INVESTIGATION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF DISSIMILAR MATERIAL SUPER DUPLEX STAINLESS STEELS (SDSS2507) & AUSTENITIC STAINLESS STEELS (ASS316) OF 3MM THICKNESS USING LASER BEAM WELDING(LBW) PROCESS

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ABSTRACT

This study explores the mechanical and microstructural properties of dissimilar metal joints between 3 mm thick Austenitic Stainless Steel (ASS 316) and Super Duplex Stainless Steel (SDSS 2507), welded using the Laser Beam Welding (LBW) technique. LBW was chosen for its ability to produce high-quality welds with minimal distortion and narrow heat-affected zones. Nitrogen shielding gas was used to create square butt joints with no root gap. Mechanical testing included tensile and microhardness tests, while microstructural evaluation was performed using optical microscopy, SEM, EDAX, and XRD. The SEM results revealed varied grain morphologies, with double-pass welds exhibiting improved fusion, grain refinement, and consistent element distribution due to reheating effects. All tensile test specimens fractured at the ASS 316 base metal, indicating superior weld strength. The study concludes that LBW, especially with double-pass welding, effectively joins ASS 316 and SDSS 2507, producing structurally sound and metallurgically robust joints suitable for demanding industrial applications.

Keywords: Fiber Laser Beam Welding, SDSS 2507, ASS 316, dissimilar welding, single pass, double pass, SEM, EDAX, XRD, tensile strength, microstructure.

I . INTRODUCTION

In industries where high strength, corrosion resistance, and long service life are essential, like petrochemical, marine, nuclear, and chemical processing, welding is essential to the production of industrial components. Dissimilar metal welding has grown in significance in recent years as engineers strive to maximise material performance and cost. The combination of austenitic stainless steel (ASS 316) with super duplex stainless steel (SDSS 2507) is a well-known example. These two materials have complementing qualities: ASS 316 offers good weldability, ductility, and toughness, while SDSS delivers high strength and exceptional resistance to stress corrosion, cracking, and pitting. However, because of their different metallurgical, thermal, and physical properties, welding these disparate materials is difficult.

Unwanted phases, residual strains, and unequal heat distribution throughout the weld and heat-affected zones (HAZ) can result from mismatched thermal expansion coefficients, melting points, and alloy compositions. If these problems are not adequately addressed, the welded joint's structural integrity may be jeopardised. Because of this, choosing the right welding method and process parameters is essential when working with dissimilar junctions.

A highly sophisticated fusion welding technique that has grown in favour for precise applications involving both comparable and dissimilar metals is laser beam welding (LBW). It is distinguished by its narrow fusion zones, decreased HAZ, and capacity to generate deep penetration welds with less heat input. These characteristics reduce metallurgical issues and thermal distortion, which makes them especially beneficial for dissimilar welding of SDSS and ASS materials. Additionally, LBW makes it possible for localised heat input, automation, and faster welding speeds—all of which improve the process' suitability for high-performance components.

The laser beam welding of dissimilar connections between 3 mm thick ASS 316 and SDSS 2507 is the main subject of this study. Three distinct configurations are examined in the study: two involving conventional two-plate couplings utilising single-pass and double-pass welding procedures, and one with three dissimilar plates welded together. Multiple passes in LBW have an impact on the microstructure and temperature cycles, which in turn affect the weld joint's corrosion and mechanical properties. In order to assess the impact of pass number on weld quality and material reaction, a comparison of single-pass and double-pass welds was conducted.

The current study uses advanced characterisation techniques like Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDAX), and X-ray Diffraction (XRD) in addition to mechanical testing (tensile strength and hardness) to fully comprehend the behaviour of these weldments. SEM is very useful for analysing the microstructural characteristics of the HAZ and weld, enabling the identification of weld flaws, phase changes, and changes in grain size. Phases and any strain-induced changes are identified using XRD, while the distribution of alloying elements throughout the weld areas is ascertained using EDAX.

The objective of this work is to determine how the weld pass technique and LBW parameters affect the mechanical performance and microstructural integrity of SDSS 2507–ASS 316 dissimilar junctions. This knowledge will help optimise laser welding procedures for crucial applications where corrosion resistance and mechanical robustness are crucial.

