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An Assessment of Duplex stainless Steel pipe for Oil and Gas Application

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Abstract

STAINLESS steels are an important category of engineering materials that have been used in a variety of industries and environments. Welding is an important method for stainless steel. In the last 75 years, many articles, manuals and other guides have been published that provide information on the techniques and precautions necessary to successfully weld these materials. In general, stainless steels are considered wieldable materials, but there are many rules that must be followed to ensure that they are easily manufactured without defects and that they function in the manner expected in the service in question. Stainless steel is an iron alloy with a minimum of 10.5% chromium. Chromium produces a thin layer of oxide on the steel surface known as the "negative layer". This avoids any additional corrosion of the surface. They are known for their resistance to corrosion.

1 INTRODUCTION

Since it was possible to manufacture tapes and sheets, people tried to bend the material and connect its edges to the manufacture of pipes. This led to the oldest manufacturing process that has been welding the forge for more than 150 years. In 1825, James Whitehouse registered a patent for British hardware in the manufacture of welded pipes.

The process consisted of forging the plate on an axle to produce an open seam, and then heating the coupling edges of the open seam and mechanically welding them on the traction seat.

This technology evolves to the point where the tape can be formed and welded in a single passage in the welding furnace. The concept of butt welding was applied in 1931 in the Fretz-Moon process, created by J. Moon, an American and Fretz partner. The welding lines that use this process continue to work successfully to manufacture pipes with an outer diameter of approximately 114 mm.

In addition to hot welding technology, American E. Thomson also invented many other processes between 1886 and 1890, which allowed for electric welding. In 1898, Standard Tool Company, EE. UU., Granted a patent for the application of welding by electrical resistance to the manufacture of tubes and pipes. Welded pipes and electrical resistance pipes received a major boost in the United States, and much later in Germany, after the construction of a hot-rolling mill for large-volume materials for large-scale manufacturing. During the Second World War, arc welding was invented again in the United States, allowing the effective welding of magnesium in aircraft.

As a result of this development, many gas-protected welding processes have been developed mainly to manufacture stainless steel pipes and tubes. The welded steel tubes and tubes are manufactured by a straight seam or a helical (spiral) seam. The diameters of these products vary from 6 to 2500 mm, and their thickness varies from 0.5 to 40 mm.

The starting material in all cases will be a flat rolled product, which may depend on the manufacturing facility or after the pipeline or its application,

hot or cold rolled steel strip or plate. The starting material is formed into its tubular shape either in hot or cold condition.

There are two tube forming processes:

1) Continuous Tube Forming process

2) Single Tube Forming process

In continuous tube forming process, uncoiled strip material is taken from the accumulator, with the leading end and trailing end of the coils being welded together.

In single tube forming process, the tube forming and welding process not performed over endless length, but rather in single pipe lengths [7].

2. WELDING PROCESSES FOR MANUFACTRING OF PIPE

There are methods for welding processes:

1) Pressure welding processes

2) Fusion welding processes

Table 1: Types of Welding Processes for Pipe Manufacturing

Pressure welding processes	**Fusion welding processes**
Fretz-Moon process	Submerged arc welding
Electric resistance welding	Gas shielded arc welding

3. PRESSURE WELDING PROCESSES

1) Fretz-Moon process

The hot-rolled steel strip is used as unlined high-speed raw material and stored in a ring accumulator. This complex acts as a buffer during the continuous welding process. The steel belt is heated in the form of continuous rolling at the welding temperature in the formation and welding line (Fig. 1). The cylinder head is assembled continuously in the open seam by the cylinder and the edges of the coupling are pressed together and welded by a welding process. In this way, tubes and pipes can be manufactured from 40 to 114 mm in diameter for welding speeds of 100 to 200 m / min [9].

