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Testing and Analysis of TIG Welded Pipe Joints Made of Stainless Steel 304 L: A Review

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Abstract: This work aims at the analysis and testing of TIG welded pipe joints made of stainless steel 304L. The mechanical properties and microstructure of 304L stainless steel welds are tested, by using stainless steel filler material. Some Special pipe inspection tests also carried out on the material when it is going to be used in aggressive environments. These tests will ensure that pipe material is able to withstand in such aggressive environments also. Some of the tests are Grain size (AS & SS), IGC- Intergranular Corrosion Test (SS), Hardness Test. The tensile test is done to check yield and ultimate tensile strength of the pipe. Impact test / Charpy V-Notch test, check the ability of material to withstand under low-temperature conditions. Creep test is done to check long term effect of temperature under constant load. Ultrasonic testing of defects was conducted to determine the welding defects more accurately and to know whether any other flaw exists in the welded specimens. Analyzing all the data obtained by conducting tests on pipe joints, we can say that ultimate tensile strength of the joint was improved.

Keywords: TIG, Stainless steel, Review, Pipe Joints, Welding, Analysis

I. INTRODUCTION

Welding process is an important domain of activity of to-day industry, especially in the sector where a lot of assembly of structures has to be done. Generally, the initial design of industrial parts requires revisions, because unpredictable changes occur in the shape or the performance of a component when it is welded because its metallurgical structure was modified by the process. The re-design is very costly since that happen late in the development [1, 2, 4] cycle of the product. It is now possible to avoid this by anticipating the undesirable effects of the manufacturing process early in the design stage, by using numerical simulation, numerical optimization and AI tools. This shows how much virtual welding process can be important in the development of a new component.

Welding is a well-established joining technique. When assessing the structural integrity of a welded pipe, all sources of loading which may increase the risk of failure should be considered. In the offshore industry, pipelines could experience displacement controlled loading during pipe installation or operation. Depending on the installation process, the pipeline can experience different levels of primary load. One method of pipeline installation is reeling which causes high plastic strains (due to bending cycles) in pipelines. For reeled pipes, fatigue and fracture assessments, referred to as Engineering Critical Assessment (ECA) should be carried out to ensure their structural integrity [3].
Austenitic stainless steels (SSs) are engineering alloys with good corrosion resistance in environments containing various compounds of sulphur, normally experienced in refinery process streams [5]. However, austenitic stainless steels are susceptible to stress corrosion cracking (SCC) under certain conditions involving high stress, changes in metallurgical structure due to high temperature operation, and the presence of specific chemicals that promote cracking. The chemicals present in refinery streams known to induce SCC in these alloys are chlorides and polythionic acids [1].

However, recent reported failures and research of annealed austenitic stainless steels under sour gas conditions with insignificant amount of chlorides suggested the contribution of H_2S in promoting SCC [2–6]. Cracking is derived from either H_2S enhanced hydrogen absorption or H_2S enhanced breakdown of the passive film by synergistic action between H_2S and Cl^-. Due to the H_2S/Cl^- synergism, the presence of H_2S extends the environmental domain of Cl^- SCC to lower temperatures and lower Cl^- concentrations [7]. Traditionally austenitic stainless steels are joined with welding electrodes that contain 5–10% residual δ-ferrite in the interdendritic boundaries. This retained metastable ferrite phase is believed to be influential

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in reducing hot cracking and micro fissuring of the weld metal.

Welded pipe has reduced flow restrictions compared to mechanical connections and the overall installation costs are less. Two common processes welding of pipe are TIG and MIG. TIG welding, also known as GTAW, is a process which fuses metals by heating them with an arc between a tungsten electrode and the work piece [8]. Shielding is obtained from a gas or gas mixture. Pressure and filler wire may or may not be used. The positive electrode does not melt and hence gas tungsten arc welding can be autogenous or non-autogenous if a filler wire is employed. MIG welding, also known as GMAW, differs from TIG in that the positive electrode is consumable.

The input parameters are the controllable welding equipment parameters, welded materials, and other parameters, which affect the properties of the finished welds [6]. Pre-selected weld parameters, indirect weld parameters affect the weld quality of TIG and MIG weld. Pre-selected weld parameters are selected prior to the start of the welding process and they cannot be changed during the welding process. These parameters, variables, include the electrode type, size, and tip geometry, the torch nozzle size, and the shielding gas type. The indirect weld parameters of the welding process include the arc voltage, arc current, travel speed, shielding gas, and wire feed rate (for filler metal process). Indirect weld parameters are parameters that can be modified in process [9]. Once the pre-selected variables are properly chosen, the quality of the weld can be controlled through proper selection and modification of the indirect weld parameters. In any welding process, the input parameters have an influence on the joint mechanical properties. By varying the input process parameters combination the output would be different welded joints with significant variation in their mechanical properties.

