited amount of d-ferrite in the weld metal), which should be maintained at a relatively low level of aiming at the minimization of hot cracking and at the same time preventing embrittlement. The review offers a conceptual model that can be directly used to compare the use of 309L and 316L and 410 fillers in SMAW welding of AISI 1020 to AISI 410. Mukherjee et al. [11] paper on multi-layer and multi-material cladding (i.e. martensitic and duplex cladding on carbon substrate) demonstrates that multilayer thermal histories have a profound effect on retained ferrite, local hardness distributions and wear/corrosion behavior. Despite emphasizing the value of cladding over single-pass SMAW dissimilar joints, this paper highlights the fact that layering and repetitive thermal cycles (such as in multi-pass SMAW) will modify the morphology and mechanical gradients of ferrite, which is why reporting ferrite morphology (not fraction) and hardness across weld/HAZ boundaries are necessary.

Firstly, a notable thermal property mismatch exists between these materials. AISI 1020 low carbon steel exhibits higher thermal conductivity compared to stainless steel. During welding, the varying rates at which heat dissipates cause the fusion zone to be unevenly shaped, and the heat-affected zone (HAZ) to spread further into the carbon steel. A major concern is the considerable difference in how much carbon steel and stainless steel expand when heated (stainless steel typically having a coefficient approximately 40% larger than carbon steel) induces substantial thermal stresses and distortion upon cooling from welding temperatures. These stresses can lead to premature joint failure and cracking, particularly under operational conditions where thermal cycling may occur [1]. Secondly, metallurgical structure heterogeneity is a common outcome. The different internal structures of the metals being joined can cause problems in the weld. These issues include uneven

proportions of ferrite and austenite, the creation of harmful intermetallic compounds, and the growth of large grain structures in both the weld itself and the heat-affected zone. These microstructural anomalies often degrade mechanical properties [12].

Tandon et al. [13] experimentally tested a range of filler electrodes (309L, 316L, 309LMo) and found that 309L-type fillers always yielded a higher δ -ferrite concentration in deposits and had better resistance to solidification cracking, whereas 316L had lower ferrite and better measures of corrosion/toughness. Their findings highlight the trade-offs that have plagued researchers in deciding on the austenitic fillers to use during dissimilar welding of martensitic steels. Luijan et al. [14] examined the weldability and joining properties of dissimilar metal welding between ferritic stainless steel and low carbon steel utilising ER308L and ER309L filler wires. With martensite and carbide forming at the fusion zone, it was discovered that welding conditions and filler wire had a major influence on the fusion zone and bend test. Abd. Wahab et al. [15] examined the effects of post-welding heating process temperature (PWHT) on the microstructure and mechanical characteristics of ASTM A240 type 316L and ASTM A36 low carbon steel. The mechanical characteristics of the two materials were tested in the study using shield metal arc welding (SMAW). The weld metal region without PWHT had the highest average hardness value, according to the results, whereas the HAZ 316L area at 400°C had the maximum impact energy.

The strategic combination of AISI 1020 (valued for its ductility, inherent weldability, and cost efficiency) with AISI 410 (chosen for its superior hardness, strength, and moderate corrosion resistance) in a dissimilar joint implies a deliberate engineering objective. This objective is to fabricate components that can selectively leverage the robust, wear-resistant, or corrosion-resistant attributes of AISI 410 in critical localized areas, while maintaining the overall structural integrity and economic viability afforded by the more ductile and less expensive AISI 1020. This approach underscores the practical utility and design flexibility offered by successfully joining these distinct material classes. For example, a component might require the high wear resistance of AISI 410 on a bearing surface, while the bulk of the structure, where cost and formability are primary concerns, could be made from AISI 1020 [16, 17].

The most critical, challenge, especially when welding martensitic stainless steels, is the formation of brittle microstructural phases. Martensitic stainless steels like AISI 410 are designed to be hardened through heat treatment, forming a hard martensitic structure. The rapid heating and cooling inherent in the welding thermal cycle invariably forms a region of hard, untempered martensite within the HAZ of the martensitic base metal. This phase is characterized by extremely high hardness, low ductility, and poor toughness, rendering it highly susceptible to hydrogen-induced cold cracking and catastrophic brittle fracture under load. Furthermore, attempting to weld carbon steel directly to stainless steel without a carefully selected filler metal can result in the formation of a brittle martensitic microstructure within the weld metal itself, compromising the integrity of the entire joint [18, 19].

2 Materials and Methods

2.1 Materials

This study focused on welding AISI 410 martensitic stainless steel and AISI 1020 low carbon steel plates, prepared with 60-degree V-grooves. The selection of an appropriate electrode was critical due to the dilution of weld metal by the base materials (up to 50%). Using typical mild or low alloy steel electrodes for this dissimilar joint would lead to a hardenable, crack-sensitive weld. Therefore, austenitic stainless-steel electrodes were chosen, specifically those with enough alloying elements (like Smooth arc S309L) to counteract dilution and ensure adequate chromium and nickel content (minimum 17% Cr, 7% Ni) for crack resistance and sufficient ferrite for hot cracking prevention. The study used three specific low-carbon electrodes: 309L (for dissimilar metals), 410 (matching a base metal), and 316L (for its molybdenum content influencing microstructure). Rutile welding consumables were preferred over basic electrodes for their versatility, all-position welding capability, and good properties with both AC and DC current.

