

A Review on Microstructure and Mechanical Properties of Dissimilar Welding Between SS 316 and S 202

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Abstract

Dissimilar welding of austenitic stainless steels such as Stainless Steel 316 and Stainless Steel 202 has gained significant attention in engineering applications due to its potential for cost reduction and optimized material performance. However, variations in chemical composition—particularly in nickel, manganese, and molybdenum content—lead to complex metallurgical interactions during welding. This review paper presents a comprehensive analysis of the microstructural evolution and mechanical properties of SS 316–SS 202 dissimilar welded joints. The weld region typically exhibits a heterogeneous microstructure consisting of an austenitic matrix with δ -ferrite, formed due to elemental dilution and solidification behaviour. The heat affected zone (HAZ) shows grain coarsening and possible sensitization, especially on the SS 316 side, while the SS 202 side demonstrates comparatively lower stability and mechanical performance. Mechanical properties such as hardness, tensile strength, and impact toughness are strongly influenced by phase distribution, heat input, and filler material selection, with failure commonly occurring in the weaker SS 202 region. Recent research indicates that optimized welding parameters and appropriate filler materials, such as ER309L, significantly enhance weld quality and reduce defects like hot cracking and residual stresses. This study consolidates existing literature and highlights key challenges and future directions for improving the reliability and performance of dissimilar stainless-steel welds.

1. Introduction

Dissimilar metal welding (DMW) has become increasingly important in modern engineering applications where a balance between performance and cost is required. Among various combinations, the welding of austenitic stainless steels such as Stainless Steel 316 and Stainless Steel 202 is widely used in industries including chemical processing, food equipment, structural fabrication, and marine environments. This combination allows engineers to utilize the superior corrosion resistance of SS 316 alongside the economic advantages of SS 202.

SS 316 is a molybdenum-bearing stainless steel known for its excellent resistance to pitting and crevice corrosion, particularly in chloride-containing environments. In contrast, SS 202 is a low-nickel, high-manganese stainless steel developed as a cost-effective alternative to conventional austenitic grades. While both materials possess an austenitic structure, their differences in chemical composition significantly influence their welding behaviour and resulting joint properties.

During dissimilar welding, variations in thermal conductivity, melting temperature, and thermal expansion coefficients between SS 316 and SS 202 lead to complex metallurgical phenomena. These include elemental dilution, formation of secondary phases such as δ -ferrite, and the development of residual stresses. Additionally, the heat affected zone (HAZ) on both sides of the weld may experience grain growth and sensitization, which can adversely affect mechanical properties and corrosion resistance.

Another critical challenge in SS 316–SS 202 welding is maintaining a balanced microstructure in the fusion zone. Improper control of welding parameters can result in defects such as hot cracking, lack of fusion, and reduced toughness. Therefore, the selection of suitable welding techniques and filler materials plays a vital role in achieving sound weld joints.

This review paper aims to provide a comprehensive understanding of the microstructural evolution and mechanical properties of dissimilar welds between SS 316 and SS 202. It also highlights key challenges, summarizes findings from recent research, and discusses potential strategies to improve weld performance.

2. Chemical Composition and Metallurgical Characteristics

The welding behaviour and resulting properties of dissimilar joints between Stainless Steel 316 and Stainless Steel 202 are strongly influenced by their chemical composition and metallurgical nature. Although both belong to the austenitic stainless-steel family, significant differences in alloying elements lead to variations in phase stability, corrosion resistance, and mechanical performance.

2.1 Chemical Composition

Table 1

Materials	C	Si	Mn	P	S	Cr	Mo	Ni	N	Co	Cu	Fe
UNS 316L ASS	0.030	0.556	1.513	0.026	0.001	17.153	2.062	10.132	0.002	–	–	Bal
UNS 202 ASS	0.061	0.352	8.563	0.098	0.020	15.566	0.010	0.836	–	–	–	Bal
ER 316 L Filler	0.03	.5	1.8	–	–	19	2.8	11.5	–	–	0.3	Bal
ER 309 L Filler	0.03	0.4	1.5	0.03	0.03	24.0	0.75	13.0	4.0	–	–	Bal

