Investigations on microstructural characteristics and mechanical properties of 316 L stainless steel welded joints using nickel coated filler material by gas tungsten arc welding

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Abstract

The main objective of this present study is to weld the 316 L stainless steel (SS) joints by gas tungsten arc welding (GTAW) process using nickel coated filler materials. The existing modified filler metals with flux coatings used in GTAW are generally accompanied with more complications. Therefore it is essential to suppress complications and enhance the welding strength which significantly depends on filler metals properties. In this work, the filler materials used in GTAW are coated with nickel in several grades for welding process. The results of these filler metals are compared with the Plain-316 filler metal. Ni-304 filler metal shows better uniformed weldment and heat affected zone (HAZ) with less planer slip microstrucutre on its surface. The tensile test results reveal that Ni-316, Ni-304 & Ni-308 filler metals produces fracture on the parent metal. Among the various filler metals used, Ni-304 filler metal shows the highest impact toughness of 69.10 J and it is 71% higher toughness than Plain-316 filler. Average hardness of Ni-308 filler metal is 2.78% higher than the Plain-316 filler metal. Scanning electron microscope (SEM) images of weldments and HAZ were analysed to investigate the effect of nickel on the microstructure changes.

1. Introduction

Gas tungsten arc welding (GTAW) process finds broad range of applications in various sectors such as petroleum industries, manufacturing industries, automobiles, refineries and construction industries due to its capability of high quality weld [1]. GTAW is one of the prominent welding technique which employing an arc between non consumable electrode and work metal to weld the sections. Moreover, welding is an essential feature on any kind of product; therefore this research mainly focuses on the welding of metals through GTAW. On the other hand, fast growing and modernization of industries creates the new challenges to join the metal and requires the sufficient strength on weldments to warrant their performance. Hence, the necessity of modifications in the conventional GTAW process is also unavoidable. Although, micro structural and mechanical properties of the welding are mainly depend on the type of filler material, filler coating and electrical parameters [2]. In line up with that various research attempt were carried out by the researchers in the last decade. In view of improvement of GTAW performance, Tembhurkar et al [3] studied the mechanical properties of dissimilar welding of SS 316 L and 430 SS using different filler metals such as ER316L and ER309L. The mechanical properties increased significantly with the ER316L filler metal compared to other filler metals. Sumitra et al [4] investigated the Molybdenum (Mo) and Niobium (Nb) added ERNiCrMo-4 & ERNiCrMo-3 filler metals to study the dissimilar weldments characteristics using GTAW process. They observed less melting zone on both side of parent metal due the low solubility of work material. Also, excellent mechanical properties were found on using of Mo added ERNiCrMo-4 filler metal for the GTAW process. Porchilamban et al [5] used the nickel chromium (Ni-Cr) based ERNiCr-3 and SS 316L filler metals to join the ferrite and SS 430 in GTAW process. Less deleterious phase
formation on the weldment and base metal failures were noted on the base metal side with the Ni-Cr filler metals. Kumar et al.[6] used tungsten inert gas and plain ERNiCrMo–4 filler metal for joining the Nitronic 50 SS. The presence of carbide particles in the welding region leads to increased hardness of weld. Kazempour et al.[7] employed Inconel alloy and age hardenable filler metals to weld the nickel based IN939 alloy. They noted that additional alloying elements such as aluminium, Ti, Mo plays the vital role in weldments. They suggest the IN 617 and 625 filler materials for effective welding of IN939. Abbas et al.[8] compared mechanical strength of gas tungsten arc welding and electrical arc welding process with ER70S–3 filler metal on DP steel. Using this 20% higher impact toughness are obtained in GTAW process than normal arc welding. Murali et al.[9] applied the Ti carbide nano particles coated filler metal such as ER5183 are adopted to weld the dissimilar aluminium alloys. They noted the effective bonding, crack free and refined grain structure in the weldments with nano treated filler metals. Ahmadi et al.[10] used the aluminium 4043, Zr and Ti carbide mixed hybrid composite as filler metal in GTAW process and it is prepared by accumulative roll bonding method which ensures the uniform grain particles distribution. They concluded that the Al hybrid composite filler metal increases the mechanical strength of weldments significantly. Sabeghdam et al.[11] used powder metallurgy technique to fabricate carbon and magnesium (Mg) composite filler metal to employ in GTAW process. They observed that tensile strength using composite filler metal increases by 65% when compared to the normal filler metal. Fattahi et al.