2.2 Welding

Stainless steel's heat-affected zone (HAZ) is susceptible to hydrogen cracking due to its hardness, a risk that increases with carbon content. To prevent this, it's essential to use dried welding consumables and preheat the material, which helps hydrogen diffuse away from the weld. So, Plates and base metals were heated to 200°C for 30 minutes before welding.

Table -1 Chemical Composition of Base Metal (wt %) and Welding Electrodes Used

Material	Iron (Fe) (%)	Carbon (C) (%)	Chromium (Cr) (%)	Manganese (Mn) (%)	Silicon (Si) (%)	Phosphorus (P) (%)	Sulfur (S) (%)	Nickel (Ni) (%)	Molybdenum (Mo) (%)
AISI 1020	Balance	0.2	-	0.45	-	0.04	0.05	-	-
AISI 410	Balance	0.12	12.5	1	1	0.04	0.03	0.75	-
E309L-16	Balance	0.035	23.5	1.75	0.65	0.03	0.025	13	0.75
E316L-16	Balance	0.035	18.5	1.5	0.7	0.03	0.02	12.5	2.5
E410-16	Balance	0.1	12.2	0.8	0.52	0.04	0.03	0.65	0.75

Coated electrodes can absorb moisture during storage or transit, leading to defective welds. To prevent this, store electrodes in a dehumidified room, or one where the temperature is 15°C above ambient with 45-50% relative humidity. If these conditions aren't met, you must re-dry the electrodes in a drying oven before use [20].

To mitigate under bead cracking in thick, high-tensile welds, hydrogen-controlled electrodes are indispensable, engineered to keep diffusible hydrogen below 15 cc per 100 grams of weld metal as specified by BS: 639-1976. Prior to welding, these electrodes necessitate drying in an oven at 200-350°C for one to two hours, although excessive high-temperature drying should be circumvented. For prolonged storage, a temperature of 100°C is suitable. In this particular study, electrodes were dried at 250°C for one hour, adhering to ASME standards. The welding process involved manual Shielded Metal Arc Welding (SMAW) using a DC machine on a single V-joint configuration. Three distinct electrode types were employed: E309L-16, E316L-16, and E410-16. The welding parameters were set at 30V for voltage, 130A for current, a travel speed of 1.15 mm/s, and a calculated heat input of 2.37 kJ/mm. The selected heat input of 2.37 kJ/mm is suitable in the range normally used in shielded metal arc welding and other arc welding processes of medium-thickness steels and is suitable in controlling microstructural development of both heat-affected zone (HAZ) and the weld metal. Garcia et al. used heat inputs of up to 2.5 kJ/mm during SMAW/arc welding of structural steels and proved that HAZ toughness and grain size are severely affected by the increased level of heat input, indicating that a similar amount of heat input should be applied during dissimilar joint welding [21]

**Fig.1 - Plates before Welding Process Having V groove at Center**

2.3 Mechanical test

Different tensile test samples were made for each of the three electrode types in order to determine the mechanical integrity of the welded junctions. In particular, a transverse section was made across the weldment of one specimen per electrode (E309L-16, E316L-16, and E410-16). These samples closely complied with the ASTM E8M-13 standard's geometric specifications thanks to precision processing using a milling machine. After that, mechanical characterisation was carried out at the INDIANA FERRO ALLOYS LAB, Industrial Area, Phase 8, Mohali. Tensile tests and important

mechanical properties were determined using a 2000 kN Universal Testing Machine (UTM). Tensile test specimen are shown in below in Fig. 2 and Fig. 3.

