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Review Article

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TIG Welding Cladding of Stainless Steel Using Inconel Series Alloy: A Review

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Abstract

In oil and gas industries the most important stage is planning stage of drilling in sea and under earth which have highly corrosive environment, high pressure, and have high temperature inside. We require material which has capability to be protected from this type of environment and gives a long life to material because repairing is expensive and impossible under sea and earth. Clad pipes are more effective and improved alternate over conventional carbon steel line pipes. Stainless steel has good corrosion and oxidation resistance in operating conditions so it's appropriate for oil and gas sectors. The present study focused on behavior and improvement of properties of stainless steel by cladding of Inconel series such as 600, 617, 625, 718, 825 fabricate using TIG welding. Techniques for cladding of Inconel series on stainless have been studied. It was found that TIG welding cladding is most suited for Inconel 825 on stainless steel.

Keywords

Inconel 825, TIG, Sliding wear, Hardness, High temperature, Pin on disc

Introduction

Industries are facing some problems to take out crude oil form under sea and earth. In the sea and under earth many types of minerals and material present like sodium, potassium, calcium, aluminum, cobalt, nickel, etc. cause damage to pipe and structure and reduce life of material. Clad pipes improve the corrosion resistance and durability of pipes while coating protects from abrasion and corrosion as compared to others. Cladding of Inconel 825 provides solubilization treatment at 1200 °C and increases the properties of stainless steel. TIG welding offers greater control over weld areas compare to other welding and produced high quality welds so with use of TIG welding Inconel 825 welding on pipes creating strong and thin films and layer on stainless steel [1]. Inconel 825 super-alloy has titanium, copper, molybdenum additives, which protect materials from corrosive environment, and sulfuric or phosphoric acid atmosphere. Every Inconel alloy have some specific properties and grades which makes them unique and different from each other like Inconel 617 is an additional material, which is resistant to high temperature, corrosion and oxidation and has high weldability Inconel 625 is innovative acid resistant and has good weldability [2]. Inconel 690 is low consumption of cobalt element and energy for nuclear use. Inconel 713 C is an age hardening nickel-chromium based cast alloy, it has excellent resistance properties up to 1800 °F. Inconel 718 is a dual gamma with excellent weldability. Inconel X-750 is utilized in gas turbine parts to improve explosive power of 1600 °F. Inconel 751 has an enhanced aluminum percentage to upgrade properties at extreme temperatures and is utilized in gas turbines. Inconel 825 contains the required amount of nickel for a wide variety of laboratory activities and is suitable for applications that are required for machining. Inconel 939 is an advanced prime range for higher welding efficiency [3]. Inconel 925 is a low carbon volatile austenitic stainless steel. Nickel has ductile, malleable, and hard metal so nickel contains alloys that have ductility, strength, corrosion and heat resistive properties. Iron has silver-gray and lustrous metal [4]. It has a low-cost combination and high strength. Chromium has brittle, hard and lustrous metal. It is unstable metal in presence of oxygen and formed oxide layer that protects the metal below because it is impermeable to oxygen. Molybdenum has a high melting point, low thermal expansion, and heat resistance. Copper is a ductile and malleable metal. Titanium has high strength and low corrosive metal and also has light weight. Magnesium has properties which improve fabrication, mechanical, and welding characteristics of its alloy. Silicon is very hard and has brittle properties [5]. Aluminum has corrosion resistance due to formation of self-protecting oxide layer, lightweight, and malleable. All metals have their unique properties which made an Inconel 825 a super alloy. Austenitic stainless steel with molybdenum iron with excellent resistance towards chemical environment differentiate with traditional chromium nickel based stainless steels. Inconel 825 has a nickel-iron-chromium centered super alloy that has sufficient amount of molybdenum, copper, and titanium. Nickel has the ability to chloride stress corrosion fracturing resistive. Combination of nickel-molybdenum-copper also provides excellent resistance to corrosive or bad environment like them sulfuric and phosphoric with molybdenum helps to pitting or crevice corrosion resistive [1]. So, Inconel 825 has good required applications and properties than other grade alloys, which allow it to long life, corrosive resistive, easily fabricate, easily machined, etc. Table 1 shows the chemical composition of Inconel 825 in weight percentage.

History

Inconel 825 has titanium, molybdenum, and copper additives which protect materials from corrosive, sulfuric or phosphoric acidic environments [1]. The existence of titanium has advantages because it improved the alloy properties like strength, rigidity, and hardness at high temperature [6]. Inconel 825 mostly preferred in oil and gas refinery, chemical methods, acid manufacture, wherever high fatigue strength, strong hardness accompanied by higher corrosion resistance are extreme important due to its application and components [2].