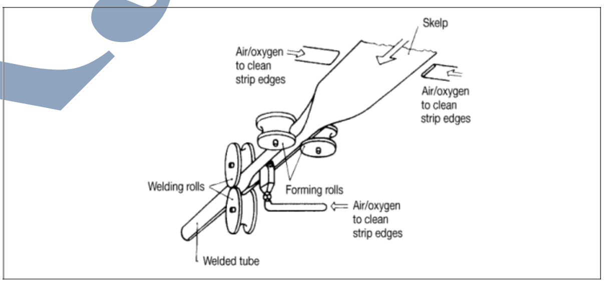

Fig 1: Fretz-Moon welding line viewed from below

Electric resistance welding process

(a) DC processes

The processes operated by a direct current for the longitudinal welding of a tube with a diameter of 20 or 30 mm have been developed with a small wall thickness that varies from 0.5 to approximately. 2.0 mm. This process is superior to the operation of high frequency and low frequency in the smooth surface method. This process does not provide more than a minimum of internal reinforcements and this is very important in the case of the tube where the internal surface is the critical area.

(b) Low Frequency

In this process, AC welding is performed from 50 to 400 Hz. The electrode, which consists of two insulated copper alloy discs, not only serves as a source of energy supply, but also serves as a tool to form and apply the welding pressure needed.

Therefore, the electrode is an extremely important part of this process, since not only must the groove match the diameter of the tube, but also the corrosion must be controlled during the production process. There are internal and external cutters to remove the internal and external pulp near the welding area during the welding process.

(c) High Frequency

The process involves the application of high frequency AC power within 200 - 500 kHz, with tube formation and energy input by separate units.

The weld metal uses this pressure and heat simultaneously to tie the edges of the tape to the seam of the seam without adding a filler metal. The pressure and pressure rollers in the welding line gradually combine the edges of the seam and apply the pressure required for welding.

The tape is formed in a rolling mill or in an adjustable roll holder in an open seam tube to manufacture a wide range of products. The sizes vary from 20 to 609 mm OD and the wall thickness from 0.5 to 16 mm. The individual files are welded together and unrolled quickly, passing the tape first through the ring picking tool. The tube welding machine works continuously from 10 to 120 m / min. Roll forming mill consists of 8-10 largely driven roll forming stands in which the strip is gradually shaped into the open seam tube [8].

4. FUSION WELDING PROCESS

Fusion welded steel pipes are nowadays predominantly manufactured in diameters in excess of 457.2 mm (18") and is used for large diameter pipe for pipeline construction.

The processes used for forming pipe are as follow:

The three roll bending process for plate forming, employed as either hot or cold forming process

- The C - ring process for cold forming plate
- The U - ring and O - ring process for cold forming plate
- The spiral tube forming process for cold forming wide strip or plate.
- JCO press forming

The process of arc welding, or a series of welding welding with gas protection with submerged arc welding, has become a widely accepted method for welding large diameter pipes. Another field can be found to apply the fusion welding process in the manufacture of tubular and spiral tubes and alloys of high grade stainless steel and non-ferrous metals (such as titanium, aluminum and copper) [9].

a) Submerged-arc welding process

Submerged arc welding is an electric fusion welding process performed through a hidden arc. Unlike arc welding with welding electrodes, the arc in this case is hidden from view and burns under the slag and flow cover. A high sedimentation rate is one of the characteristic features.

The metal used in the filling takes the form of a bright welded wire that is continuously fed into the molten metal bath by the fast feed coil dictated by the deposition ratio. At the top of the original metal (tube), the welding current is made by moving the contacts to the cable pole and returning it through the ground wire connected to the pipe material (Fig. 2).