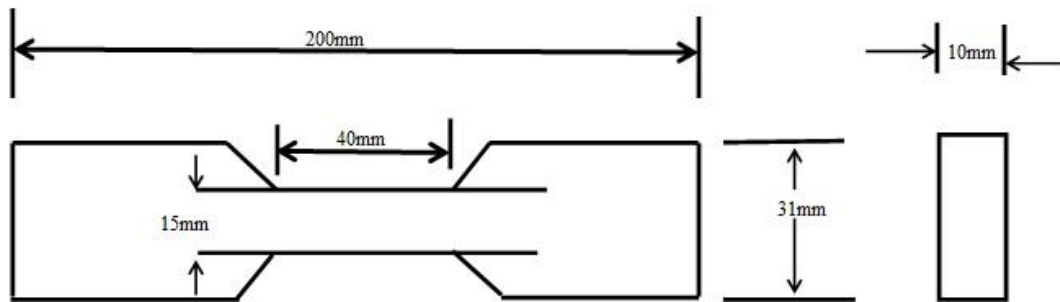


Fig. 2 - Tensile Specimen Dimension



Fig. 3 - Sample for Tensile test

To comprehensively assess localized mechanical properties, micro-hardness measurements were performed using a Vickers hardness tester (e.g., Shimadzu HMV-G21). Test specimens (10mm x 10mm x 50mm, Fig. 3) were extracted from weld coupons, encompassing both weld metal and HAZ, then meticulously ground and polished to a reflective, scratch-free surface (Fig. 4). A square-based pyramidal diamond indenter applied a 20 kgf (196.1 N) load for 15 seconds to create indentations. Vickers Hardness (HV) values were calculated from the measured indentation diagonals. All testing occurred at Chandigarh University, Gharuan. To study the weld microstructure, transverse sections were prepared by grinding (SiC papers) and polishing (diamond, colloidal silica/alumina), then etched with Kalling's No. 2 reagent. These samples were subsequently examined under an optical microscope (e.g., Olympus BX51M) at various magnifications.



Fig.4 - Sample for Hardness Test



Fig.5 - Samples for microstructure

Charpy V-notch impact tests were conducted on three samples (one from each welded plate) using specimens measuring 10 x 10 x 55 mm and meeting ASTM A370 specifications. The tests, which were carried out at room temperature at Chandigarh University in Gharuan, assessed the energy absorbed during fracture using a pendulum-type machine (such as the ZwickRoell RKP 450). The term "microstructure" describes the internal structure of a material that can be seen under an optical microscope (25x to 1000x magnification; $\sim 0.2 \mu\text{m}$ resolution), which has a big influence on qualities like strength. Grain size, phases, and material behaviour can all be seen in micrographs. Samples are first cut, then ground using silicon carbide emery sheets (600 grit), polished, cleaned, dried, and etched using solutions such as Kalling's No. 2 solution in preparation for analysis.

3 Results and Discussion

3.1 Micro Hardness Testing

Vickers Hardness (HV) profiles for three distinct weld types —309L, 316L, and 410— are displayed in the combined graph (Fig. 10, Table 2). The distance from the weld centre determines this. The bell-shaped curve shows a distinct pattern in all three varieties. As measurements approach the weld centre (0 mm), hardness rises noticeably before falling towards the base materials. Positive lengths are used to measure the AISI 1020 side, whereas negative distances are used to measure the AISI 410 side. The maximum overall hardness is typically found in Weld Type 410, which reaches about 532 HV at the weld centre. This demonstrates how well it resists indentation in the welded area. Weld Type 316L exhibits the lowest peak hardness at approximately 461 HV, followed by Weld Type 309L, which has a peak hardness of about 480 HV. Furthermore, for all weld types, the hardness decrease from the peak appears to be higher on the AISI 1020 side than the AISI 410 side. This comparison draws attention to the various mechanical characteristics and metallurgical reactions of these weld materials throughout the welding process. It offers crucial information about how well they function in actual circumstances.

Table 2 - Micro Hardness Values at Base Metals and Welded Region

Sr NO	Distance In mm From Centre of Weld Metal										
	AISI 410 Side					Weld Centre	AISI 1020 Side				
	-10	-8	-6	-4	-2	0	+2	+4	+6	+8	+10
309L	291	318	346	396	446	480	432	404	288	206	167
316L	284	304	332	386	432	461	442	381	321	234	182
410	285	328	389	465	501	532	481	423	312	265	175

