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EXPERIMENTAL INVESTIGATION ON DISSIMILAR WELDING OF MSS TO ASS FOR POWER PLANT APPLICATION

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Abstract:. Austenitic stainless steels (ASS) are widely used in industries due to their excellent corrosion resistance and mechanical properties. Traditionally, nickel (Ni) is the key alloying element that stabilizes the austenitic phase in stainless steels, but recent trends are shifting towards the use of reduced nickel content. Manganese (Mn) and nitrogen (N) have emerged as replacements for nickel, leading to the development of austenitic grades like the 200 series, particularly grade 202, which offers high hardness, strength, and corrosion resistance at a reduced cost. However, the sustainability of austenitic steels, especially in aggressive environments, remains a challenge. Duplex stainless steels (DSS), which combine ferritic and austenitic phases, may offer a cost-effective alternative with improved properties. This review explores the challenges of dissimilar welding between martensitic P91/P92 steel and austenitic stainless steel, focusing on their application in Ultra Super Critical (USC) power plants. The review covers the mechanical behavior, microstructural issues, and weldability challenges such as hot cracking, carbon migration, and formation of brittle intermetallic compounds. The role of filler metals, post-weld heat treatment (PWHT), and the effects of precipitate coarsening are also discussed. Finally, the potential for composite welds combining duplex and austenitic steels is highlighted for improved strength and corrosion resistance, offering new opportunities in high-performance applications.

Keywords: Austenitic stainless steel, duplex stainless steel, dissimilar welding, P91/P92 steel, Ultra Super Critical power plants, weldability, hot cracking, nickel substitution, manganese, nitrogen, post-weld heat treatment (PWHT), microstructure, precipitates, filler metals, corrosion resistance, mechanical properties.

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I.INTRODUCTION:

Austenitic stainless steels (ASS) are commonly utilized in the manufacturing industry because of their outstanding performance against corrosive and mechanical properties.[1] To keep the austenite phase stable in typical austenitic steel (i.e., 300 series), nickel (Ni) is a primary alloying element, and this alloying element is known as chrome-nickel (Cr-Ni). Industries are increasingly turning to austenitic steel that does not have much nickel. This austenitic grade uses manganese (Mn) and nitrogen (N) to replace the properties of nickel (Ni) that help keep the austenite stable. As a result, austenitic steels with the same chromium (18%) concentration, such as the 200 series, were developed. Austenitic steel grade 202 is one of the most widely used precipitations hardening grades of the 200 series, which possesses high hardness, strength, and good corrosion resistance. By adding a 5–7 weight percentage of manganese (Mn) to austenitic 202 grade, the austenite phase is stabilized, and the addition of nickel (Ni) is reduced from a 9– 11 weight percentage to a 3–5 weight percentage, making the austenitic 202 steel more affordable.[2] Adding nitrogen (N) to austenitic 202 grade also improves their mechanical and corrosion characteristics. Due to the sound mechanical and corrosion characteristics matching up with each other, austenitic 202 steel may be able to replace the commonly used convectional 300 series austenite grade. However, lower sustainability in aggressive environments is a major problem associated with austenitic steel.[3] Duplex stainless steels (DSS), which consist of balanced ferritic and austenitic phases, may provide a cost-efficient substitute. In this review article, microstructure and mechanical behavior of the dissimilar welded joint (DWJ) between ferritic-martensitic steel and austenitic grade steel along with its application have been summarized in Ultra Super Critical (USC) power plant. Creep-strength enhanced ferritic-martensitic (CSEF/M) P91 steel was developed to sustain at extreme operating conditions of ultra-supercritical (USC) power plants, and later, P92 was developed to achieve better mechanical properties, higher creep-rupture strength and high operating temperature with the reduction in wall thickness as compared to P91 steel. The most common application of P91/P92 material in power plants includes high pressure and high-temperature steam piping, headers, super-heater tubing, and water-wall tubing. The other most commonly used material in the power plants is austenitic stainless steel, i.e., SS 304 L. The austenitic grade stainless steel offers high resistance to corrosion due to the high wt. % chromium and nickel content (18–20 and 8–12, respectively). Due to the low carbon content, the SS 304 L is less sensitive to the sensitization problem and offers excellent weldability. The joining of these dissimilar materials is frequently required in the power generation industry. The current review focuses on the main difficulty associated with dissimilar welding of martensitic P91/P92 and austenitic grade stainless steel. The different chemical composition, mechanical, physical and metallurgical properties of the martensitic P91/P92 and austenitic grade stainless steel leads to the problems such as hot cracking and carbon migration. The other weldability issues are the formation of a brittle intermetallic compound, the formation of soft transaction heat affected zone along with martensitic steel, δ ferrite formation in fusion zone, diffusion related problem, and residual stresses, which necessitates thorough study and qualification of welds. The effect of coarsening of various precipitates such as M23C6 carbides, MX carbonitrides, and effect of laves phase, z-phase, and sigma phase on mechanical property, and creep-rupture strength of DWJ are also discussed in detail. Based on the literature reviewed, it has been found that some of the above-stated problems can be solved by using nickel-based filler wire due to its intermediate physical and mechanical properties. The selection of the proper filler metal is another vital issue in dissimilar welds joint that is also covered in this review article. The reason behind the formation of the unmixed zone, filler deficient region, peninsula, island, beach, migrated grain boundaries, solidified grain boundaries, and solidified subgrain boundaries during DWJ of martensitic P91/P92 and austenitic grade stainless steel is also discussed. The heat treatment is required to eliminate the heterogeneous microstructure during the dissimilar welding.