Gas tungsten arc welding process; consist of non-consumable tungsten electrode which is used to provide the arc for welding. A separate filler metal with an inert shielding gas is used. Gas tungsten arc welding process welding set utilised suitable power source, a cylinder of argon gas, welding torch having connection of cable for current supply, tube for shielding gas supply and tube water for cooling torch [11-12]. In all welding, the best weld is one that has the properties closet to those of base metal; therefore, the molten puddle must be protected from the atmosphere. The atmosphere oxygen and nitrogen combine readily with molten metal which yields weak welds beads. The major inert gases that are used are argon and helium. Electrode is used only to create the arc in Tungsten inert gas welding and it is not consumed in the weld. For joining similar metal, where additional weld metal is needed, a filler metal or rod is fed into the puddle.

Welding is a material joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure. In some welding processes, a filler material is also added to facilitate coalescence. Among all welding process gas tungsten arc welding (GTAW) process is a very versatile, all-position welding process that is widely used to join Ni-/Co-base alloys. TIG welding developed during 1940 at the start of the Second World War. In GTAW, the heat for welding is generated from an electric arc established between a non-consumable tungsten electrode and the work-piece [10]. GTAW can be performed manually or adapted to automatic equipment, and can be used in production as well as repair welding situations. GTAW is most commonly used to weld thin sections of stainless steel and nonferrous metals such as aluminium, magnesium and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques [13]. In spite this, it has further more advantages over other types of welding processes and welds almost all metals including dissimilar ones with a wide range of power supplies.

II. METHODOLOGY

Gas-tungsten arc welding (GTAW) is a process that melts and joins metals by heating them with an arc established between a non-consumable tungsten electrode and the metals. The tungsten electrode is normally contacted with a water cooled copper tube, which is connected to the welding cable to prevent overheating [14-16]. The shielding gas (Ar, He) goes through the torch body and nozzle toward the weld pool to protect it from air. Filler metal (for joining of thicker materials) can be fed manually or automatically to the arc. It is also called tungsten inert gas (TIG) welding.

A. Electrodes

Tungsten electrodes with 2% cerium or thorium give better electron emissivity, current-carrying capacity, and resistance to contamination than pure electrodes. Hence, the arc is more stable.

B. *Shielding Gases*

Ar is heavier and offers more effective shielding and cheaper than He.

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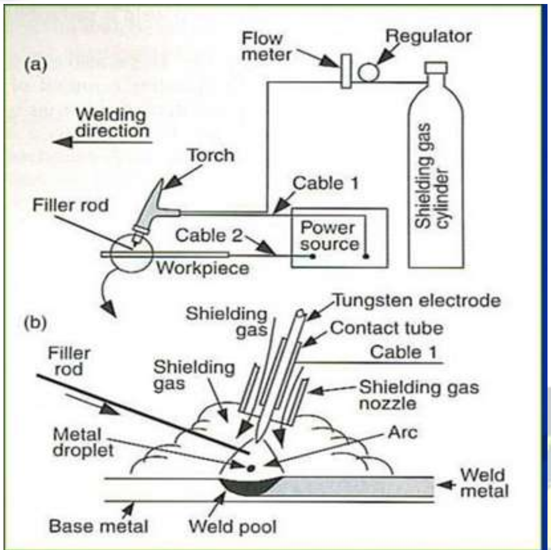

Fig. 1. Tungsten Inert Gas Welding

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours [1]. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000oC and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig. 1 & fig. 2 respectively.