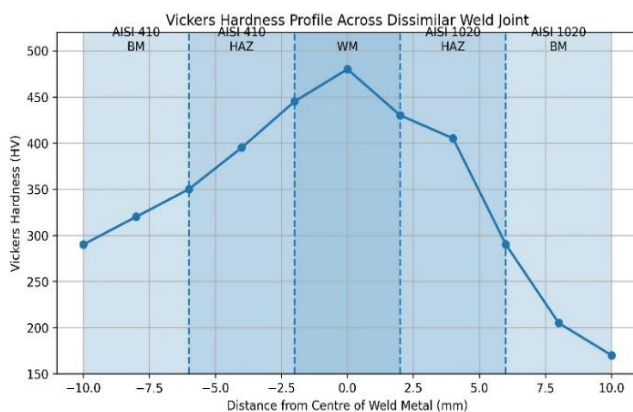


Fig. 7 - Microhardness of Weld and HAZ using 309L electrode

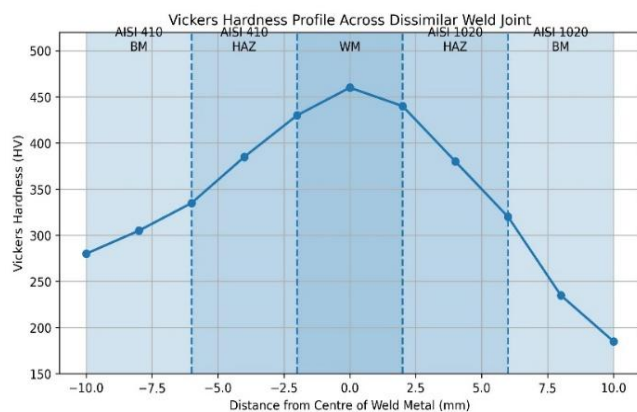


Fig. 8 - Microhardness of weld and HAZ using 316L electrode

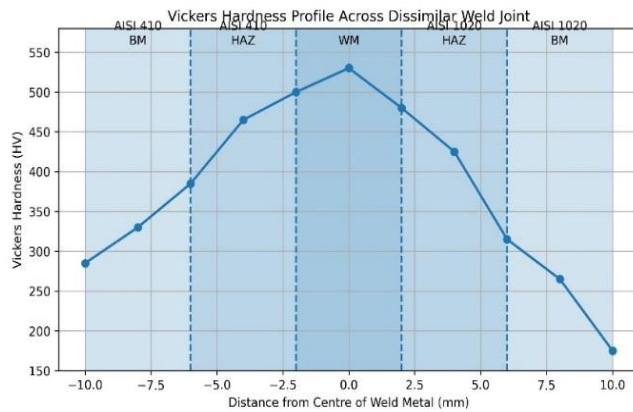


Fig. 9 - Microhardness of weld and HAZ using 410 electrode

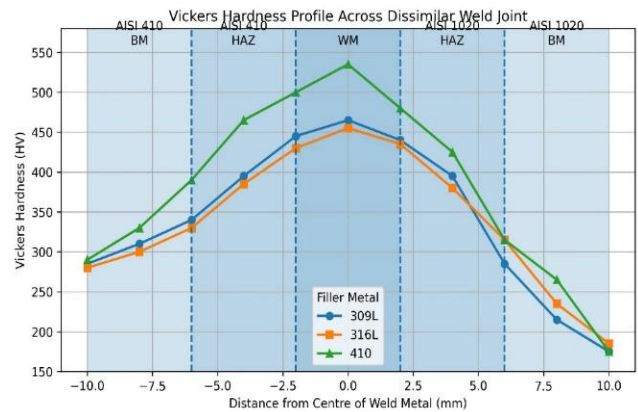


Fig. 10 - Comparison of Microhardness of Weld and HAZ

A direct comparison of the peak hardness values recorded in the primary and benchmark studies [18] reveals a striking and critically important correlation. The primary study's weld made with the 410 martensitic fillers exhibited a peak hardness of approximately 532 HV, located in the center of the weld metal. In the benchmark study, the HAZ of the AISI 420 martensitic stainless steel reached a peak hardness of approximately 500 HV. The remarkable proximity of these two values—both exceeding 500 HV—is not a coincidence. It strongly indicates the formation of a nearly identical, hard, and brittle microstructure in both joints: untempered martensite. This phase is the expected product of rapidly cooling a steel with the carbon and chromium content of AISI 410 or AISI 420 from the high temperatures experienced during welding.

The hardness profiles of the joints made with austenitic fillers also provide valuable information. In the primary study, the 309L and 316L filler welds showed peak hardness values of 480 HV and 461 HV, respectively. These peaks are likely located at the fusion line with the AISI 410 base metal, where a combination of the hard martensitic HAZ and some dilution of carbon from the AISI 410 into the austenitic weld metal contribute to elevated hardness. It is noteworthy that these values are significantly higher than the peak hardness of approximately 300 HV observed in the HAZ of the S355MC structural steel in the benchmark study's austenitic welds. This difference can be attributed to the nature of the base metals. The peak hardness in the primary study's austenitic welds is dominated by the very hard HAZ of the AISI 410 martensitic steel, whereas the peak in the benchmark study is in the much softer structural steel. The dilution of carbon from the AISI 410 into the weld pool of the 309L and 316L fillers likely also contributes to a localized increase in the weld metal's hardenability and hardness near the fusion boundary.

3.2 Tensile test

The examination of the ultimate tensile strength (UTS) of three different welding electrodes—309L, 316L, and 410—reveals notable differences in their mechanical performance (Fig. 11 & Fig. 12).