[12] adopted the aluminium and ceramics mixed composite filler metal in GTAW process. The ceramics used in the composite increase the mechanical strength and surface finish of welding. Also excellent yield strength was obtained in the welding with this composite filler metal. Xu et al.[13] employed the high strength non magnetic alloy (Cr25–Ni13) as filler metal to weld the dissimilar metals such as molybdenum copper alloy (Mo–Cu) and nickel based super alloy (GH4169) using GTAW process. It is observed that the massive Cu assemblages in the HAZ on Mo–Cu side due to the softening which causes the uneven weldments. Ramkumar et al.[14] investigated the TiO2 Nano–composite as filler material in GTAW process and optimized its process parameters; rate of gas flow, current and welding speed using response surface methodology. The uniform distribution of reinforcements in nano composite produces the better strength to the weldments. Based on the analysis of variance, welding speed plays a major role in the filler material distributions on the welding area. Aziz et al.[15] investigated the effects of TIG welding rod compositions on micro structural and mechanical properties of dissimilar AISI 304 L and 420 stainless steel weld. The mechanical properties of the weldments have high significance in the selection of welding filler materials. The literatures discussed above are tried various coated and modified filler metals in GTAW process. However, the Ni present in the SS increases the creep strength and corrosion resistance in the weldments due to the interfacial bonding of metals which increases the mechanical properties significantly. Also, the melting of Ni with other constituents in filler metals improves the micro hardness and wear resistances of weldments effectively.[16]. Hence the Ni based filler metals are utilized in GTAW process by researchers. In line with that, Sahoo et al.[17] studied the effect of Ti carbide and Ni composite coating on filler metals in GTAW process for SS 304 work material. They have noted the excellent bonding of filler metals due to the affinity of grains which increases the mechanical and micro structural properties on the weldments. Mageshkumar et al.[18] studied the GTAW process parameters for Ni based superalloy 617 using various filler metals such as ERNiCrMo–4, ERNiCrMo–10 and ERNiCrMo–14. They have noted defects free weldments using ERNiCrMo–4 filler metal which is due to the presence of Mo. Also, highest tensile strength obtained in the ERNiCrMo–14 than others. Prabu et al.[19] used the filler metal such as ERNiCrMo–4 and ERNiCrCoMo–1 to weld the Inconel 625 and AISI 904 L through GTAW method. They noted an excellent mechanical strength on both filler metals and high micro hardness obtained on the Inconel side due to the presence of W, Ni, Cr and Mo. Also, highest impact toughness value 40 J noted using ERNiCrMo–4 filler metals. Devendranath et al.[20] employed the Ni based filler such as ER2553 and ERNiCrMo–4 to weld the Inconel 718 and AISI 430 in GTAW. They found that more parent metal accumulation on the weldment which improves the mechanical properties significantly. Ramkumar et al.[21] studied the mechanical and micro structural properties of Inconel 718 through GTAW with the filler metals such as ERNiCr–3, ERNiCu–7 and ERNiCrCoMo–1. Also, they have heat treated weldments in furnace at the temperature of 720 °C. The mechanical strength of weldments improved significantly with the heat treated weldments irrespective of all filler metals. Mohanraj et al.[22] studied the effect of filler materials like E308L and ENiCu–7 using in GTAW of SS 304 to find the corrosion and mechanical characteristics. They noted that E308L filler materials produced the higher mechanical strength than the ENiCu–7. The aforementioned literatures clearly indicate that the research attempts were carried out for improving weldments strength using various modified filler materials. Although many techniques for coating or commercially available filler metals for welding are becomes complex or inadequate welding strength when the welding of stainless steels (SS). Hence in this research, a simple and prominent technique such as electro plating is considered for uniform metal coating over the filler metal to enhance the weldments strength. Commercially available filler metals such as SS 316 L, SS 304 L, SS 308 L, Cu coated MS and plain MS are coated with Ni through electroplating method which termed as Ni-316, Ni-304, Ni-308, Ni &Cu-MS and Ni-MS and considered for welding. Also, electroplating is cost effective and ensures the
homogeneous metal coating [23]. Therefore, it is necessary to study the effect of Ni coated filler metals on the performance of GTAW. The most significant process parameters such as current in A, filler wire diameter in mm, voltage in V and arc length in mm are considered for the experiments. The performances of GTAW are revealed in terms of micro structural, micro hardness, tensile and impact strength of weldments.