Table 1: Chemical composition of Inconel 825.

Element	Weight (%)
Ni	38 - 46
Fe	22
Cr	9.5 - 23.5
Mo	2.5 - 3.5
Cu	1.5 - 3.0
Ti	0.6 - 1.2
C	0.05 max
P	0.02 max
S	0.3 max
Mg	1.0 max

Still, with costly material and chemical rapport to the cutting tool material, Inconel 825 utilization cost also expressed, which control its applications to manufacture mass components [7]. As a result, cladding of Inconel 825 is comparatively low cost and easily machined ingredients is an alternate option to manufacture a component of nickel-based alloy. Researchers have tried to upgrade different graded steel plates by cladding of Inconel alloy using different techniques such as plasma spraying, laser cladding and welding cladding methods like shielded metal arc welding and TIG. Inconel 718 cladding is done on Inconel 718 plate to prove the appropriateness of laser cladding for manufacture and refurbishing the components of aeronautics [8]. Nickel based Inconel 617 cladding is done on ductile iron through the tungsten insert gas welding techniques, which extremely enhanced the specimen's hardness and the wear resistance. It was noticed that carbide layer formation inside the nickel rich dendrite becomes reasons for mechanical properties improvement [4]. It was clear that mechanical properties which are needed for industrial purposes satisfying by coating possesses [9, 10]. AISI 304 grade stainless steel is the maximum demanded and widely utilized austenitic stainless steel due to its exceptional oxidation and corrosion resistance in a wide atmospheric range [11]. But applications of AISI 304 steel are reluctant for components that work with moving parts due to its comparatively insufficient wear resistance and low hardness to its hardest counterpart [5, 12]. So, different surface modification methods are developed to improve their surface properties using cladding including excellent advanced properties which also involves improvement of such as corrosive, wear, and frictions properties [13]. Researched done on clad layer's microstructure and wear properties by cladding of Ni-based alloy Ni-Cr-B-Si by using TIG welding method on austenite stainless steel to enhancing the properties of stainless steel such as tribology and corrosion [14], NiTi material cladding on stainless steel done by TIG welding method [15]. From a study on the deposition of composite TiB_2-TiC-Al_2O_3 through laser cladding technique, coatings on AISI 1020 and AISI 304 steels [16], Researcher present important differences in metallurgical and mechanical properties using different substrates substances. It has also shown that stainless steel AISI 304 has significantly enhanced pitting corrosion resistance with minimal thinning of Inconel 625 cladding traces deposited through laser cladding technique [17]. Coatings of Inconel-based are especially deposited using laser beams and have the potential to form strong bonds to substrates with minimal dilution [18, 19]. However, high system and running price, in conjunction with technical difficulty limit its use in small-scale industries likewise, the inadequate absorption of low-wavelength laser beams by metals further limits the uses of laser coatings on a materials range. From now on, welding based TIG surfacing technology is becoming an upcoming important tool preferred in small scale industries where cladding budget or price is an important issue. While TIG welding technique cladding has attained significant consideration for the cladding of stiff and wear-resistant coatings [20, 21, 25]. The studies disclosed that utmost of the work in this area has focused on analyzing the mechanical and metallurgical properties of cladding layers. Inadequate work has highlighted the influence of TIG

Table 2: Literature review of cladding of Inconel series on stainless steel.

S. No	Base and Materials added	Material Fabrication process	Properties Examined	References
1	Inconel 825	WEDM method	Surface integrity of the machined surface is disposed to micro-voids, micro-cracks, craters, and reorganize layer	[2]
2	Inconel 825	Turning process	Investigating Inconel 825 dry machining chip properties and tool wear are affected by cutting speed and tool coating	[7]
3	Inconel 617	TIG welding process	After various thermal treatment, the development of the microstructure of Inconel 718 multilayer coatings created by laser cladding as well as the mechanical characteristics of a completely aged sample were investigated	[4]
4	TiC-Inconel825	TIG cladding process	Micro-hardness, coefficient of friction, sliding abrasive wear, and coating morphology	[20]
5	4340 AISI alloy steel	TIG welding process	Analysis was done on how the overlapping operation affected substrate preheating, TiC particle dissolution, and the depth and hardness of the composite layer that resulted	[21]
6	Inconel 825	WEDM process	In the WEDM process, define the critical machining parameters for performance metrics like MRR, SF, and SG individually	[3]
7	Inconel 718	TIG welding	When these fillers were used, microstructure tests suggested that there was no harmful Nb rich Laves phase, which is thought to affect the examined weld's mechanical characteristics	[22]
8	Inconel 617	TIG welding	At both room temperature and 923 K, analyzed the impact toughness, microhardness, and uniaxial tensile characteristics were examined	[23]
9	Inconel 825	TIG welding	ER2594, ERNiCrMo-3, and ERNiFeCr-1 filler elements were used to describe the corrosion behaviour of dissimilar welding between Incoloy 825 Ni-based superalloy and SAF 2507 SDSS	[24]