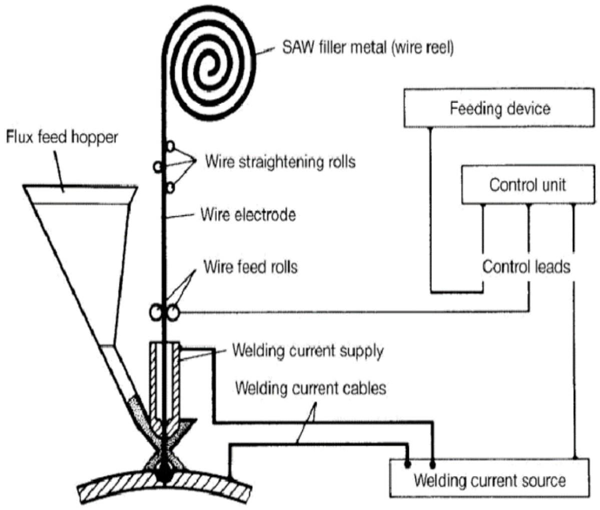

Fig 2: Submerged-arc welding process

The arc dissolves the incoming cable and the open edges of the seam. Part of the weld flow that is fed continuously is also dissipated by the heat of the arc, forming a covering of slag liquid that protects the welding pool and the pole of the fusion cable, as well as the arc itself against the effects of the air.

In addition, the weld flow also facilitates the formation of the weld bead and acts as a donor of the alloying elements to compensate for melt and oxidation losses. In many cases, it is also used specifically for metal alloys to be transported to specific mechanical and chemical properties. When the arch moves, the liquid slag left behind hardens.

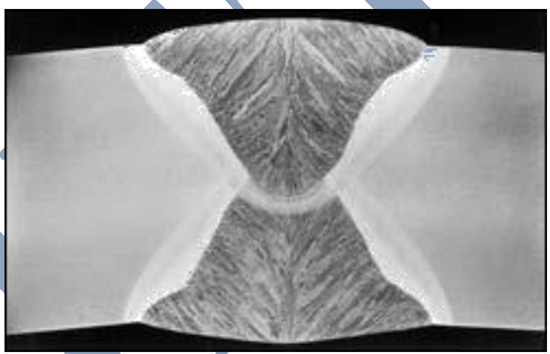

Fig 3: Submerged-Arc Weld

The weld flow that has not melted is recovered by vacuum extraction and reuse. The slag is easily removed once it is frozen. The chemical structure of the electrode and the welding flow must match the welding material. Arc welding Arc welding is generally done in the normally applied exercise method (ie, the first operation followed by sealing or rear operation) with internal traffic first and the second is an external step. This ensures that the two overlap sufficiently (Figure 3).

5. Submerged Arc Welding Parameters

(a) Welding Current, Voltage and Electrode size

The size of the electric wire, the voltage welding, the current and the speed are the four most important welding variables, independently of the flow. The welding current is the most powerful variable because it controls the fusion speed of the electrode, the depth of penetration and the amount of molten metal. However, the very high current must cause a great penetration, which leads to the burning of the metal, increase the reinforcement and increase the contraction of the weld, which produces a significant deformation. On the other hand, the low current must lead to an inadequate penetration, low fusion and an unstable arc [11].

The welding voltage has a nominal effect on the fusion speed of the electrode wire, but the high voltage leads to a wider flattening and lacing, increases the flow consumption and the corrosion resistance caused by the oxide or the volume , and it helps to separate the bridge when the preparation is poor. The low tension produces resistance to the arc punch, but a tightly fitting cord with poor slag removal. The welding voltage used varies from 22 to 35 volts [12].

In the case of a higher welding speed, the power or heat input are reduced for each unit of welding length. Less welding material is used for each length of the welding unit, which reduces the results of weld reinforcement and decreases penetration. Travel speed is mainly used to control the size and penetration of the cord. They are interconnected with the current.

The high speed of excessive movement reduces the work of urination, increases the tendency to undermine, brushstroke, porosity and irregular shapes of the pearls, while reducing the speed of slow movement of the tendency to porosity and insertion of scum.

The size of the electrode mainly affects the depth of penetration of the constant current. Small cables are generally used in semiautomatic equipment to provide flexibility to the welding gun. Small cables are also used in multiple electrodes and parallel cable devices.