2. Materials and methods

In this study AISI 316 L SS plates are considered as work specimens. The manual GTAW setup has been considered for the experiments. The welding process parameters are preferred based on the review on AISI 316 L Stainless steel welding joints. The chemical composition of the parent material AISI 316 L stainless steel and different filler materials are shown in table 1.

The filler metals are most prominent tool to enhance the welding quality. Different filler metals of size 1.5 mm in diameter are used in this research work. Nickel has been coated over the filler metals such as 304 L SS, 308 L SS, 316 L SS, Mild Steel (MS), Cu coated MS and plain 316. To ensure the homogenous coating of Nickel, electro plating method is considered with constant power supply. A typical experimental setup for electroplating is shown in figure 1. The process parameter considered for GTAW process includes; current in amperes, Filler wire diameter, Voltage and arc length. Table 2 represents the welding process parameters selected for different filler materials considered in this research work. After welding, specimens are cut into separate test samples using wire cut electrical discharge machine (WEDM) to examine the mechanical properties of the weld. The Vikers hardness test is carried out on the welded samples at 2 mm from the mid position of weldments, HAZ and base metal as per the ASTM 384 [24]. As per the ASTM standard E8/E8M-13a, test samples are prepared for the tensile test and experiments conducted using computerized universal testing machine (UTM). To investigate the

| Table 1. Chemical Composition. |
|------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Material              | C(%)               | P(%)               | S(%)               | Mn(%)              | Si(%)              | Cr(%)              | Ni(%)              | Cu(%)              |
| 316 L                 | 0.03               | 0.045              | 0.03               | 2.0                | 1.17               | 17.45              | 11.91              | 0.11               |
| 308 L                 | 0.018              | 0.017              | 0.010              | 1.90               | 0.32               | 19.70              | 10.10              | 0.271              |
| 304 L                 | 0.017              | 0.028              | 0.010              | 1.79               | 0.37               | 18.1              | 8.0                | 0.34               |
| Cu Ms                 | 0.199              | 0.045              | 0.059              | 0.582              | 0.154              | 0.11              | 0.131              | 0.75               |
| MS                    | 0.16               | 0.028              | —                  | 0.18               | 0.168              | —                  | 0.384              | —                  |

| Table 2. Welding process parameters. |
|-----------------------------|--------------------|--------------------|--------------------|
| Filler wire                 | Current (A)        | Filler wire diameter (mm) | Voltage (V) | Arc length (mm) |
| Plain-316                   | 75                 | 1.5                | 13                 | 1.6 |
| Ni-316                      | 75                 | 1.5                | 13                 | 1.6 |
| Ni-308                      | 75                 | 1.5                | 13                 | 1.6 |
| Ni-304                      | 73                 | 1.5                | 12.1               | 1.6 |
| Ni & Cu-Ms                  | 70                 | 1.5                | 11.4               | 1.6 |
| Ni-MS                       | 72                 | 1.5                | 11.9               | 1.6 |
toughness of weld, V-notch Charpy impact test is carried out and impact specimens are prepared based on the ASTM E23 standard dimensions. SEM analysis is carried out on the welding area and HAZ.

The 316 SS plates are welded using different filler materials by GTAW process and the samples of the weldments are shown in figure 2. The mechanical properties of the weldments are tested for tensile strength and impact strength using universal testing machine and impact testing machine respectively. The tensile test specimens and impact test specimens of the weldments welded by GTAW are presented in figures 3(a) and (b).