II. LITERATURE REVIEW

Welding dissimilar metals like super duplex stainless steel (SDSS) and austenitic stainless steel (ASS) has attracted growing attention in industries seeking advanced mechanical, thermal, and corrosion-resistant properties. Research emphasizes the importance of heat input, welding method, and metallurgical compatibility for joint performance.

TIG Welding Insights:

Vemulawada [1] reported dual-phase microstructures (austenite + ferrite) in AISI 316–SDSS 2507 welds. However, a wide heat-affected zone (HAZ) led to phase imbalance and grain coarsening, reducing mechanical strength and corrosion resistance. Failures often originated from the ASS base, pointing to lower ductility on that side.

Heat Input & Weld Integrity:

Mohammed et al. [2] noted that excessive heat during arc welding promotes residual stress and intermetallic phases, degrading performance. Low-heat input methods like Laser Beam Welding (LBW) mitigate these drawbacks via rapid solidification.

LBW Superiority & Microstructure: Brytan and Ouali [3] highlighted LBW's benefits: higher tensile strength (~690 MPa), finer HAZ, and deeper penetration. Advanced analysis (SEM, EDAX, XRD) revealed improved phase distribution and elemental diffusion. Double-pass LBW enhances grain uniformity and reduces distortion.

Optimization Parameters:

Mehta [4] stressed controlling shielding gas, welding speed, and laser power to avoid brittle phase formation and element segregation (Cr, Ni, Mo), which impacts ductility and corrosion behavior.

Fusion Quality & Cooling Rates: Rapid cooling in LBW results in refined grains and balanced austenite-ferrite distribution, outperforming TIG welding. Multi-pass LBW acts as in-situ heat treatment, refining microstructure and reducing residual stress (Clemens et al. [5]).

Hardness & Elemental Diffusion:

LBW shows elevated hardness on the SDSS side due to chromium-rich ferrite and fast phase transitions. TIG welds display lower, uneven hardness. EDAX and XRD confirm elemental gradients and suppression of embrittling phases under laser welding.

Corrosion Resistance:

Studies by Zanotto et al. [6] reveal LBW weld zones provide stronger resistance to pitting and intergranular corrosion than arc welds, thanks to fine-grained dual-phase structures.

LBW in Practice:

Kumar [7] describes LBW's precision and adaptability across industries, citing high welding speed, low distortion, and suitability for automation. While equipment is costly and reflective metals pose challenges, LBW remains a top-tier choice for performance-critical applications. Future prospects include AI-driven controls and real-time monitoring.

Laser welding is emerging as the preferred technique for joining amorphous alloys and delicate substrates due to its precision, minimal heat-affected zones (HAZ), and ability to retain unique microstructures.

Amorphous Alloy Welding:

Pulsed and continuous-wave lasers effectively join bulk metallic glasses (BMGs), provided cooling rates remain high to prevent crystallization. Studies highlight the need for precise control of laser power, pulse duration, and welding speed to minimize cracking and porosity.

Microstructure & Mechanical Properties:

Laser settings directly influence weld integrity. When optimized, strong amorphous joints with low flaw content are possible. This process is critical for maintaining corrosion resistance and high strength.

Modelling & Simulation (Jimenez-Xaman [9]): Physics-based models—covering thermal flow, phase transitions, and keyhole dynamics—enable predictions of weld performance. Gaussian and double-ellipsoidal heat source models improve understanding of stress distribution and temperature gradients.

Numerical Techniques:

CFD and FEM are widely used to simulate weld conditions and address complexities like vaporization and fluid motion, facilitating better defect control.

Industrial Applications (Deepak et al. [10]): Laser welding excels in automotive, aerospace, electronics, and medical industries. Benefits include deep penetration, contactless precision, and automation compatibility—despite equipment cost and safety challenges.

Transmission Welding (Sopeña et al. [11]): Offers high precision and minimal surface damage when fusing materials like silicon and sapphire, crucial for photonics and microelectronics.

Keyhole Stability (Vollertsen & Volpp [12]): Stable keyholes ensure deep, defect-free welds. Modelling supports optimization of laser power and focus, especially for thick or reflective substrates.