Fig.11- Samples of welded plates after tensile loading

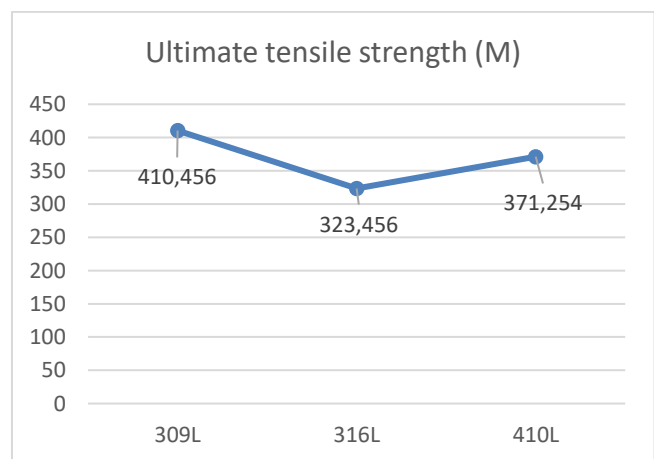


Fig.12 -Tensile strength of the all three weld zones

The 309L electrode is the best option for applications needing extraordinary joint strength because it demonstrated the maximum tensile strength of 410.456 MPa among the examined samples. The 316L electrode's lowest UTS of 323.456 MPa may limit its use in high-stress scenarios, despite the fact that its well-known corrosion resistance may still make it useful in some circumstances. The 410 electrodes showed a moderate tensile strength of 371.254 MPa, suggesting a trade-off between strength and other desired properties including hardenability. The average UTS across the electrodes was approximately 368.39 MPa with a standard deviation of approximately 43.57, indicating significant variability.

A quantitative comparison of ultimate tensile strength provides an initial measure of joint performance, but a deeper analysis of the failure mode and location is essential for a true assessment of mechanical integrity. The primary study reported a UTS of 410.5 MPa for the weldment fabricated with the 309L filler metal. This result is broadly comparable to the average UTS of 472 MPa reported by Baskutis et al [18] for their successful austenitic-to-structural steel weldments (AISI 304, 314, and 316L to S355MC) made with an ER308LSi filler. Both values are in a range that suggests the joints possess strength adequate for many structural applications, likely approaching or exceeding the strength of the weaker carbon steel base metal.

The most illuminating comparison, however, lies in the analysis of the martensitic joints. The primary study's 410-filler weld yielded a UTS of 371.3 MPa. In the benchmark study, the dissimilar joint between AISI 420 martensitic steel and S355MC structural steel recorded a UTS of 459.8 MPa. While the benchmark's value is numerically higher, this figure is profoundly misleading when viewed in isolation. The critical differentiating factor is the failure mode. In the Baskutis et al. study, all successful austenitic stainless-steel welds failed in a ductile manner within the weaker S355MC base metal, far from the weld zone. This is the desired failure mode, as it indicates that the weld and its associated heat-affected zones are stronger than the parent material, ensuring a safe and predictable joint. This observation is consistent with other studies on dissimilar carbon-to-stainless steel welding, where fracture is often observed in the low-carbon steel base metal due to it being the softest region of the joint.

3.3 Microstructure

The welded joint's microstructural examination reveals distinct variations in a number of important regions (Fig. 13, Fig 14 and fig. 15). Delta ferrite is combined with an austenite matrix in the weld zone. Moving on to the carbon steel's heat-affected zone (HAZ), the structure is primarily composed of pearlite with trace amounts of ferrite and cementite. Tempered martensite is made on the HAZ's stainless steel side. Tempered martensite predominates in the weld zone of welds produced with 410L electrodes, with relatively few carbide particles and very little ferrite. The microstructure of AISI 1020 carbon steel is composed of small carbide, ferrite, and bainite particles in the heat-affected zone (HAZ). These various structures form as a result of welding heat and significantly impact the welded joint's strength and properties.

The microstructure of the weld fusion zone is dictated by the chemical composition of the filler metal and the degree of dilution from the base metals [22]. For the joints made with austenitic fillers (309L, 316L, and the benchmark's ER308LSi), the resulting microstructure is designed to be predominantly austenitic. The primary study's observation of a duplex structure of austenite with delta ferrite in the 309L weld is a classic example of a well-designed dissimilar weld metal. Filler metals like AWS 309L are intentionally over-alloyed with austenite-stabilizing elements (like nickel) and ferrite-stabilizing elements (like chromium) compared to standard grades like 308L or 316L. This higher alloy content serves a crucial purpose: it ensures that even after being diluted by the lower-alloy carbon steel and martensitic steel base metals, the final composition of the weld pool solidifies as austenite with a small, controlled amount of residual delta ferrite. This can be predicted using constitutional diagrams like the Schaeffler or WRC-1992 diagrams [14]. This microstructure is key to the joint's success, as it is both ductile and resistant to hot cracking.

Heat-affected zones on either side of a weld are often the sites of mechanical failure, and their microstructures are crucial. The AISI 1020 carbon steel side has a typical microstructure of pearlite, ferrite, and cementite, typical for low-carbon steel subjected to a welding thermal cycle. A critical phenomenon identified in the benchmark study is the likely formation of a carbon-depleted zone adjacent to the fusion line. This can create a soft, decarburized band in the base metal HAZ, contributing to the complex hardness gradient across the joint.

The HAZ on the martensitic stainless-steel side (AISI 410/AISI 420) is the most critical region of the entire weldment. The benchmark study reports "fine untempered martensite" in the AISI 420 HAZ, which is the root cause of the joint's 62% hardness increase and subsequent brittle failure during tensile testing. The success of the 309L filler lies not in its ability to

prevent the formation of a brittle HAZ in the AISI 410, but in its systemic success. The 410-filler weld fails because it lacks this protective, ductile buffer, creating a continuous path for rapid crack propagation.