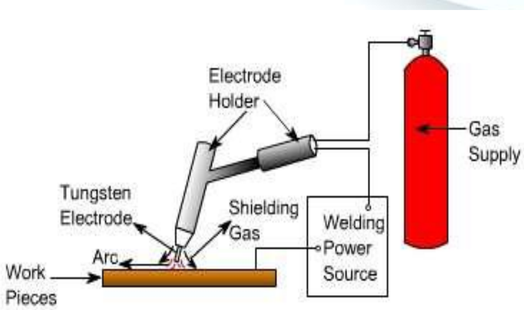

Fig. 2. Schematic Diagram of TIG Welding System

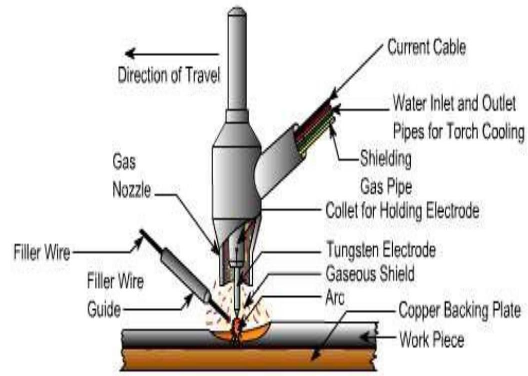

Fig. 3. Principle of TIG Welding

III. EXPERIMENTAL ANALYSES

A. Materials Used

Austenitic is the most widely used type of stainless steel. It has a nickel content of at least of 7%, which makes the steel structure fully austenitic and gives it ductility, a large scale of service temperature, non-magnetic properties and good weld ability. The range of applications of austenitic stainless steel includes house wares, containers, industrial piping and vessels, architectural facades and constructional structures. When welding stainless steels it is advisable to follow the general welding guidelines valid for the type of steel, e.g. austenitic Stainless steels have, due to their chemical compositions, a higher thermal elongation compared to mild steels. This may increase weld deformation. Dependent of weld metal microstructure they might also be more sensitive to hot cracking and sensitive to intermetallic precipitations compared to mild steels. Austenitic grades are those alloys which are commonly in use for stainless applications. The austenitic grades are not magnetic [17]. The most common austenitic alloys are iron chromium- nickel steels and are widely known as the 300 series. The austenitic stainless steels, because of their high chromium and nickel content, are the most corrosion resistant of the stainless group providing unusually fine mechanical properties. They cannot be hardened by heat treatment, but can be hardened significantly by cold-working. The special material properties of stainless steels affect all four mach inability factors: in general, it can be said that the higher the alloy content of a stainless steel, the more difficult it is to machine. The special properties that make stainless steels difficult to machine occur to a greater or lesser extent in all grades of stainless steels, but are most marked in the austenitic grades [18]. They can be summarized in five points: 1. Stainless steels work harden

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considerably 2. Stainless steels have low thermal conductivity 3. Stainless steels have high toughness 4. Stainless steels tend to be sticky 5. Stainless steels have poor chip-breaking characteristics. As the stainless steel is classified in different categories like austenitic, ferritic, martens tic etc., from this we have chosen austenitic stainless steel (304) because of its low cost, easy availability in the market. Stainless steel is selected for carrying out the experimental analysis because of its many advantages and easy availability in the market [19].

Table I
Composition ranges for 304 L grade stainless steel

Element	Type 304L (%)
Carbon	0.03 max.
Manganese	2.00 max.
Phosphorus	0.045 max.
Sulfur	0.03 max.
Silicon	0.75 max.
Chromium	18.00-20.00
Nickel	8.00-12.00
Nitrogen	0.10 max.
Iron	Balance

Table II
Physical properties of 304 L Stainless steel

PROPERTIES	
Density	0.803g/cm^3
Electrical resistivity	72 microhm-cm (20C)
Specific Heat	0.50 kJ/kg-K (0-100°C)
Thermal conductivity	16.2 W/m-k (100°C)
Modulus of Elasticity (MPa)	193 x 10^3 in tension
Melting Range	2550-2650°F (1399-1454°C)

B. Semi Automatic TIG Welding Machine

The Tip Tig process is a semi-automatic, hot wire variant of manual Gas Tungsten Arc Welding (GTAW). The continuously fed, preheated filler metal very significantly improves the deposition rate.

The equipment system includes a filler wire agitation mechanism that improves the dynamics of the molten weld puddle. The agitation appeared to increase fluidity of the puddle and help break up impurities and release evolving gases for reduced risk of inclusions and porosity. The basic equipment is shown in Figure4 below. Figures 5 and 6 show the torch and wire feed oscillation device respectively.