Copper Alloys (Auwal et al. [13]): Due to high reflectivity and conductivity, welding copper poses challenges. Innovations like pulse modulation, beam shaping, and green lasers significantly enhance weld quality.

Non-Destructive Evaluation (Stavridis et al. [14]): Real-time monitoring via AI, thermography, and acoustic sensors boosts weld reliability. Data-driven approaches help detect porosity, cracks, and shape deviations.

Melt Pool Dynamics (Ebrahimi et al. [15]): Laser beam profiles influence convection, keyhole formation, and thermal gradients. Fine-tuning laser shape and intensity improves microstructural consistency.

Laser Welding Literature Review: Emerging Techniques and Applications

Laser welding has seen significant innovation, with attention on real-time control, precision modelling, and versatile material applications.

Process Efficiency & Automation

Klimpel [16]: Highlights how LBW and Laser Hybrid Welding (LHW) enable high-quality fusion of steels and non-ferrous alloys. Automation, AI-based monitoring, and adaptive control improve productivity and minimize defects in industrial systems.

Keyhole Dynamics & Modelling

Vollertsen & Volpp [17]: Explores numerical modelling of keyhole formation, showing how welding parameters affect penetration and flaw formation. Stable keyholes are essential for defect-free, high-precision welds.

Parameter Optimization

Patel & Mazmudar [18, 22]: Show that tuning laser parameters like power, speed, pulse duration, and gas flow is vital to avoid porosity, uneven microstructure, and weak joints. Emphasize material-specific approaches to enhance weld strength and surface quality.

Predictive Modelling & Machine Learning

Farshidianfar et al. [19]: Reviews advanced modelling methods—CFD, FEM, and AI—for predicting metallurgical transformations and mechanical outcomes. Stresses real-time monitoring for better defect mitigation and parameter optimization.

Automotive Applications

Sen et al. [20]: LBW improves energy efficiency, precision, and material compatibility in welding EV modules, body panels, and gearboxes. Integration with robotics supports high-throughput manufacturing.

Laser-Material Interaction

Patterson [21]: Explains how absorption rates, conductivity, and energy density influence welding mode and geometry. Discusses control techniques to reduce common weld flaws like humping and porosity.

III. THEORY

Welding Theory for Dissimilar Stainless Steels

3.1 Overview of Welding

Combining different metals enhances component performance for demanding environments like marine, nuclear, and petrochemical systems. Austenitic stainless steel (ASS 316) and super duplex stainless steel (SDSS 2507) are commonly joined to leverage their complementary traits: corrosion resistance, strength, and ductility. Yet, welding them poses challenges due to metallurgical incompatibilities, phase imbalance, and residual stress formation.

Laser Beam Welding (LBW) offers a high-precision solution by delivering controlled heat, minimal distortion, and narrow heat-affected zones (HAZ). LBW enables deep, defect-free welds suitable for safety-critical applications.

3.2 Material Characteristics

3.2.1 Composition & Microstructure

Element	SDSS 2507	ASS 316
Cr	25–26%	16–18%
Ni	6–7%	10–14%
Mo	3.5–4%	2–3%
N	~0.3%	≤0.1%
Structure	Duplex (50/50 mix of ferrite & austenite)	Fully Austenitic
Strength	High	Moderate
Corrosion	Excellent	Good

3.2.2 Mechanical Properties

Property	SDSS 2507	ASS 316
Tensile Strength	800–900 MPa	~515 MPa
Yield Strength	600–700 MPa	~205 MPa
Elongation	~30%	>40%
SCC Resistance	High	Susceptible
Thermal Expansion (CTE)	$\sim 12.7\times10^{-6}$ /°C	$\sim 16\times10^{-6}$ /°C
Thermal Conductivity	~25 W/m·K	~16 W/m·K

3.3 Welding Challenges

Intermetallic Formation: Sigma and chi phases can weaken welds.

Elemental Segregation: Uneven diffusion alters phase balance and corrosion resistance.

Stress from Thermal Expansion: Mismatch causes residual stress and cracking.

Microstructure Variability: Grain differences increase susceptibility to localized failure.

3.4 Principles of LBW

Laser Sources:

CO_2: High output, low focusability

Nd:YAG: Solid-state, precision welding

Fiber Laser: High efficiency, ideal for dissimilar metals.