The effect of post-weld heat treatment (PWHT) on the microstructure and mechanical behavior of the DWJ also reviewed. The residual stress developed during the DWJ may cause the premature failure of the components under service, has also been discussed in detail.

The effect associated with the residual stress deformation has been reviewed in the different conditions of the DWJ.

Their microstructural study revealed a balanced austenite-ferrite morphology that mainly consisted of Widmanstatten austenite (WA), grain boundary austenite (GA), and intergranular austenite (IGA). The study showed that the use of flux reduced the heat input necessary to achieve complete penetration, which tends to increase ferrite count in the heat-affected zone and the weld zone of weldment, resulting in minimizing the hot cracking propensity. Further, structure-property connections were also established by evaluating these two weldments' tensile strength, impact strength, and microhardness. It was determined that weldments of activated tungsten inert gas weldment had better mechanical properties than traditional tungsten inert gas weldment. A weld zone fracture occurred near the austenitic weld interface in both weldments.

Thus, a composite of duplex and austenitic steel may be utilized to provide increased strength and extensive resistance to a corrosive environment. Super duplex stainless steels (SDSS) are improved variants of duplex steel with greater pitting resistance equivalent number (PREN > 40), which is the identity of the steel pitting index and is derived using the empirical formula PREN = % Chromium (Cr) + 20% Nitrogen (N)+ 3.3% Molybdenum (Mo).[4,5] Consequently, the welding process parameters that provide the best mechanical and corrosion properties and the longest service life for dissimilar austeniteferritic joints must be discovered. However, issues like hot crack, solidification crack, and the production of undesired auxiliary phases continue to wreak havoc on weld mechanical characteristics when fusing dissimilar metals.