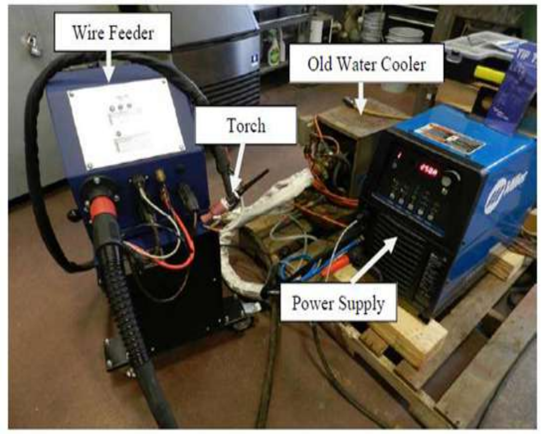

Fig. 4. Basic Tip TIG Equipment

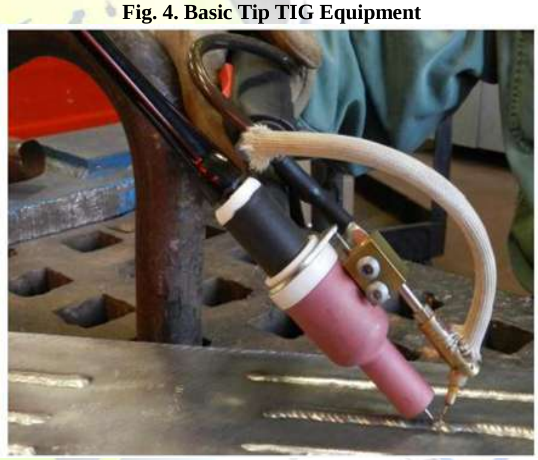

Fig. 5. Tip TIG Torch

Fig. 6. Wire Feeder

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C. Specifications
TIG: 18 Amps- 315v
Cooling: Air cooling
Frequency: 50Hz

D. Metallography

The specimens for metallographic examination were sectioned to the required size from the welded joints transverse to the welding direction, polished with different grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) on the disc polishing machine and then etched with a solution 5 ml hydrochloric acid, 1 g picric acid and 100 ml methanol applied for 10–15s.

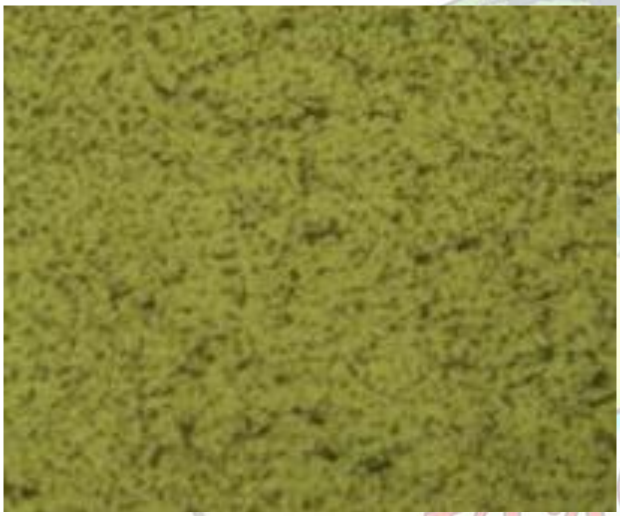

Fig. 7. Weld zone microstructure of welds made by TIG Welding

E. Rockwell Hardness measurement

Specimens were cut at the middle of the joints in transverse direction for conducting hardness survey. The Rockwell Hardness measurement based on the net increase in depth of impression on a material as a load is applied. The higher the number on the scale, the harder the material. The mild steel specimen of 18 mm thickness was placed on the surface of the Rockwell Hardness tester. A minor load is applied and the gauge is set to zero. Then different loads were applied by tripping a lever. After 15 seconds the major load is removed and the specimen was allowed to recover for 15 seconds and then the hardness was read off the dial with the minor load still applied.

Table III
Hardenss test Results

MATERIALS	PEAK CURRENT AMPS	BASE CURRENT AMPS	WELDING SPEED MM/MIN	HARDNESS HRB
SS 304 L	130	80	50	101
	130	95	60	102
	130	100	70	105
	140	80	70	108
	140	95	60	106
	140	100	50	105
	150	80	60	104
	150	95	50	102
	150	100	70	101

Fig. 8: Hardness Test Equipment

F. Tensile Test

TIG Welded joints are evaluated for their mechanical characteristics through tensile testing. A tensile test helps determining tensile properties such as tensile strength, yield strength, percentage of elongation, and percentage of reduction in area and modulus of elasticity. The welding parameters were randomly chosen within the range available in the machine. The joints were made with random parameters and evaluate tensile strength and burn off. Then the joints were made and evaluate the mechanical and metallurgical characteristics. The friction welded specimens were prepared as per the ASTM standards. The test was carried out in a universal testing machine (UTM) 40 tones FIE make. Elongation Deformation in continuum mechanics is the transformation of a body from a reference

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configuration to a current configuration. A configuration is a set containing the positions of all particles of the body. Contrary to the common definition of deformation, which implies distortion or change in shape, the continuum mechanics definition includes rigid body motions where shape changes do not take place A deformation may be caused by external loads, body forces (such as gravity or electromagnetic forces), or temperature changes within the body.