Keyhole Welding:

Delivers deep, narrow welds with localized heat input and efficient energy absorption.

Heat Cycles:

Rapid heating and cooling shape grain structure and residual stress patterns.

3.5 Microstructure Evolution

Fusion Zone (FZ):

Mix of SDSS and ASS with complex solidification modes. Ferrite-first (duplex) improves crack resistance.

Heat-Affected Zone (HAZ):

Risk of grain coarsening and phase precipitation, especially in SDSS.

3.6 Mechanical Integrity

Strength: Weld strength lies between both base metals.

Hardness: Peaks near brittle regions.

Ductility: Dependent on homogeneity and defect absence.

3.7 Corrosion Performance

Chemical segregation and phase imbalance can reduce corrosion resistance. Minimizing sensitization in weld zones is essential.

3.8 Characterization Techniques

SEM: Microstructure imaging

EDAX: Elemental mapping

XRD: Phase identification

Microhardness Profiling: Local mechanical property assessment.

3.9 Process Optimization

Fine-tuning laser power, speed, beam focus, and shielding gas is key to improving weld quality and avoiding defects.

3.10 Equipment Insights

Fiber Lasers dominate LBW for precision tasks. They offer superior beam focus and energy efficiency, enabling seamless welding of ASS 316 and SDSS 2507—despite their differing thermal and metallurgical profiles.

3.11 Laser Beam Welding Equipment: Fibre Laser Focus

Fibre laser welding is a cutting-edge LBW technique that uses an optical fibre as the gain medium, offering unmatched precision, energy efficiency, and low maintenance. Operating around a 1070 nm wavelength, these lasers achieve high absorption in metals like steels—making them ideal for joining dissimilar alloys such as ASS 316 and SDSS 2507.

Key advantages include:

- Deep, narrow welds with minimal heat-affected zones (HAZ).
- High beam concentration, enabling fast, efficient melting.
- Robotic compatibility, ensuring automation-friendly integration.
- Reduced defects, such as cracking and intermetallic phase formation.

Fibre lasers allow fine-tuned control over welding variables—power, speed, and focus—to produce structurally sound, corrosion-resistant joints. Their effectiveness with materials of differing thermal behaviors has made them a go-to in industries like aerospace, automotive, nuclear, and chemical processing.

IV. EXPERIMENTAL PROCEDURE

Material Selection and Preparation:

Austenitic stainless steel (ASS 316) and super duplex stainless steel (SDSS 2507) plates, each 3 mm thick, were used as the base metals for the Laser Beam Welding (LBW) procedure in this study. Both plates were extensively cleaned with ethanol to get rid of grease, grime, and other surface impurities before welding. This promoted strong metallurgical bonding and reduced the possibility of weld flaws by guaranteeing a clean interface.

In order to guarantee correct alignment and complete penetration throughout the welding process, a square butt joint configuration with zero (0 mm) root gap was employed.

A K-TECH Laser Beam Welding (LBW) machine was used to accomplish the welding under carefully monitored conditions. During welding, 99.99% pure nitrogen gas was utilised as the shielding gas to stop oxidation and safeguard the weld pool.

4.2 Experimental Procedure:

Laser Beam Welding (LBW)

Dissimilar welding between Super Duplex Stainless Steel (SDSS 2507) and Austenitic Stainless Steel (ASS 316) was performed using a precision-controlled, high-power fibre laser system. Optimized settings were applied to ensure consistent joint integrity, minimal defect formation, and microstructural stability.

Key LBW Parameters:

Laser Type: High-power continuous-wave fibre laser

Welding Mode: Keyhole mode for deep penetration

Shielding Environment: Inert gas (Argon) to prevent oxidation

Power Output: Adjusted to match the thermal conductivity of both materials

Beam Focus & Spot Size: Precisely aligned for uniform energy distribution

Welding Speed: Calibrated to balance heat input and cooling rate

Joint Configuration: Butt joint with optimized gap for laser penetration

This configuration provided stable melting, reduced intermetallic phase formation, and fine control over the heat-affected zone (HAZ). All samples were prepared under identical conditions to ensure repeatability and accurate characterization in subsequent analysis.