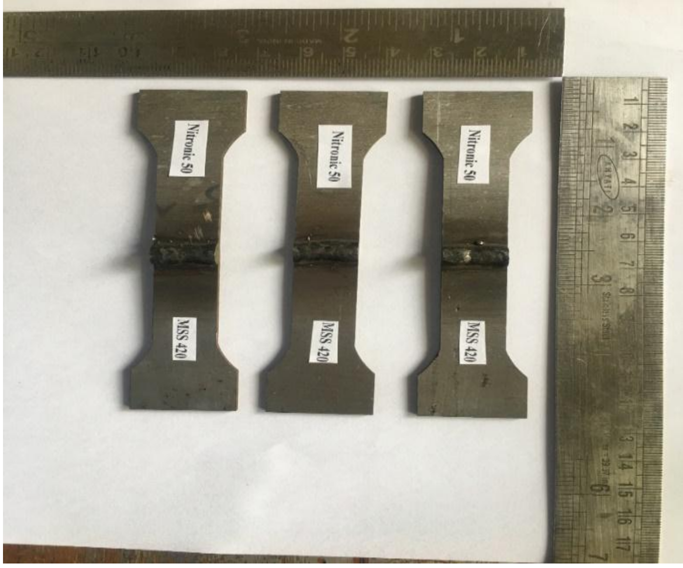


Fig. 1 : Tensile test before

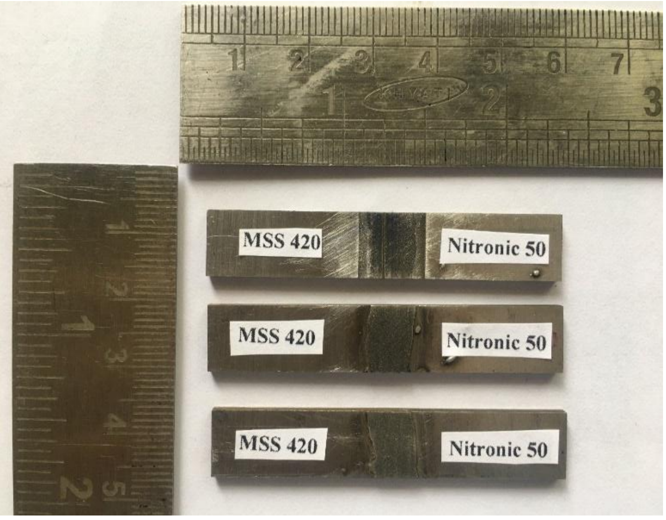
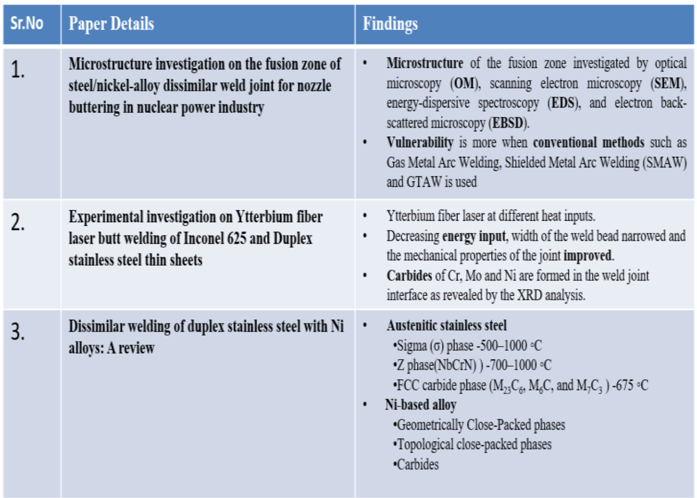


Fig. 2 : Tensile test after

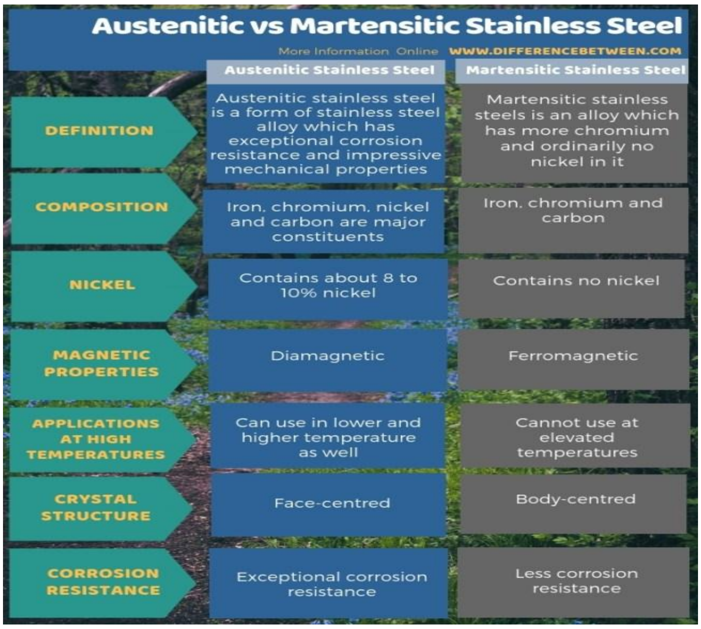
Most of the welding conducted with activated tungsten inert gas welding is a bead on trial,[13–16] and relatively few findings have been outlined on the welding of dissimilar grades. The review shows that austenitic and super duplex stainless steel has not been utilized for dissimilar fabrication using this novel approach. In this study, super duplex 32760 and austenitic 202 grades were selected for fabrication after a detailed analysis of their thermophysical and thermodynamical properties. This dissimilar austenitic-ferritic welded joint is widely used in the power plant, chemical, and petrochemical industry, and even in the offshore industry. Furthermore, this combination can significantly affect the material's microstructural, mechanical, and corrosion properties. After reviewing a number of literature studies, it was noticed that the TiO2 and SiO2 flux dramatically improved the penetration depth with reduced weld width without affecting the base metal's metallurgical and mechanical properties. It was noticed that SiO2 has a strong activating flux to carry out the arc constriction effect, and TiO2 plays a vital role in accommodating the reverse Marangoni effect; both effects majorly play a role in improving the depth of penetration with reduced weld bead width. Here in this research, by understanding their effect on the austenitic and the duplex steel, the combination of both fluxes in the ratio of 1:1 is employed to look at how it affects the welding of this dissimilar combination.