Strain is a description of deformation in terms of relative displacement of particles in the body. Different equivalent choices may be made for the expression of a strain field depending on whether it is defined with respect to the initial or the final configuration of the body and on whether the metric tensor or its dual is considered. In a continuous body, a deformation field results from a stress field induced by applied forces or is due to changes in the temperature field inside the body. The relation between stresses and induced strains is expressed by constitutive equations, e.g., Hooke's law for linear elastic materials. Deformations which are recovered after the stress field has been removed are called elastic deformations. In this case, the continuum completely recovers its original configuration. On the other hand, irreversible deformations remain even after stresses have been removed. One type of irreversible deformation is plastic deformation, which occurs in material bodies after stresses have attained a certain threshold value known as the elastic limit or yield stress, and are the result of slip, or dislocation mechanisms at the atomic level. Another type of irreversible deformation is viscous deformation, which is the irreversible part of visco elastic deformation.

Table IV
Tensile Test – Results

S.No	**Area mm^2**	**Tensile Load KN**	**Tensile Strength N/mm^2**
1	75.60	28.62	378.55
2	76.89	31.42	408.66
3	73.59	28.62	388.39
4	75.25	27.56	366.52
5	75.66	30.27	399.58
6	73.04	31.45	430.25
7	77.77	30.68	394.56
8	76.91	29.85	390.23
9	76.68	31.25	408.55

G. Corrosion Test

The test specimen shall be in the as welded state after normal weld cleaning operation and have a dimension of full wall thickness by 25 mm along the weld and 50 mm across the weld. The test shall expose the external and internal surface and a cross section surface including the weld zone in full wall thickness. The exposure time shall be 24 hours. The test temperatures shall be 40°C for Type SS 304 L.

Free iron, welding oxidation and embedded materials, such as dirt, sand, flux, metals other than steel or iron, etc. may be removed by either chemical cleaning or by abrasive cleaning. Chemical cleaning agents that will successfully remove free iron and most other contaminants are commercially available. These cleaning agents are acids which typically remove a little of the material (about 0.001 inches) from the surface to which they are applied. They need to be left on the surface long enough to remove any free iron and any visible oxides. Most contain nitric and hydrofluoric acids, so they must be handled using rubber gloves and other personal protective equipment, and they must be thoroughly rinsed off the surface, and the rinse water should be neutralized with baking soda, baking powder, limestone or other basic material.

H. Non – Destructive Testing

NDT is used to detect internal defects formed in the weld region. NDT is a wide group of analysis techniques used in science and industry to evaluate the characteristics of a material or component without causing damage to it. Many different types of NDT methods exist, the most commonly used ones being ultrasonic testing, magnetic particle testing, liquid penetrate inspection, radiographic testing and eddy current testing. NDT is used in almost every field of engineering and can be applied to any types of materials including metals, ceramics, plastics and composites. The detection of these flaws is critical for the safety criteria of all designs. These flaws include cracks, internal voids, surface cavities, defective welds and any sort of imperfection in the welds. Successful attempts have been made on NDT techniques on TIG welds of stainless steel pipes.

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Fig. 9. Ultrasonic testing of pipes

This test was conducted to determine the welding defects more accurately and to know whether any other flaw exists in the welded specimens [2]. The ultrasonic test was performed using the Ultrasonic Flaw Detector. The ultrasonic test results showed defects of penetration, even though delta ferrite in 309L could dissolve Sulphur which causes the penetration defects. From the images shown in Table 6, the specimens G& H are observed to have fewer defects when compared to other specimens.

I. Creep Testing

Different multiaxial stress states were introduced by varying notch profiles. There were five multiaxial stress states for which specimens were creep tested. The nomenclature followed here is in the ascending order of notch depth of specimens i.e. SS 304L1, SS 304L2, SS 304L3, SS 304L4, and SS 304 L 5. The creep test was carried out at constant load of 300 MPa and 873 K in air. The stress concentration factor, Kt was calculated for each notch profile as per the literature [7, 8].

IV. Conclusion

Experiments were carried out with accuracy in order to keep the error minimum and determine the results appropriately. The results are prone to deviations due to some uncontrolled conditions, but are not taken into consideration during this work.

- Greater tensile strength of 430.25 N /mm^2 while minimum tensile strength of 378.55 N /mm^2 for the specimen studied.
- The ultrasonic test results showed defects of penetration, but in general results indicate that the defect does not create much impact.
- Microstructure images show that 304L has prominent second phase formation because of varying chromium percentage retarded transformation and uncontrolled heat input.
- Rockwell Hardness measurement gives 108 HRB.
- Stress concentration factor, Kt was studied by creep test.
- Corrosion treatment, appropriately selected for the stainless steel being tested, which induces stable grain dropping.

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