Equipment Configuration: Wire, Gas & Laser Settings

To ensure consistent quality during the LBW of SDSS 2507 and ASS 316, precise wire feeding and laser parameters were employed under controlled conditions.

Wire and Gas Parameters

The wire feeding and shielding gas setup was optimized for automatic delivery and effective weld protection.

Parameter	**Value**
Wire Feeding Speed	6 mm/s
Pre-Gas Time	100 ms
Post-Gas Delay	100 ms
Wire Feeding Mode	Automatic
Wire Direction	Forward
Wire Activation	Disabled (Off)

Laser Operating Parameters:

High-power laser parameters were selected for stable melting and minimized thermal distortion.

Parameter	**Value**
Laser Power	3.9 kW
Pulse Intensity	100%
Frequency	1000 Hz
Mode	Series
Laser Status	Enabled
Scan Frequency	25 Hz
Weld Width	4.50 mm
Bead Settings	Not Applicable (NA)

These settings supported precision welding by regulating heat input, maintaining beam consistency, and providing optimal gas shielding—all essential for achieving high-integrity joints in dissimilar stainless steels.

Welding Setup Photos:

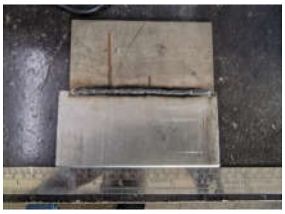



Figure. 4.1: LBW Machine

During Welding Photos


Figure. 4.2: LBW samples

LASER Welding Parameters for 3 Samples

Parameter	**Dual Pass Weld**		**Single Pass-1**	**Single Pass-2**
	Root	**Hot**		
Machine Laser Power (3.9KW)	47% (1.83KW)	47% (1.83KW)	40% (1.56KW)	35% (1.36KW)
Pulse	100%	100%	100%	100%
Frequency (HZ)	1000	1000	1000	1000

4.3 Sample Sectioning

After completing the welding process, the welded plates were sectioned using a EDM wire cutting

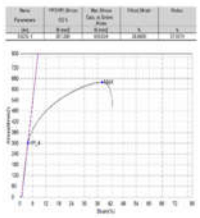

Figure. 4.3: Electric discharge wire cutting

V. RESULTS AND DISCUSSION

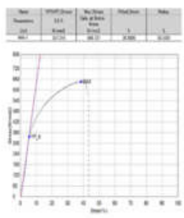
Laser Beam Welding (LBW) was employed to join dissimilar metals—SDSS 2507 and ASS 316—via single-pass and dual-pass methods. Mechanical and microstructural evaluations revealed distinct differences in joint performance.

5.1 Tensile Performance:

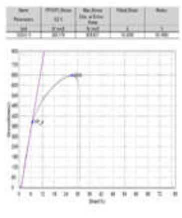
Failure consistently occurred in ASS 316 regions, suggesting weld zones were stronger than the parent metal.



Graph.5.1: Dual Pass LBW joint



Graph.5.2: Single Pass LBW joint-1



Graph5.3: Single Pass LBW joint-2

Method	**0.2% YS (MPa)**	**UTS (MPa)**	**Elongation (%)**	**Failure Zone**
Dual Pass	301	639	28.80	SS316 HAZ
Single Pass–1	337	645	30.50	SS316 Base Metal
Single Pass–2	**385**	**658**	**18.32**	SS316 Base Metal

Single Pass–2 achieved highest strength but compromised ductility.

Single Pass–1 offered a balanced combination of strength and elongation.

Dual Pass exhibited moderate strength with enhanced uniformity due to thermal cycling.

Weld selection depends on application: choose Single Pass–2 for strength-critical use; opt for Single Pass–1 where ductility matters.

5.2 Micro-hardness Analysis

Both welding types showed a **noticeable hardness drop across HAZ**, especially on SDSS side.

Feature	Dual Pass Weld	Single Pass Weld
SDSS Base Metal	270–305 HV	260–295 HV
Weld Zone	200–220 HV	200–230 HV
SDSS HAZ	Drop to ~210 HV	Drop to ~215 HV
SS316 HAZ	Drop to ~180 HV	Drop to ~175 HV
Hardness Transition	Gradual	Steeper

Dual Pass technique improved hardness uniformity across fusion boundaries, reducing sharp gradients.