II.LITERATURE REVIEW



Sr.No	Paper Details	Findings
1.	**Microstructure investigation on the fusion zone of steel/nickel-alloy dissimilar weld joint for nozzle buttering in nuclear power industry**	• **Microstructure** of the fusion zone investigated by optical microscopy (**OM**), scanning electron microscopy (**SEM**), energy-dispersive spectroscopy (**EDS**), and electron back-scattered microscopy (**EBSD**). • **Vulnerability** is more when **conventional methods** such as Gas Metal Arc Welding, Shielded Metal Arc Welding (SMAW) and GTAW is used
2.	**Experimental investigation on Ytterbium fiber laser butt welding of Inconel 625 and Duplex stainless steel thin sheets**	• Ytterbium fiber laser at different heat inputs. • Decreasing **energy input**, width of the weld bead narrowed and the mechanical properties of the joint **improved**. • **Carbides** of Cr, Mo and Ni are formed in the weld joint interface as revealed by the XRD analysis.
3.	**Dissimilar welding of duplex stainless steel with Ni alloys: A review**	• **Austenitic stainless steel** •Sigma (σ) phase -500–1000 °C •Z phase(NbCrN)) -700–1000 °C •FCC carbide phase ($M_{23}C_6$, M_6C, and M_7C_3) -675 °C • **Ni-based alloy** •Geometrically Close-Packed phases •Topological close-packed phases •Carbides

Properties comparison of ASS and MSS



Austenitic vs Martensitic Stainless Steel

More Information Online WWW.DIFFERENCEBETWEEN.COM

	Austenitic Stainless Steel	Martensitic Stainless Steel
DEFINITION	Austenitic stainless steel is a form of stainless steel alloy which has exceptional corrosion resistance and impressive mechanical properties	Martensitic stainless steels is an alloy which has more chromium and ordinarily no nickel in it
COMPOSITION	Iron, chromium, nickel and carbon are major constituents	Iron, chromium and carbon
NICKEL	Contains about 8 to 10% nickel	Contains no nickel
MAGNETIC PROPERTIES	Diamagnetic	Ferromagnetic
APPLICATIONS AT HIGH TEMPERATURES	Can use in lower and higher temperature as well	Cannot use at elevated temperatures
CRYSTAL STRUCTURE	Face-centred	Body-centred
CORROSION RESISTANCE	Exceptional corrosion resistance	Less corrosion resistance