2.2 Materials and Methods

Two plates of stainless steel (SS 316 L and SS 202) are welded with GTAW mode . Table 1 shows chemical composition in weight percentage of base metal and filler matel.the following is the procedure to follow when estimating the heat input

$$HI = \eta \times V \times A \text{ KJ/mm}$$

Where w – welding speed in mm/s, A-welding current in amperes. V-voltage in volts and η -efficiency of GTAE AS-0.7

Welding parameters of cold metal transfer welding with GTAW mode

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ER 309 L Filler	0.03	0.4	1.5	0.03	0.03	24.0	0.75	13.0	4.0	–	–	Bal

Specimen	Filter materials	Welding speed[w][mm/s]	Current(A)	Voltage(V)	Heat input(KJ/mm)
316 & 202	ER 316L	1.5-2.0	100	10	0.47-0.35
316 & 202	ER309L	1.0-1.5	100	10	0.70-0.47
316 & 202	Without Filler	2.0-2.5	100	10	0.35-0.28

2.3 Microstructural properties

Following the welding process, specimens were subsequently sectioned to required in order to conduct an analysis of the microstructure, microhardness, and corrosion characteristics. The weld samples underwent a polishing process, employing silicon carbide polishing paper. Finally in order to examine the microstructure of both the base metal [BM] and weld metal [WM], the samples underwent electrochemical etching using a solution of 10 wt% oxalic acid.

2.3 Mechanical properties

The Vicker's hardness test is conducted by applying a consistent load of 300 gf for a duration of 10 s [18]. The evaluation of the tensile properties of joints, with yield/ultimate tensile strength, and percentage elongation, is conducted through a utilization of a universal testing machine (UTM). Under typical environmental circumstances, an impact test that is commonly referred as the V-notch Charpy test was carried out. The specimen for the test was 3 x 10 x 55 mm in size. The acquisition of three samples for each test ensured the reliability of the data, and the calculation of the average value for each test ensured that the results could be reproduced accurately

2.4. Corrosion resistance study

A Double Loop Electrochemical Potentiokinetic Reactivation

(DLEPR) test was carried out in this investigation by utilizing a Solartron- 1285 potentiostat and a solution containing 0.5 M H₂SO₄ and 0.01 M NH₄SCN. In order to conduct the potentiodynamic polarization (PDP) studies, a BIO logic VMP-300 potentiostat that was outfitted with a standard cell configuration was used [01]. The working electrode, reference electrode and the counter electrode was the three electrodes that made up the cell. The counter electrode was composed of platinum gauze. These electrodes were submerged in a solution that had 3.5% of their

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weight comprised of sodium chloride (NaCl). During the PDP test , open circuit potential (OCP) was measured to a period of 1 h until a stable potential condition was established.[11]

3.Results and discussions

3.1 microstructural examination

The microstructure of weldments of Base Metals (BM), Interface Zone (IZ), Weld Zone (WZ) and Heat Affected Zone (HAZ) is shown in fig 2. From the microstructure, it was observed that the 202 BM consist

3.2 Summary

- SS 316 → High corrosion resistance, stable austenite
- SS 202 → Cost-effective, lower corrosion resistance, less stable
- Dissimilar welding → Produces a mixed microstructure influenced by dilution and alloying elements

3.3 Implications in Dissimilar Welding

During welding of SS 316 and SS 202:

- **Elemental dilution** occurs in the fusion zone
- Mixing of Mo (from SS 316) and Mn (from SS 202) alters phase balance
- Formation of **δ-ferrite** helps prevent hot cracking
- Differences in composition lead to:
 - Microstructural heterogeneity
 - Variation in mechanical properties across the weld

3.4 Filler Materials

Selection of filler material is crucial in dissimilar welding:

- **ER308L:**
 - Suitable for similar stainless steel welding
 - Moderate corrosion resistance
- **ER309L (Preferred):**
 - Higher alloy content
 - Better compatibility for dissimilar joints

Welding Parameters

Important parameters affecting weld quality:

- **Heat Input:**
 - Excess heat → grain growth and sensitization
 - Low heat → lack of fusion
- **Welding Current & Voltage:**
 - Controls penetration and bead shape
- **Travel Speed:**
 - Affects cooling rate and microstructure
- **Shielding Gas:**
 - Argon or argon-based mixtures used to prevent oxidation

3.4 Challenges in Welding SS 316–SS 202

- Difference in thermal expansion → residual stresses
- Elemental dilution → microstructural imbalance
- Risk of:
 - Hot cracking
 - Sensitization
 - Distortion

4. Microstructural Evolution

The microstructural evolution in dissimilar welds between Stainless Steel 316 and Stainless Steel 202 is complex due to differences in chemical composition, thermal properties, and solidification behaviour. The weld joint can be broadly divided into three regions: the fusion zone (FZ), the heat affected zone (HAZ), and the base metal (BM). Each region exhibits distinct microstructural characteristics.