3. Results and discussions

3.1. Effect of filler metals on microstructure of Weldments
Scanning electron microscope is used to study the micro structural characteristics of the weldments. The macro photographs of welded samples which are welded with application of different filler materials are analysed. The uniformity of weldments on both sides of base metals is found to be relatively normal in Ni-316 and Ni-304 fillers than Plain-316 filler metal and less weld uniformity is found to be in Ni-MS filler. The weldments and heat affected zone (HAZ) using different filler metals such as Plain-316, Ni-316, Ni-304, Ni-308, Ni & Cu-MS and
Ni-MS are shown in figures 4(a)-(f). The microstructure of HAZ for all filler metals is taken nearer to the weld region using SEM analysis. The SEM microscope study reveals that diffusion of grains due to high temperature of GTAW process increases the HAZ on the weldment which can be seen through bright surfaces near to the weld. The microstructure of different weldments infer that connected coarse grains with uniform grain boundaries in HAZ is obtained due to high heat of GTAW.

The figure 4(a) shows the micro structure of HAZ and weldment for Plain-316 filler. This filler produces the slight non uniform weld on the base metal and few micro voids were formed on weld. Welding through Ni-316 filler material forms micro cracks on welding and intergranular cracks in HAZ and it is seen in figure 4(b). The effective diffusion of Ni, Chromium (Cr) and Ferrous (Fe) forming the long dendrites in weld region leads to micro cracks formations on the weldment. Figure 4(c) indicates Ni-304 filler material provides better uniformed weldment and HAZ with considerable planer slip microstructure across its surface. The higher carbon content in the filler material induces the significant oxidations in high temperature leads to the formation of molten metal on weldment. Figure 4(d) depicts the SEM pictures of weldment and HAZ for the Ni-308 filler. It is due to moderate cooling rate of carbon particles and thermomechanical processing of nickel induces the carbide precipitations and transgranular feature on the weldment [25]. The microstructure of Ni&Cu-MS weldment and HAZ are shown in figure 4(e). The bright precipitated particles found over its surface is due to the diffusion of Cu.
and Ni materials into the gray matrix surface layer of MS. The uniform elongated grain structure is obtained in Ni-MS filler weldment which is shown in the figure 4(f). It is due to the differences in melting duration of MS elements and Ni, it causes the grain boundry growth over the weld surface. The spread of weldment are maximum on using of Ni & Cu-MS and Ni-MS filler than the others.

3.2. Micro hardness
The Vickers micro hardness for different filler metals on weldments, HAZ and base metal are represented in the figure 5. The values of micro hardness and standard deviations for the all filler metals are displayed in table 3. It is observed that the hardness of the Ni-316 filler metal is least. The micro hardness of weldments and HAZ commonly depends upon the microstructure changes. It is observed from figure 6 that the average hardness of weldments produced using Ni-316 filler is 2.59% higher than that of weld using plain-316 filler wire. Also, hardness for Ni-316 filler material at HAZ is found to be higher when compared to weld zone using Ni -316 due to enrichment of carbon and Cr in the base metal. The average hardness of Ni-304 filler material is 1.8% higher than using of plain 316 filler wire. The weldments and HAZ hardness are found to be 73 and 83 HV respectively on using of Ni-304 filler material.

The coating of Ni on 304 filler metal takes higher time to melt than base metal which causes the micro structure transformation. It is understood that average hardness on using of Ni-308 filler metal produces the 2.78% higher hardness when compared to Plain-316 filler metal. The change of cooling rate in HAZ changes the crystal metal structure to an austenitic structure [26]. Also, the crystal structure is enlarged with increase in temperature which leads to soften the weldments. Hence the average hardness of weldments found to be lesser than the HAZ and base metal except Ni & Cu-MS and Ni-MS filler metals weldments.

![Figure 5. Micro Hardness.](image)

| Table 3. Values of Micro hardness. |
|-----------------------------------|
| **Distance from the weldments centre (mm)** | **Filler material** | **Mean Value** | **Stranded deviations** |
| 2 | 4 | 6 | 8 |
| Plain -316 | 71 | 77 | 79.5 | 84 | 77.88 | 5.42 |
| Ni-316 | 78 | 79.5 | 83 | 85 | 81.38 | 3.19 |
| Ni-304 | 73 | 78 | 82 | 84 | 79.25 | 4.85 |
| Ni-308 | 74 | 77.5 | 83 | 85.6 | 80.03 | 5.24 |
| Ni & Cu-MS | 71.5 | 75 | 77 | 86 | 77.38 | 6.18 |
| Ni-MS | 70 | 74 | 76 | 86.7 | 76.68 | 7.13 |
3.3. Tensile properties

The average tensile strength of weldments using various filler metals are shown in figure 6. It is observed that the Plain-316 filler metal produces 556.1 MPa tensile strength. The tensile strength of 316 stainless steel plates welded with Ni-316, Ni-304 & Ni-308 filler materials are obtained as 615.6 MPa, 639.6 MPa and 636.4 MPa respectively, which is higher than plain filler material. It is observed that all samples produce higher tensile strength than Plain-316 filler metal. The Ni & Cu—MS and Ni-MS filler metals produces 560.4 MPa & 559.0 MPa tensile strength respectively.