welding technique conditions on cladding layer geometry and coating thinning behavior in the substratum surface and vice versa. It is clear that the efficiency of the cladding is strongly dependent on the thickness of the cladding and the thinning of the substratum material within the cladding [26]. Present study, an effort had made to Inconel 825 cladding on the AISI304 grade stainless steel base via TIG welding cladding technique. Inconel 825 wear behavior and micro-hardness were compared with the uncoated base material. Super alloy demands are increasing day by day due to high temperature application and high performance in industrial boilers, turbines heat exchangers, etc. Researchers determined that the effect of cutting parameters such as prominent shear strength, lower thermal conductivity, higher chemical similarity and higher hardening rate, nickel-based alloys material are defined as most "difficult to machine". All components fabricated by the nickel-based alloy become more difficult and overpriced. Cladding nickel-based alloy on stainless steel base discover more cost-effective, and an approaching exploration field [6, 27]. Cladding of Inconel alloy on austenitic stainless steel AISI type (302, 303, 304, 305, 308, 309, 310, 316, 321, 330, etc.) has vast application in chemical, aerospace industries, etc. because of its good corrosion and extreme strength performs in equally high and room temperature. In previous years many researchers have stated on different welding processes. Still, compared to other different welds, few publications inform different welding methods for Inconel plates to stainless steel alloys. A few papers are described below. Dev et al. [22] reports that the mechanical performances and microstructure of different welds of Inconel 718 and stainless-steel grade AISI 416 which is sulfur full. To bond these dissimilar combinations metals. Different types of filler used such as two niobium-free fillers are ERNiCrMo-4, ERNiCu-7, and the dual phase ER2553 filler. Studies confirm that formation of the welds with these fillers are non-harmful substances. Tensile failure occurs in base metals to AISI 416 regardless of filler. Zhang et al. [23] described the Inconel 617 and novel heat-resistant steel welded joint's mechanical properties Microstructure between them. A joint micro hardness report was obtained, and the reverse was found to have the highest micro hardness value. This is due to the grain refining effect. The joint exhibited sliding separation or ductility failure after together at room temperature and 923 K tensile tests. Kangazian et al. [24] investigating the effects such as steel type, welding method and rate of welding on the rusty behavior of nickel base alloy Inconel 825 and SAF2507 stainless steel welding area. The outcome complete establishment of some of the second stages in the welding metal. Vendors use filler on nickel-based wire exposed the anti-resistance properties, ever SAF2507 stainless steel welded metal proven that excellent corrosion behavior.

Conclusion

Among all studied, Inconel 825 cladding on stainless steel have better performance, good required application and properties which allow it to long life, corrosion resistive, easily fabricate, easily machined, etc.

- From the literature it was found that among various techniques TIG welding is the most used technique for cladding of Inconel series on stainless steel series.
- While Inconel coating prevents abrasion and corrosion, cladding pipes increase their longevity and resistance to corrosion.
- Mechanical characteristics that Inconel 825 cladding need to have in order to fulfil industrial purposes.
- Inconel 825 shows better efficiency or performance comparing Inconel 825's wear characteristics and micro-hardness to the basic material without a coating.
- In small-scale companies where cladding budget or price is a key concern, TIG surfacing technology is emerging as a major tool preferred. While the use of TIG welding for cladding stiff, wear-resistant coatings has gained substantial attention.
- Inconel 825 expressed their capability, effectiveness and performance at weld joints means it don't lose their properties due to high heat formation during fabrication with TIG welding.
- Different types of fillers, such as the dual phase ER2553 filler and the niobium-free ERNiCrMo-4, ERNiCu-7, and ERNiCu-7, are used to link dissimilar metals. Studies have shown that these fillers do not cause harm when they are used to produce welds.

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Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Vivek: Literature review, Writing - original draft preparation; Pawan Kumar: Writing - review and editing; Sandeep Kumar Khatkar: Writing - review and editing; Amit gupta: Writing - review and editing. All the authors read and approved the manuscript.

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