Microstructure Evaluation

Etched samples at 200× magnification revealed:

Dual Pass Weld: Refined duplex structure with balanced ferrite and austenite; lower porosity; enhanced stability.

Single Pass Weld–1: Columnar ferrite with some austenite precipitation; effective fusion but narrower bead.

Single Pass Weld–2: Coarser grain, slight asymmetry, and higher ferrite content due to rapid cooling.

5.3 Metallography Overview

To enable microstructural analysis, specimens were prepared using standard metallographic procedures involving grinding, polishing, and etching.

Sample Preparation Steps

Grinding
Samples were ground using silicon carbide papers (grits: 220–1200) under continuous water flow to avoid overheating and surface damage.

Polishing
Polishing was performed with a cloth wheel and 1 µm diamond paste to achieve a scratch-free, mirror finish suitable for microscopic observation.

Etching
Etchants were selected based on the material type:

- **SDSS 2507:** Electrolytic etching or Beraha's reagent
- **ASS 316:** Aqua Regia or Glyceregia

Etching conditions were carefully controlled to highlight grain boundaries, phase distribution, and fusion characteristics.

Microstructural Analysis: Optical & SEM Microscopy

5.5 Optical Microscopy: Macro & Microstructures

Etched weld samples were inspected to evaluate **base metal**, **weld zones**, and **heat-affected zones (HAZ)**.

Macrostructure Overview (12.5× Magnification)

Sample	Weld Appearance	Penetration	Defects	HAZ Symmetry
Dual Pass	Uniform with balanced beads	Full	Minor porosity only	Symmetrical
Single Pass–1	Narrower bead	Full but shallower	Some underfill	Compact HAZ
Single Pass–2	Slight asymmetry	Suspected partial	Minor imperfections	Uneven HAZ

Microstructure Insights (200× Magnification)

Region	Dual Pass Weld	Single Pass–1	Single Pass–2
Weld Zone	Duplex with refined ferrite-austenite mix	Ferritic matrix with austenite pockets	Coarser ferritic grains, less intragranular austenite
SDSS HAZ	Controlled grain coarsening	Expanded ferrite, reduced austenite	Larger grains, tougher phase imbalance
SS316 HAZ	Risk of carbide sensitization	Pronounced HAZ due to rapid heating	More coarsening, wider heat effect
Base Metals	Stable duplex and austenitic phases		

	retained across all samples		

Dual pass welds offered microstructural refinement and balance, while single pass variations revealed different thermal effects.

5.6 Etching for Microstructure

- **Duplex Steel:** Glyceregia or Beraha's reagent
- **Etching Duration:** 30–60 seconds
- **Microscopy:** Conducted at 200× magnification

5.7 Scanning Electron Microscopy (SEM)

Dual Pass Weld (300× & 500× Magnification)

- **Fusion Zone:** Fine dendritic structures; duplex phases observed
- **Interfaces:** Clear transition from base metal to weld; consistent metallurgical bonding
- **Remelting Effects:** Second pass enhanced grain mixing and bond strength
- **Defect Presence:** Minimal porosity; clean fusion boundary

Single Pass Weld

- **Fusion Zone:** Directional dendrites; equiaxed grains indicate rapid solidification
- **Interface Quality:** Sharp fusion lines; good grain continuity
- **Defects & Cleanliness:** No cracks or voids; stable heat gradient control
- **Structural Insight:** Dense grain patterns aligned with heat flow direction

5.8 SEM Comparison Summary

Feature	Single Pass LBW	Double Pass LBW
Fusion Zone	Equiaxed dendrites; sharp interface	Wider zone; coarsened dendritic grains
Dendritic Growth	Fine, directional	Mixed grain sizes; remelting observed
Grain Morphology	Mostly fine, some columnar	Coarser grains, reduced boundary clarity
HAZ	Narrow, localized heat effect	Broader due to second cycle
Microdefects	Clean interface, no cracks	Minor signs of boundary remelting
Thermal Input	Low, controlled	Higher, with minor distortion potential

5.9 EDAX & SEM Analysis of Weld Zones

Energy Dispersive X-ray Analysis (EDAX) and Scanning Electron Microscopy (SEM) were performed to evaluate the elemental distribution and microstructural features in fusion zones created by **single-pass** and **double-pass laser beam welding (LBW)**.