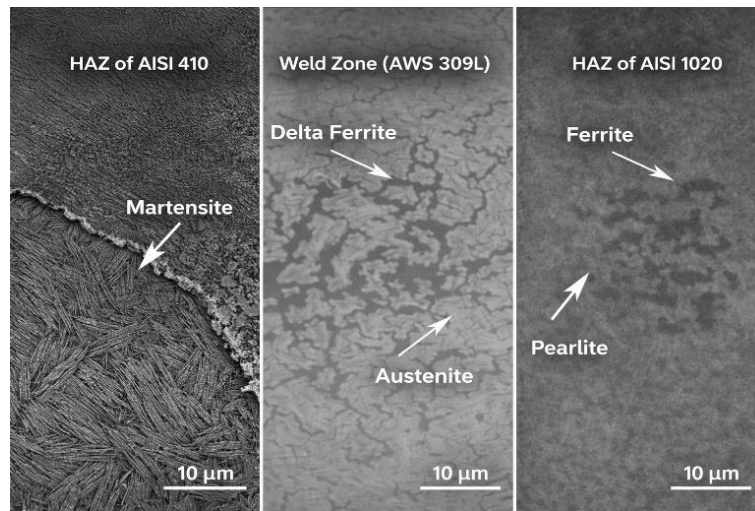


Fig. 13 - Microstructure of weld zone and HAZ of plates using 309L electrodes

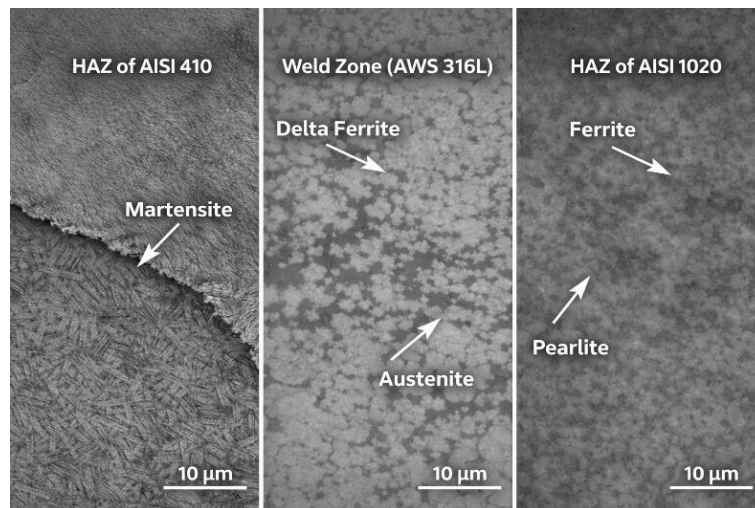


Fig. 14 - Microstructure of weld zone and HAZ of plates using 316L electrodes

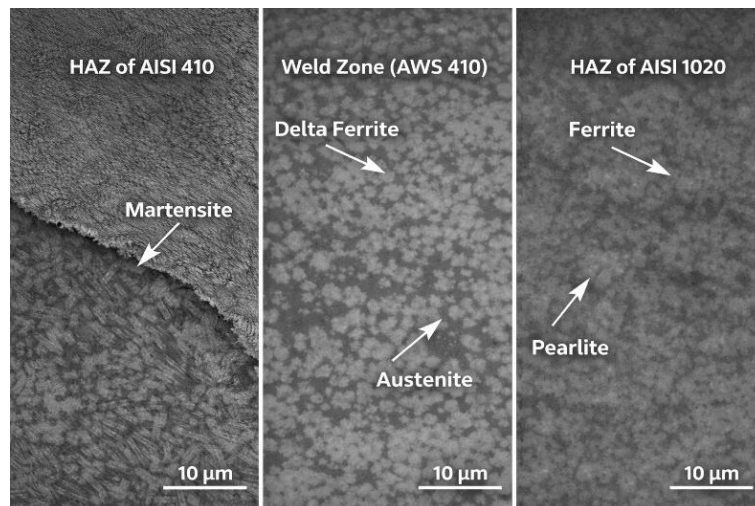


Fig. 15 - Microstructure of weld zone and HAZ of plates using 410 electrodes

3.4 Impact Strength

The impact strength values, expressed in Joules, for three different electrode types—309-L, 316-L, and 410—are displayed in the chart. The highest impact strength is displayed by the 309-L electrode, which registers about 24.2 J. After this, the 316-L electrode's impact strength sharply declines and eventually reaches 17.7 J. The impact strength of the 410 electrodes then shows a slight increase, recording a value of roughly 18.7 J. This information points to a significant difference in the toughness properties of the several tested electrode materials.