The larger electrodes are generally used to take advantage of higher currents and consequently higher deposition rates. Where poor fit-up is countered a larger electrode is capable of bridging gaps better than smaller ones [13].

Table 2: Recommended Current Ranges for Wire Diameter

Diameter (mm)	Welding Current (A)
1.6	150-300
2	200-400
2.5	250-600
3.15	300-700
4	400-800
6	700-1200

(b) Welding Speed

The desired geometry and penetration of the cord in the welded joint is obtained only with the maximum speed of the welding arc during the SAW. The selection of the speed exceeding the optimum speed reduces the heat input per unit length, which in turn leads to a decrease in the deposition rate of the weld metal and a lower weld strength and surface penetration (Fig. 3.6). In addition, the very high welding speed increases the tendency to (a) undermine the weld due to the low heat input, b) the strike of the arc due to the greater relative movement of the arc in relation to the surrounding gases) and the porosity because The air bag is clogged due to the fast fixation of the welding metals. On the other hand, the low welding speed increases the heat input per unit length, which in turn can increase the melting tendency and reduce the tendency to develop porosity and slag insertion [13].

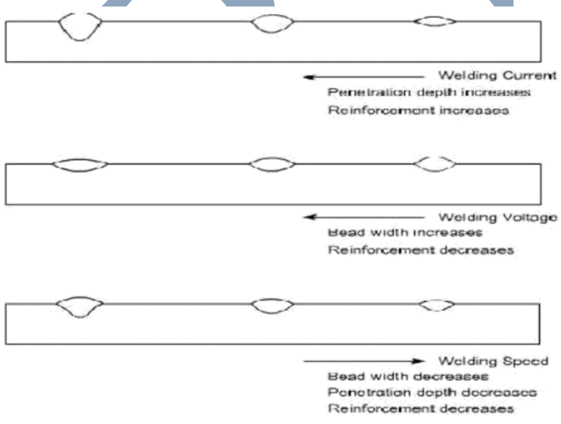

Fig 4: Effect of Welding Voltage on Bead Width and Reinforcement

(c) Bead geometry and effect of welding parameter

The geometry of the bead and the depth of penetration are important characteristics of the weld bead that are affected by the size of the electrode to prepare the specified welding current. In general, increasing the size of the pole reduces the depth of penetration and increases the width of the weld bead to a specific welding current (Fig. 5). The large diameter electrodes are mainly selected for two advantages: a) high deposition rate due to their ability to withstand high current, and b) the ability to fill the proper gap under adequate conditions for the plates to be welded due to the cord. wider welding.

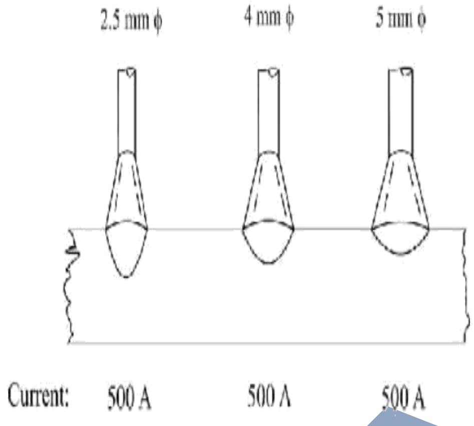

Fig 5: Influence of Electrode Diameter on Weld Bead Geometry

6. SUBMERGED ARC WELDING DEFECTS

Most of the cases, the SAW defect contains more than one cause and more than one treatment is possible. The treatment of the problem is often the opposite. For example, if the drawback is due to an overcurrent, simply reducing the current produces a faulty solution. But choosing the right treatment depends on your goal. For example, casting can be achieved by reducing the welding current, increasing the flow velocity or reducing the angle of inclination. In most cases, reducing the angle of inclination is not a realistic option, so you should reduce the current speed or increase the speed of travel. Since most manufacturing applications favor greater productivity, it is generally reasonable to increase the speed of travel [14].