Elemental Composition Comparison

Element	Single Pass (%)	Double Pass (%)	Role in Weld Integrity
Iron (Fe)	66.66	68.67	Core structural matrix
Chromium (Cr)	21.27	20.53	Enhances corrosion resistance, stabilizes ferrite
Nickel (Ni)	10.94	9.67	Stabilizes austenite, improves ductility
Molybdenum (Mo)	2.13	1.13	Boosts pitting resistance

Single-pass welds showed slightly higher Cr, Ni, and Mo retention—beneficial for localized corrosion resistance. Double-pass welds exhibited improved Fe content and structural uniformity.

Sample1 (Dual Pass Weld) Sample2 (Single Pass Weld) Sample3 (Single Pass Weld)

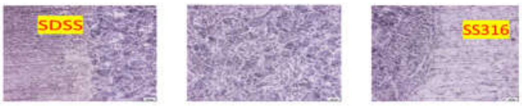
5.1 Macrostructures , Magnification 12.5x

Microstructure Observations

Dual-Pass Weld (Sample 1)

- **SEM Imaging (600 µm):** Revealed refined, evenly distributed dendritic grains from remelting and fusion.

• **Surface Features:** Minor, well-dispersed voids; smooth grain boundaries.



Sample 1 (Dual Pass Weld)

Sample 2 (single Pass Weld)

Sample 3 (single Pass Weld)

5.2 (a) Interface SDSS(Left) Weld (Right); (b)Weld Zone; (c) Interface Weld (Left) SS316 (Right), MAGNIFICATION 200X

Metallurgical Advantages:

- Enhanced grain refinement
- Greater elemental homogeneity
- Deeper penetration and consistent alloy dispersion

Single-Pass Weld (Sample 2)

- **SEM Imaging (600 µm):** Coarser dendrites with directional solidification due to rapid cooling.
- **Surface Features:** Isolated pits and grain inconsistencies.

Observations:

- Less fusion depth and homogenization
- Higher alloy element retention (notably Mo)
- Increased potential for microsegregation

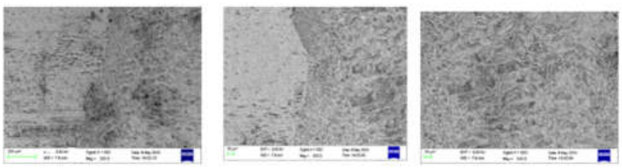
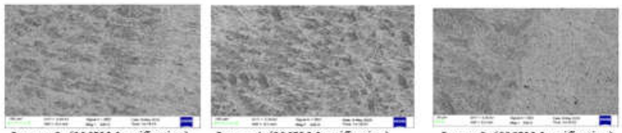


Image 1 (200X Magnification) Image 2 (500X Magnification) Image 3 (500X Magnification)



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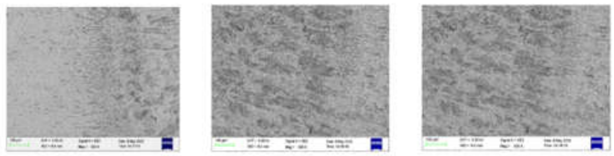
5.3 SEM Dual pass structures



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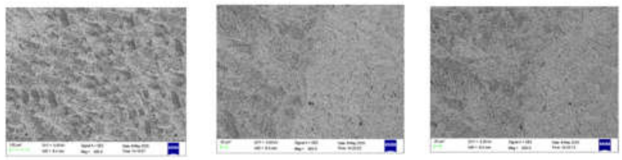


Image 4 (300X Magnification) Image 5 (500X Magnification) Image 6 (500X Magnification)