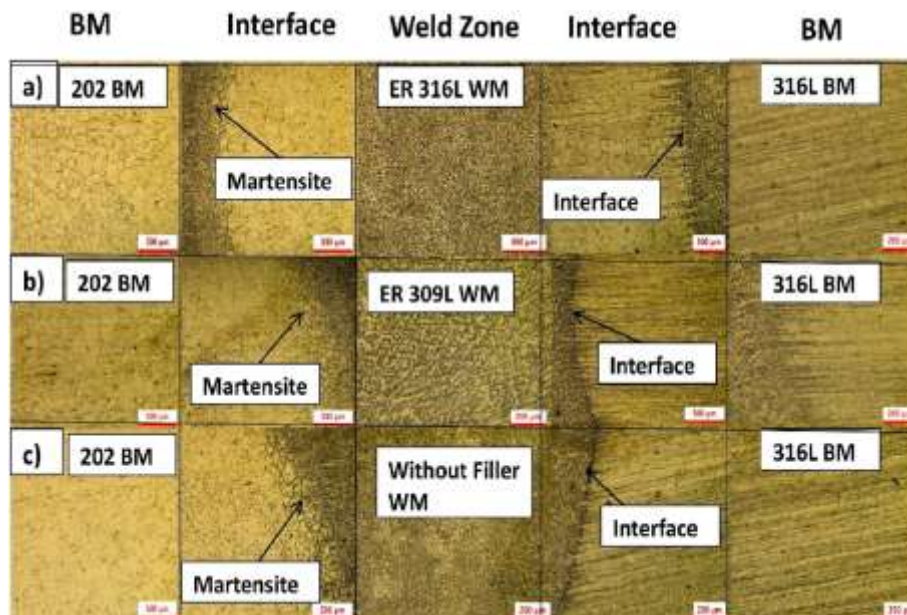


Fig. 2. Optical Micrograph for (a) Weldment with ER 316 L filler, (b) Weldment with ER 309 L filler, (c) Autogenous weld with no filler for CMT Welding

4.1 Fusion Zone (FZ)

The fusion zone is formed by the complete melting and mixing (dilution) of both base metals along with filler material.

Microstructural Features:

- Predominantly **austenitic matrix (γ -phase)**
- Presence of **δ -ferrite** in the interdendritic regions
- **Dendritic solidification structure**

Formation Mechanism:

- Solidification generally follows:

Liquid $\rightarrow$ Liquid + δ -ferrite $\rightarrow$ Austenite + δ -ferrite

- Alloying elements influence phase balance:
 - Mo (from SS 316) stabilizes ferrite
 - Mn and N (from SS 202) stabilize austenite

Significance of δ -Ferrite:

- Prevents **hot cracking** during solidification
- Excess δ -ferrite can reduce toughness

4.2 Heat Affected Zone (HAZ)

The HAZ experiences thermal cycles without melting, leading to microstructural changes.

(a) HAZ on SS 316 Site

- **Grain coarsening** near fusion boundary
- Possible **chromium carbide precipitation (Cr_{23}C_6)** at grain boundaries
- Leads to **sensitization**, reducing corrosion resistance

(b) HAZ on SS 202 Side

- More unstable compared to SS 316
- Features:
 - Grain growth
 - Possible local hardening
 - Reduced corrosion resistance
- Due to lower nickel:
 - Less stable austenite
 - Higher susceptibility to microstructural changes

4.3 Interface Region (Transition Zone)

- Narrow region between fusion zone and base metals
- Shows:
 - Gradual compositional gradient
 - Mixed microstructural features
- No sharp boundary due to:

- Diffusion of alloying elements
- Partial melting and mixing
-

4.4 Solidification Behaviour

The solidification mode depends on:

- Composition (Cr/Ni equivalent ratio)
- Cooling rate

Typical modes:

- **FA mode (Ferrite → Austenite)** is common
- Ensures:
 - Reduced cracking
 - Improved weld integrity

4.5 Factors Affecting Microstructure

- **Heat input:** Controls grain size and cooling rate
- **Cooling rate:** Influences phase formation
- **Filler material:** Determines final composition

4.6 Summary of Microstructure

Region	Microstructure	Key Features
Fusion Zone	Austenite + δ -ferrite	Dendritic, crack-resistant
HAZ (SS 316)	Coarse grains	Sensitization risk
HAZ (SS 202)	Unstable structure	Higher variability
Interface	Mixed phases	Gradual transition

4.7 Key Observations

- Weld metal is **heterogeneous**
- δ -ferrite is essential but must be controlled
- SS 202 side shows more instability
- Microstructure directly governs mechanical properties

Understanding microstructural evolution is crucial for optimizing welding parameters and improving the performance of SS 316–SS 202 dissimilar welded joints.

5. Mechanical Properties

The mechanical properties of dissimilar welds between Stainless Steel 316 and Stainless Steel 202 are strongly influenced by microstructural heterogeneity, phase distribution, and welding parameters. Due to differences in base

metal properties, the weld joint exhibits non-uniform mechanical behaviour across different regions such as the fusion zone (FZ), heat affected zone (HAZ), and base metals.

5.1 Hardness

Hardness variation across the weld joint is a key indicator of microstructural changes.

Observations:

- Fusion Zone (FZ):
 - Shows **higher hardness** due to presence of δ -ferrite and refined microstructure
- HAZ (SS 316 side):
 - Moderate hardness with slight reduction due to grain growth
- HAZ (SS 202 side):
 - Often exhibits **higher hardness variation** due to instability and possible strain hardening

Typical Trend:

SS 316 < Weld Zone > SS 202 (variable)

5.2 Tensile Strength

Tensile properties determine the load-bearing capability of the welded joint.

Key Findings:

- Ultimate tensile strength (UTS) depends on:
 - Weld quality
 - Filler material
 - Heat input

In fig 6(b) changes takes place due to solid solution strengthening of weld include tensile strength, yield strength, and percentage elongation.[11]

- In most cases:
 - Joint strength is **limited by SS 202**
- Failure location:
 - Commonly occurs in **SS 202 base metal or HAZ**

5.3 Impact Toughness

Impact toughness indicates the ability to absorb energy under sudden loading.

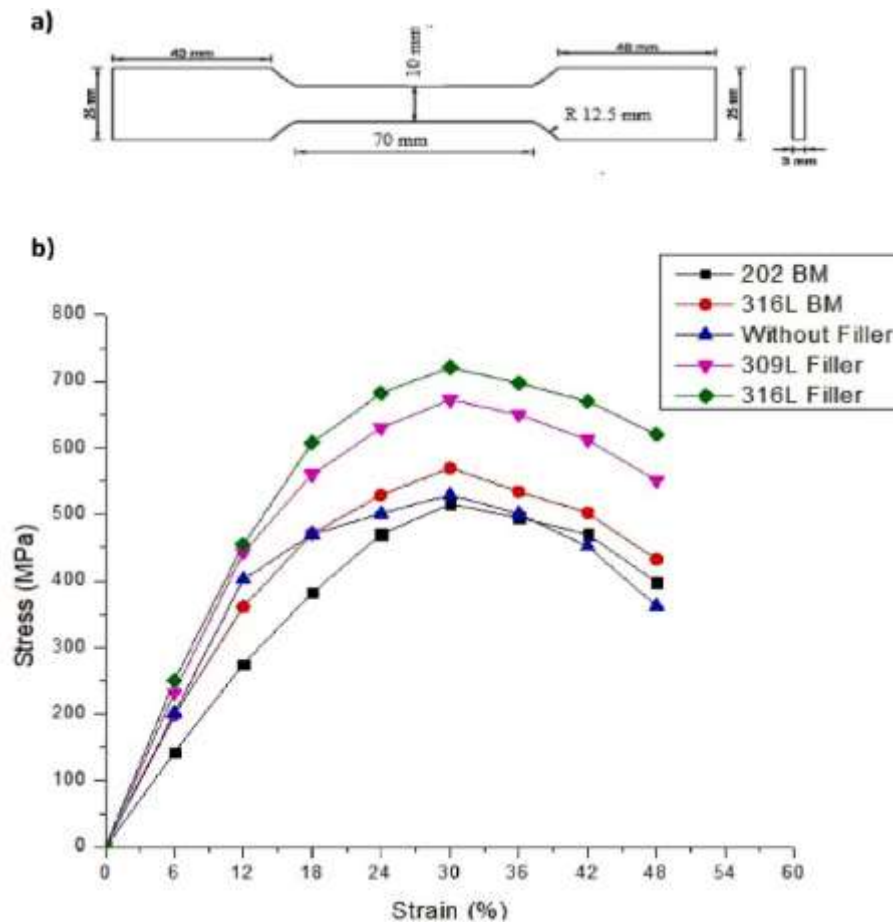
Factors Affecting Toughness:

- δ -ferrite content:
 - Moderate amount $\rightarrow$ beneficial
 - Excess $\rightarrow$ reduces toughness
- Grain size:
 - Coarse grains $\rightarrow$ lower toughness

Observation:

S 316 contributes better toughness zone depends on phase balance and cooling

Fig. 6. Tensile Test a) Specification test sample b) Stress Strain Diagram.



5.4 Residual Stresses

Residual stresses develop due to:

- Differences in thermal expansion
- Non-uniform cooling rates

Effects:

- Distortion of welded components
- Increased susceptibility to cracking
- Reduction in fatigue life

5.5 Correlation with Microstructure

Mechanical properties are directly linked to microstructure:

- Austenite → improves ductility and toughness
- δ -ferrite → reduces cracking but increases hardness

- Grain coarsening → reduces strength and toughness

5.6 Factors Influencing Mechanical Properties

- Welding parameters (current, voltage, speed)
- Heat input and cooling rate
- Filler material selection (e.g., ER309L)
- Degree of dilution between base metals

5.7 Summary

Property	Key Observation
Hardness	Highest in weld zone
Tensile Strength	Governed by SS 202
Toughness	Depends on ferrite content
Residual Stress	Due to thermal mismatch

5.8 Key Conclusion

- Mechanical performance of the joint is **non-uniform**
- SS 202 side is the **weakest region**
- Proper welding control is essential to optimize strength and toughness

Understanding these mechanical properties is essential for predicting the performance and reliability of SS 316–SS 202 dissimilar welded joints in real-world applications.

6 Metallurgical Challenges

Dissimilar welding between Stainless Steel 316 and Stainless Steel 202 presents several metallurgical challenges due to differences in chemical composition, thermal behavior, and phase stability. These challenges directly affect weld quality, service performance, and long-term reliability of the joint.

6.1 Hot Cracking (Solidification Cracking)

- Occurs during solidification of the weld metal
- Caused by:
 - Wide solidification temperature range
 - Segregation of alloying elements

- Influenced by:
 - High dilution between SS 316 and SS 202
 - Improper filler selection

Control Measure:

- Use of δ -ferrite in weld metal (typically 3–10%)
- Preferred filler: ER309L

6.2 Sensitization

- Formation of chromium carbide (Cr_{23}C_6) at grain boundaries
- Leads to:
 - Chromium depletion
 - Reduced corrosion resistance

More severe in:

- HAZ of SS 316 due to higher carbon exposure and thermal cycling

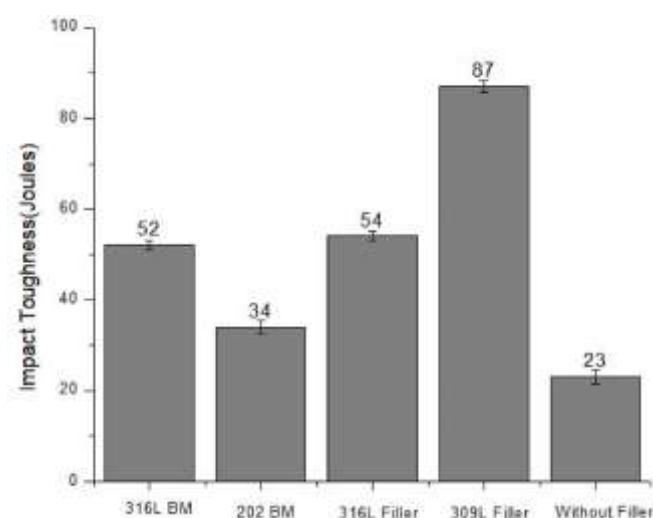
Control Measures:

- Low carbon grades (e.g., 316L)
- Controlled heat input
- Rapid cooling

3.5 Impact test

The Charpy test V-notch impact test conducted showing the results as shown in fig 7[11] .

BM 316L ASS and BM 202AS impact toughness value 52 and 34 J

**6.3 Elemental Dilution**

- Mixing of base metals and filler material in fusion zone
- Causes:

- Change in Cr/Ni/Mn balance
- Unpredictable phase formation

Effects:

- Variation in hardness
- Microstructural heterogeneity
- Reduced corrosion resistance in localized regions

6.4 Residual Stresses and Distortion

- Caused by non-uniform heating and cooling
- Differences in thermal expansion coefficients between SS 316 and SS 202 intensify the effect

Consequences:

- Warping of welded components
- Increased susceptibility to fatigue failure
- Stress corrosion cracking risk

6.5 Corrosion Mismatch

- SS 316 has high corrosion resistance due to molybdenum
- SS 202 has comparatively lower resistance

Result:

- Formation of galvanic cells in aggressive environments
- Preferential corrosion at SS 202 side or HAZ

6.6 Phase Imbalance

- Improper welding conditions may lead to:
 - Excess δ -ferrite $\rightarrow$ reduced toughness
 - Fully austenitic structure $\rightarrow$ increased cracking risk

Requirement:

- Balanced austenite–ferrite ratio for optimum performance

6.7 Grain Coarsening

- Occurs in Heat Affected Zone (HAZ) due to thermal exposure
- Leads to:
 - Reduced strength
 - Lower impact toughness

6.8 Summary of Challenges

Challenge	Effect
Hot cracking	Weld failure during solidification
Sensitization	Loss of corrosion resistance
Dilution	Unstable microstructure
Residual stress	Distortion and cracking
Corrosion mismatch	Localized corrosion attack
Grain coarsening	Reduced mechanical strength

6.9 Key Conclusion

Metallurgical challenges in SS 316–SS 202 dissimilar welding are primarily driven by compositional differences and thermal mismatch. Proper control of welding parameters, filler selection, and cooling rate is essential to minimize defects and ensure weld integrity.

7. Conclusion

The dissimilar welding of Stainless Steel 316 and Stainless Steel 202 presents a practical engineering solution for achieving a balance between cost effectiveness and corrosion resistance. However, the significant differences in chemical composition, particularly in nickel and molybdenum content, lead to complex microstructural evolution and variations in mechanical performance across the weld joint.

The review shows that the fusion zone typically consists of an austenitic matrix with δ -ferrite, which helps reduce hot cracking but must be controlled to maintain toughness. The heat affected zones on both sides exhibit distinct behaviour, with SS 316 being more prone to sensitization and SS 202 showing comparatively lower stability and mechanical performance. These variations result in non-uniform hardness distribution, reduced toughness in certain regions, and residual stress development due to thermal mismatch.

Mechanical properties of the joint are largely governed by the weaker SS 202 base metal or its heat affected zone, making it the critical region for failure under loading conditions. Additionally, challenges such as elemental dilution, corrosion mismatch, grain coarsening, and hot cracking significantly influence weld integrity.

Recent studies indicate that proper selection of filler materials (such as ER309L), optimized welding parameters, and controlled heat input can significantly improve weld quality by stabilizing microstructure and minimizing defects. Advanced welding techniques further offer potential improvements in joint performance.

In conclusion, while SS 316–SS 202 dissimilar welding is feasible and widely applicable, achieving a sound and reliable joint requires careful control of metallurgical and processing parameters. Future research should focus on advanced welding methods, post-weld treatments, and computational modelling to further enhance weld performance and long-term service reliability.

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