Table 3 - All Weld Metal Charpy V- Notch Impact Test Results (Joule)

Sample No	Electrode (AWS)	Impact Test Results (J)			
		Trial 1	Trial 2	Trial 3	Impact strength (average)
1	309L	22.5	25.4	24.7	24.2
2	316L	17.3	18.2	17.6	17.7
3	410	17.9	18.9	19.3	18.7

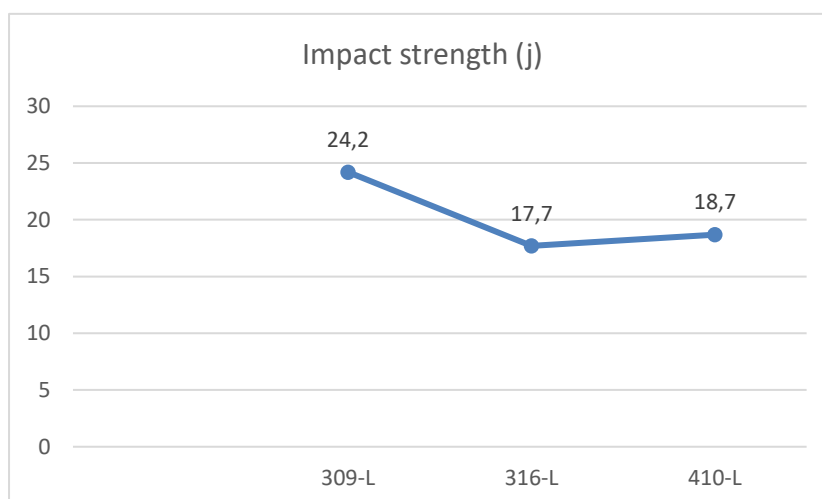


Fig.16- Impact Strength of all weld joints

The development of a duplex microstructure (austenite with distributed delta ferrite) in the weld metal is the main cause of the higher impact strength of 309L weld joints between AISI 1020 and AISI 410 plates. By successfully preventing fracture propagation and reducing the formation of brittle phases like martensite, which can arise from the AISI 410, this particular structure, even when diluted from the base metals, improves overall toughness.

4 Conclusions

The present study examined the mechanical performance of welds formed between AISI 1020 carbon steel and AISI 410 stainless steel using 309L, 316L, and 410 as filler electrodes. The following conclusions were drawn:

- The 309L electrode showed the best overall performance, with the maximum tensile strength of 410.456 MPa and the highest impact strength of 24.2 joules.
- Duplex microstructure was observed with 309L electrode, which is a combination of delta ferrite and austenite. Due to this, weld durability increases and inhibits the spread of cracks formation.
- 410 electrode exhibited the hardest weld zone with a Vickers hardness measurement of 532 HV, because of its tempered martensite composition.

- Comparing the 410 welds to the 309L, they showed a moderate impact strength (18.7 J) and tensile strength (371.254 MPa) despite their toughness.
- The 316L electrode consistently performed the lowest in all mechanical tests, suggesting it may not be the best choice for high strength or impact resistance.