Impact test

The process of impact testing is used to study the various characteristics of materials. These include toughness, hardness, ductility and strength. It involves the sudden application of a load to a specimen in order to determine its impact value.The impact value of a material can change based on temperature, size and the amount of plastic deformation it can absorb. This is why it is important to ascertain whether the material is tough or brittle.Temperature can bring change to the impact value in a positive correlation. This means that, generally, the lower the temperature, the lesser the impact energy of the material. As the temperature rises, the impact energy of the material is increased.Size is a factor that greatly affects the results from the Izod Impact Tester. The factor gives way for a number of imperfections to occur in the material. These can serve as stress risers that make the impact energy lower.The toughness of a material indicates its ability to absorb energy during deformation. Materials with low toughness are often able to endure only a small amount of plastic deformation.ASTM E23 standard was used to produce the impact testing specimen. To establish the repeatability of the findings, two trials of impact testing from both the weldments were undertaken at room temperature. The photographs and fractographs of base metal and weldments. The austenitic 202 grade had the highest impact value (130 J) due to its pure austenite microstructure [Face Centered Cubic (FCC)] The surface morphology of super duplex 32760 (104 J) base metal mainly consists of small and large dimple-like bumps, It was demonstrated that autogenous dissimilar tungsten inert gas weldment has shown the compromised impact toughness value (86J) of the base metal. However, a lower impact value was observed in the activated tungsten inert gas weld specimens (68 J). This could have been due to an increase in the ferrite number (lowering in heat input) in activated tungsten inert gas weld specimen compared to tungsten inert gas welded specimen, which further led to a decrease in the number of dimples on the impact fractured surface, while the quasi-cleavage pattern on the impact fractured surface increased .

TENSILE TESTING:-

The preparation of test specimens depends on the purposes of testing and on the governing test method or specification. A tensile specimen usually has a standardized sample cross-section. It has two shoulders and a gauge (section) in between. The shoulders and grip section are generally larger than the gauge section by 33% [4] so they can be easily gripped. The gauge section's smaller diameter also allows the deformation and failure to occur in this area.[2][5]The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine (see the image below). Each system has advantages and disadvantages; for example, shoulders designed for serrated grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures.[6]In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimens may not be exact representation of the whole workpiece because the grain structure may be different throughout. In smaller workpieces or when critical parts of the casting must be tested, a workpiece may be sacrificed to make the test specimens.[7] For workpieces that are machined from bar stock, the test specimen can be made from the same piece as the bar stock.

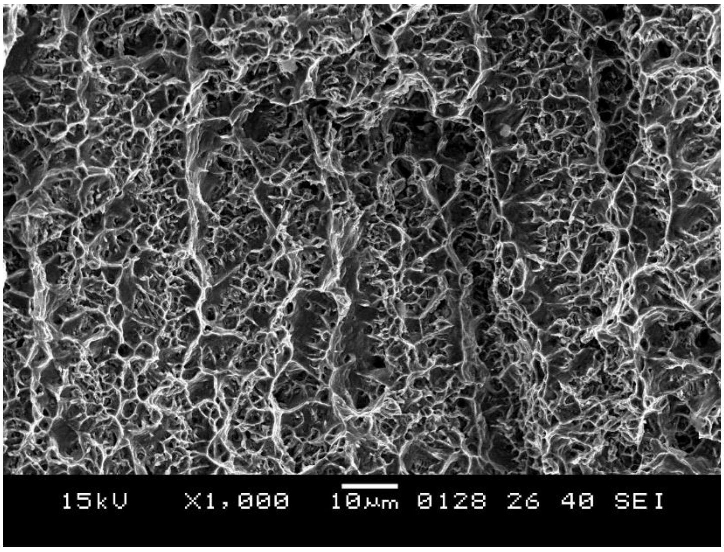


Fig 3.CMT welding

Microhardness:-

Microhardness testers are advanced instruments used to characterize the mechanical properties of small samples. This encompasses low volume materials and small regions of interest on larger substrates. The levels of detail that can be attained are largely dependent on the capabilities of the testing equipment itself.Clemex is known for providing cutting-edge solutions for microstructural analysis and materials characterization, using our combined knowledge of various imaging methods and process automation. This has enabled us to develop a series of microhardness testers that forefront user flexibility and convenience, regardless of the required test parameters or objectives.Hardness is one of three interrelated mechanical properties that determine how materials perform in dynamic conditions. Though it is often incorrectly used interchangeably with the others (strength, toughness, etc.), hardness is defined as how well materials withstand applied loads. As a result, researchers can assess material hardness as a function of abrasion, bending, or indentation. The latter is the most common method used in materials characterization, and descriptions of indentation hardness are typically broken down into one of two regimes:

macro- or microhardness tests.Microhardness testers characterize how materials respond to applied loads of up to 1,0000g (10N), using a physical probe known as an indenter. Various types of load testing exist, but the same general principles apply to most test profiles. Typically, a sample is positioned on a high-precision stage and the indenter tip is brought into contact with the surface at negligible loading forces. This force is then applied to a pre-defined set-point, then relaxed and removed at the same rate.