3.4. Impact strength

Figure 7 exhibits the impact toughness for the weldments using different filler metals. It is obvious that coating of Ni with filler metals stimulates the creep strength in filler material leading to the high toughness. Among the various filler metal used, the Ni-304 filler metal shows the highest toughness of 69.10 J and its fractured surface is shown in figure 8(b). Ni-304 filler metal shows the 71% higher toughness than that weldments welded by Plain-316 filler. SEM image represented in figure 8(a) shows the fractured surfaces with Plain-316 filler metals weldments sample. It is clear from the figure that, the sample consists of cleavage surface and few dimples as designated by white arrows. The Ni-316 filler metal provides 59.16 J impact toughness and this is the second highest value among others. Hence in Ni-316 filler metal impact toughness is 46% higher compared to the Plain-316 filler metal. Figure 8(c) represents the fractured surface of weldments using Ni-316 filler metal. Based on the figure the Ni-316 filler metal produces the fibrous surfaces and micro voids over the fractured surface. It is due to the easy migration of Nickel from the filler rod to weldments, this is because of externally coated Nickel which melts quickly and mixes with the base metal constituents such as Cr, C, and Fe provides the high toughness strength. According to the chart Ni-308 filler metal produces the 52.95 J impact toughness and its third highest
value among other filler metals. The constituent of SS 308 such as Mo, Cr and S are mixed with the nickel elements and forms the Mo-Ni alloy which causes the high impact toughness in the weldments [18]. Due to this, uniform crack propagation noticed on the fracture surface which is evident from the figure 8(d). Therefore this Mo-Ni elements transfer to the base metal resulting in 31.16% higher impact toughness than Plain-316 filler metal. The Ni & Cu—MS and Ni-MS filler metals exhibited 43.09 J and 41.95 J impact toughness respectively. Moreover this is least high impact toughness than others and provides 2.7% and 1.6% higher impact toughness compared to Plain-316 filler metal. This is due to the presence of Cu making simple to shuffle the constituents such as Fe from filler to base metal. The fractured surface of weldments using Ni & Cu—MS and Ni-MS filler metals is shown in figures 8(e) & (f) respectively.

4. Conclusions

In Gas Tungsten Arc Welding process the welding strength predominantly depends on filler materials characteristics. This paper an attempt is made with the filler metals such as Plain-316, Ni-316, Ni-304, Ni-308,
Ni & Cu-MS and Ni-MS. Among those filler metals, the uniformity of weldments on both sides of base metals is found to be relatively normal in Ni-316 and Ni-304 filler materials than Plain-316 filler material and less weld uniformity is found to be in Ni-MS filler. The Scanning Electron Microscope study is conducted and it reveals that diffusion of grains due to high tempature of GTAW process increases the heat affected zone on the weldment which can be seen through bright surfaces near to the weld. The tensile test shows that the Plain-316 filler metal produces 556.1 MPa tensile strength. Also, tensile strength of weldments using Ni-316, Ni-304 & Ni-308 filler materials are obtained as 615.6 MPa, 639.6 MPa and 636.4 MPa respectively. The average hardness on using of Ni-308 filler metals produces the 2.78% higher hardness when compared to Plain-316 filler metal. Moreover, it is the highest hardness value among other filler metal applications in this experiment. Among the various filler metal used, the Ni-304 filler metal shows the highest toughness of 69.10 J and Ni-304 filler metal shows 71% higher toughness when compared to the usage of Plain-316 as filler material. Hence, the Ni-316, Ni-308, Ni-308 filler metals are suggested to welding the 316 base metal where high mechanical properties required in the industry.

Data availability statement
The data that support the findings of this study are available upon reasonable request from the authors.

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