REFERENCES

- [1]- S.S. Sashank, S. Rajakumar, R. Karthikeyan, Dissimilar welding of austenitic and martensitic stainless-steel joints for nuclear applications: a review. In: 3rd International Conference on Design and Manufacturing Aspects for Sustainable Energy, E3S Web Conf., 309 (2021) 01187. <https://doi.org/10.1051/e3sconf/202130901187>
- [2]- E.N. Abbas, S. Omran, M. Alali, M.H. Abass, A.N. Abood, Dissimilar welding of AISI 309 stainless steel to AISI 1020 carbon steel using arc stud welding. 2018 International Conference on Advanced Science and Engineering (ICOASE) (2018) 462-467. <https://doi.org/10.1109/ICOASE.2018.8548844>
- [3]- Fuhong Steel, AISI 1020 Carbon Steel | DIN1.0402 | 070M20. Fuhong Steel, accessed May 20, 2025.
- [4]- S.T. Selvamani, M. Vigneshwar, M. Nikhil, S.J. Hariharan, K. Palanikumar, Enhancing the fatigue properties of friction welded AISI 1020 grade steel joints by optimized post weld heat treatment. Mater. Today: Proc., 16 (2019) 1251-1258. <https://doi.org/10.1016/j.matpr.2019.05.222>
- [5]- A.G. Olabi, M.S.J. Hashmi, The microstructure and mechanical properties of low carbon steel welded components after the application of PWHTs. J. Mater. Process. Technol., 56(1-4) (1996) 88-97. [https://doi.org/10.1016/0924-0136\(95\)01824-7](https://doi.org/10.1016/0924-0136(95)01824-7)
- [6]- M. Kainth, M. Singh, A. Singh, Effect of filler metal combination and post weld heat treatment on pitting corrosion and impact toughness of GTA welded AISI 410 SS joints. Mater. Today: Proc., 56 (2022) 3035-3041. <https://doi.org/10.1016/j.matpr.2021.11.647>
- [7]- J. Shen, R.E. Kim, J. He, J. Yang, J.G. Lopes, Z. Zeng, J.P. Oliveira, Excellent strength/ductility synergy by optimization of post-weld heat treatment for gas metal arc welded CoCrFeMnNi high entropy alloys with 410 stainless filler wire: high-throughput thermodynamic modelling with experimental validation. Mater. Des., 249 (2025) 113556. <https://doi.org/10.1016/j.matdes.2024.113556>
- [8]- M. Singh, A.S. Shahi, D. Singh, Influence of heat input on the pitting corrosion and tensile behavior of GTA welded martensitic stainless steel (AISI410 SS) joints. Mater. Today: Proc., 46 (2021) 10282-10287. <https://doi.org/10.1016/j.matpr.2020.12.187>
- [9]- M. Chamim, D.B. Darmadi, A. Purnowidodo, T.D. Widodo, Z. Ismail, Influence of the welding thermal cycle on δ -ferrite evolution in the first layer of austenitic stainless steel (ASS) 308L produced by WAAM-GTAW. Case Stud. Therm. Eng., 64 (2024) 105489. <https://doi.org/10.1016/j.csite.2024.105489>
- [10]- F. Giudice, S. Missori, C. Scolaro, A. Sili, A review on fusion welding of dissimilar ferritic/austenitic steels: processing and weld zone metallurgy. J. Manuf. Mater. Process., 8(3) (2024) 96. <https://doi.org/10.3390/jmmp8030096>
- [11]- M. Mukherjee, P. Sarkar, S. Barman, P.K. Mallisetty, V. Paleu, S. Bhaumik, Investigating the wear resistance of AISI 410/AISI 2205 hybrid weld cladding on annealed EN 8 medium carbon steel. Proc. Inst. Mech. Eng., Part J: J. Eng. Tribol., 238(11) (2024) 1373-1392. <https://doi.org/10.1177/13506501241255989>
- [12]- C.H. Huang, C.H. Hou, T.S. Hsieh, L. Tsai, C.C. Chiang, Investigation of distinct welding parameters on mechanical and corrosion properties of dissimilar welded joints between stainless steel and low carbon steel. Sci. Prog., 105(4) (2022) 00368504221126795. <https://doi.org/10.1177/00368504221126795>
- [13]- V. Tandon, A.P. Patil, S. Kowshik, Impact of filler electrodes on welding properties of dissimilar welded 316L/201 austenitic stainless steels. Eng. Proc., 59(1) (2023) 90. <https://doi.org/10.3390/engproc2023059090>
- [14]- J. Luijan, K. Eidhed, P. Surin, Weldability and joining of dissimilar metal welding between low carbon steel and ferritic stainless steel. Key Eng. Mater., 973 (2024) 87-92. <https://doi.org/10.4028/p-kgyq7t>
- [15]- A. Wahab, L.H. Arma, H. Arsyad, R.B. Othman, Effect of temperature variation PWHT dissimilar welding low carbon steel ASTM A36 with ASTM A240 Type 316L. EPI Int. J. Eng., 7(1) (2024) 33-37. <https://doi.org/10.25042/epi-ije.022024.05>
- [16]- J. Liu, X. Li, Y. Zhou, P. Yu, C. He, Z. Xu, Microstructure and mechanical properties of active gas arc welding between 304 austenitic stainless steel and Q235B low carbon steel. J. Mater. Eng. Perform., 31(10) (2022) 8199-8209.

-
- [17]- Australian Stainless Steel Development Association, Welding dissimilar metals (FAQ No. 9) (Nov. 2005).
- [18]- S. Baskutis, J. Baskutiene, R. Bendikiene, A. Ciuplys, K. Dutkus, Comparative research of microstructure and mechanical properties of stainless and structural steel dissimilar welds. *Materials*, 14(20) (2021) 6180. <https://doi.org/10.3390/ma14206180>
- [19]- M. Ishak, L.H. Shah, I.S.R. Aisha, W. Hafizi, M.R. Islam, Study of resistance spot welding between AISI 301 stainless steel and AISI 1020 carbon steel dissimilar alloys. *J. Mech. Eng. Sci.*, 6 (2014) 793-806.
- [20]- H. Firmanto, S. Candra, M.A. Hadiyat, Y.P. Triastomo, I. Wirawan, Tensile strength and microstructure of rotary friction-welded carbon steel and stainless-steel joints. *J. Manuf. Mater. Process.*, 7(1) (2022) 7. <https://doi.org/10.3390/jmmp7010007>
- [21]- R.P. García, L.B.P. Martínez, F.J.B. Varela, Influence of heat input and post-weld heat treatment on the properties of the heat affected zone and weld metal of welded joints on S690QL steel. *Int. J. Adv. Manuf. Technol.*, 139(7) (2025) 4011-4028.
- [22]- Y. Ai, X. Liu, Y. Huang, L. Yu, Investigation of dissimilar fiber laser welding of low carbon steel and stainless steel by numerical simulation. *J. Laser Appl.*, 33(1) (2021) <https://doi.org/10.2351/7.0000333>