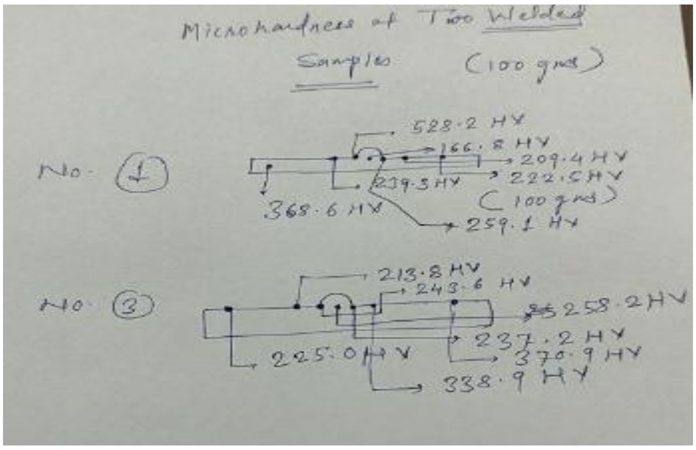


Fig. 4. Microhardness Tests

Fig 5. Mitutoyo micro hardness tester

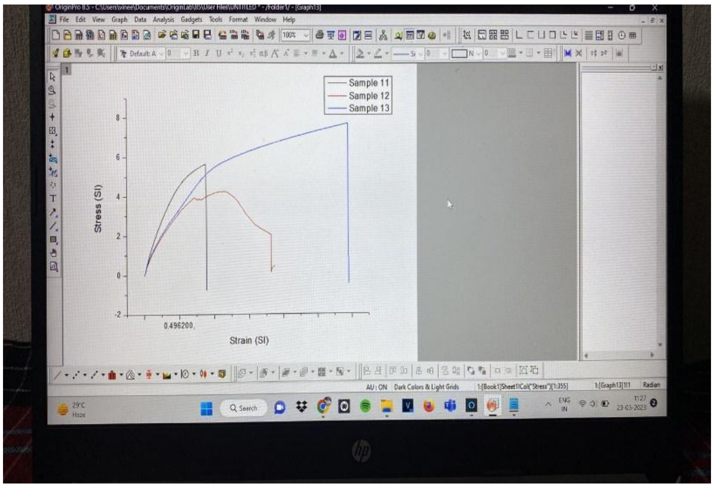


Fig 5. Graph for Tensile Test.

III.CONCLUSION:

1. The activated tungsten inert gas welding process makes it feasible to combine 6 mm thick super duplex 32760 and austenitic 202 grade in one pass with a null effect on the parent metal properties.
2. The weldment of super duplex 32760 and austenitic 202 welds solidified in the ferrite (F) mode with a higher Creq/Nieq ratio. They also had Widmanstatten austenite (WA), grain boundary austenite (GBA), and intergranular austenite (IGA) in the same weld.
3. The activated tungsten inert gas weld metal alloys were significantly strengthened by using activated flux as well as by their solidification mode and solid solution strengthening.
4. δ-ferrite phase increased in the case of activated tungsten inert gas welded weld bead, which significantly improved the property of the weldment.
5. All at once, traditional tungsten inert gas welds were a little better at resisting pitting corrosion and a little poorer at intergranular corrosion [% degree of sensitization (DOS)] than activated tungsten inert gas welds.
6. Compared to the high chromium duplex phase (super duplex base metal), the lower chromium austenitic phase (austenitic base metal) was more vulnerable to intergranular attack. However, the austenite-dominated phase (austenite 202 base metal) was superior in resistance against pitting because of the matrix’s stabilized austenitic concentration.

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