5.3 SEM Single pass structures

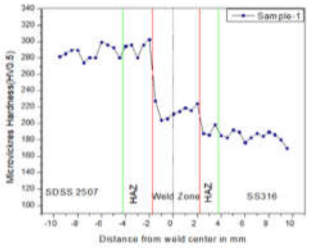
5.10 DISCUSSION

Weld Integrity & Behavior

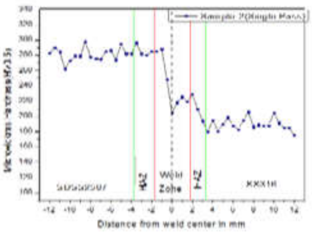
Mechanical Trends

- **Single Pass (Low Power):** Achieved highest tensile strength due to minimal heat input and rapid cooling, but reduced ductility.
- **Single Pass (High Power):** Balanced strength and elongation—ideal for applications demanding both robustness and formability.
- **Dual Pass Weld:** Lower strength, but improved ductility and grain uniformity due to second thermal cycle.

Microhardness Profile:



Graph.5.4: Dual Pass LBW



Graph.5.5: Single Pass LBW

- **SDSS Base:** Hardest (280–310 HV)
- **Weld Zone:** Intermediate hardness
- *Dual-pass:* Softer (~190–230 HV)
- *Single-pass:* Slightly harder (~220 HV)
- **ASS Base:** Softest (160–190 HV)

HAZ Zones:

- SDSS side: Slight hardness drop
- ASS side: Minor increase, likely from grain transformation.

Microstructural Interpretation

Dual Pass Welds:

- Finer grains, homogeneous fusion
- Wider HAZ but smoother transition
- Strong metallurgical bonding and improved elemental diffusion

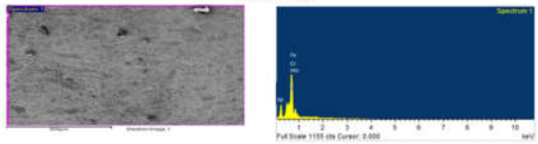
Single Pass Welds:

- Faster cooling created narrow HAZ
- Grain structure more directional and less uniform
- Sample 3 (lower power) had rougher microstructure with slight inconsistencies

EDAX Insights

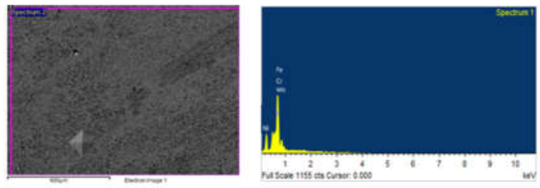
- **Homogeneity:** Enhanced in dual pass due to secondary melting
- **Alloy Retention:** Higher in single pass, aiding pitting corrosion resistance.

Sample 1: Dual Pass Weld Zone



ELEMENTS	IN WT %
Chromium	20.53
Nickel	9.67
Molybdenum	1.13
Iron	68.67

Sample 1: Single Pass Weld Zone



ELEMENTS	IN WT %
Chromium	21.27
Nickel	10.94
Molybdenum	2.13
Iron	66.66

| Table5.6:EDAX Result Analysis – Single Pass Weld (Spectrum 2)

- **Trade-off:**
- *Dual-pass:* More stable and consistent weld with better structural soundness
- *Single-pass:* Stronger mechanical results and slightly higher corrosion protection from retained elements.

CONCLUSION

The fibre laser welding of SS316 and SDSS2507 demonstrated excellent joint integrity, with parameter 3 (35% base power) achieving peak mechanical properties: 658 MPa tensile strength and 385 MPa proof stress. Microscopic evaluation confirmed sound bonding without cracks or porosity. Dual-pass welds showed wider HAZ and bead formation with lower hardness (~200 HV), while single-pass welds had narrower profiles and slightly higher hardness. EDAX analysis revealed elemental enrichment contributing to improved weld strength and hardness.

SCOPE FOR FUTURE EXPLORATION

- **Hybrid Welding Techniques:** Investigate laser-arc hybrid welding and diverse filler metals to fine-tune joint properties.
- **Thermal Treatments:** Evaluate cryogenic and PWHT methods to relieve stress and refine microstructure.
- **Extended Mechanical Assessment:** Study fatigue, fracture toughness, and heat resistance for durability insights.
- **Corrosion Performance:** Conduct electrochemical tests to gauge resistance to pitting, crevice, and stress corrosion.
- **Process Simulation:** Use computational models to predict residual stresses and optimize weld parameters.

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