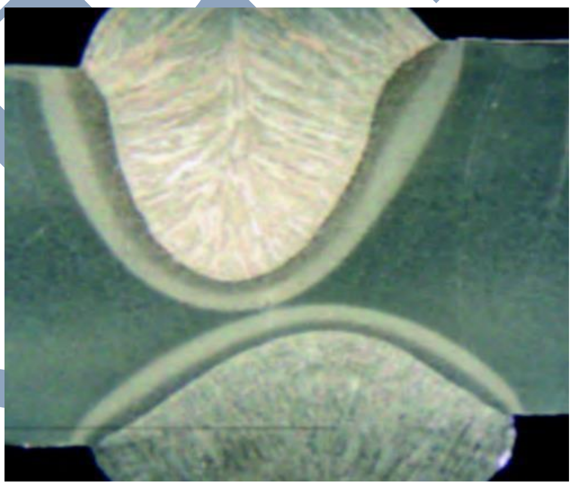

Figure 6: Insufficient penetration in the weld.

1) Incomplete Fusion

Incomplete fusion welding between basic metal or welding and welding (multilayer welding) Blood is not a fully fused joint part. The risk of incomplete (scaly) fusion area type is similar to fracture, a very serious defect. Boiler and pressure vessel procedures, standard provisions do not allow incomplete merger. The lack of fusion is usually an imbalance in the wiring, resulting in a double side of the partial fusion weld or too local bending causing fusion [15].

7. CHALLENGES

For many engineering applications in the oil refining industry, stainless steel is a double-sided material, which combines the properties of anasthenic stainless steel and iron when properly welded. When welding incorrectly, the possibility of forming harmful phases between metals can increase dramatically, which can lead to catastrophic failure.

The DSS has a perfect resistance to corrosion and mechanical properties by preserving the ferrite content from 35 to 60% throughout the weld [17].

8. Optimum Ferrite and Austenite phase balance

The DSS ferrite content will indicate whether welding and / or heat treatment techniques lead to corrosion resistance and mechanical properties that meet engineering requirements. The presence of ferrite in the DSS confers superior corrosion resistance to chloride corrosion (CSCC) and high strength.

When the amount of austenite in the DSS increases, the strength will decrease as the corrosion resistance increases and there is exposure to cracking caused by stress chloride erosion. As a result, the ferrite must be specified within a range and used as a control measure.

When low temperature effect characteristics are required, the ferrite content must be carefully controlled. Since the ferrite content exceeds 60%, there will be a marked decrease in ductile behavior and resistance to pitting. The sources suggest that there may be a negative impact on the ductile behavior if the ferrite level falls below 35%, and the resistance to SCC decreases due to the change in the sclerotic state, causing the separation and degradation of the metal phases. He believed that a range of 35-60% of ferrite would provide ideal results [17].

9. Excess Ferrite in Heat Affected Zone (HAZ)

HAZ is the surface area of the basic metal in which the microscopic and its properties change by causing extreme heat in the metal. The HAZ must have an effect of corrosion resistance and hardness similar to the minimum core requirements of metal.

The DSS has a narrow BEAM, in comparison with the austenitic SS, due to the low temperature welding processes and the high thermal conductivity of the materials. The HAZ morphology is more important than estimating the austenite / ferrite balance.

Since HAZ for DSS is critical, we have established the minimum requirements for nitrogen content at 0.14%. Nitrogen causes the formation of austenite from ferrite at elevated temperatures, allowing the recovery of an acceptable balance of austenite and ferrite after the cycle of rapid heat HAZ after welding [17].

10. Inter-metallic Phases

The DSS alloys are hardened primarily as sulphate at about 1425 ° C and partially converted to austenite at low temperatures by solid state reaction. If the cooling rate is fast, very little ferrite will be converted to austenite, which will result in an excessive ferrite phase at room temperature.

Therefore, the cooling speed of the double welds must be slow enough to allow approximately 50% of the ferrite to be converted to austenite, while being fast enough to avoid the formation of metal phases and harmful microorganisms. Unwanted phases can occur when welding heavy sections with very low thermal inputs.

When cooling begins at a temperature reduction between 475 - 955 ° C for short periods of time, deposition of carbides, nitrates and metallic phases may occur, all of which is detrimental. The most prominent stages are alpha prime, sigma, chi and laves. For this reason, DSS is not generally used when the temperature is above 315 ° C.

The cooling provided by the workpiece itself is the most effective way to reduce the time in which HAZ is in the formation of the temperature range of these phases between the metal [17].

1) Sigma phase

It is a compound between metal (Fe, Ni) and X (Cr, Mo) y, which for DSS mixed with Cr and Mo is inherently unstable at temperatures below 950 ° C. This generally occurs in the temperature range of 600 -950 C. The fall of the sigma phase leads to reduced resistance to corrosion, reduced softness, reduced impact and roughness of the fracture. The development of sigma gives a greater resistance to traction. A sigma phase formation often occurs when the cooling speed during fabrication or welding is not fast enough. The greater the steel alloy, the more likely Sigma phase formation will be. Therefore, two-way steel is more susceptible to this problem [19].

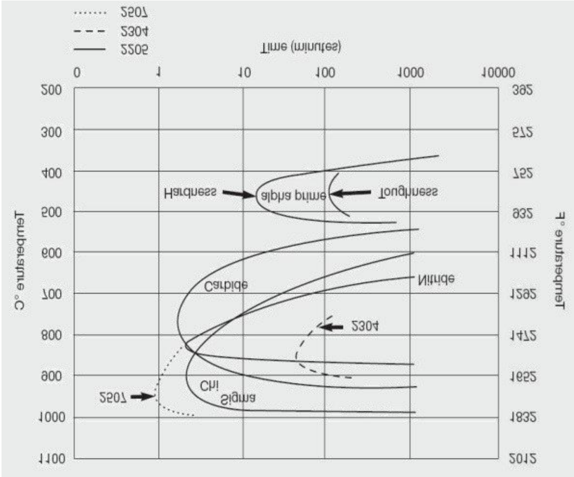

Figure 7: Micro-structural challenges in welding duplex stainless steel

*2) **Chi phase***

It is a phase of Mo-rich, $Fe_{36}Cr_{12}Mo_{10}$, which is generally considered to have the same adverse effects on material properties as the Sigma phase. They are generally present with the Sigma phase [19].

*3) **Chromium nitrides***

Since most DSS are alloyed with nitrogen, chromium nitride precipitates (Cr_2N, CrN) may form as a result of temperature exposure in the range 70-900 C. Precipitation of nitride generally occurs from the ferrite phase. This is generally a inter-granular precipitation, nucleation at ferrite-austenite or ferrite-ferrite grain boundaries. It is generally occur as a result of rapid cooling observed in HAZ during welding. Nitrides can be harmful to the impact toughness and corrosion resistance [19].

*4) **Secondary austenite***

Sigma phase, chi phase and chromium nitrides precipitate normally contain ferrite stabilizing components as Cr and Mo, which result in shift in the ferrite/ austenite phase balance of DSS. This decomposition of ferrite may result in formation of new austenite as a secondary phase precipitation, know as secondary austenite. This phase can cause loss of corrosion resistance [19].

11. Heat Input and Toughness

Inlet welding temperatures have a significant impact on the properties of the welds. The mechanical properties and the hardness of the welding depend on the microscopic structure of the welding metals. The figure shows the effect of the heat input on the cooling rate, and the cooling rate is the main factor that determines the final metallic structure of the weld. The cross-sectional area of the weld is proportional to the amount of heat input. With more energy for the arch, more fillings and core metals will melt per unit length, which will result in a larger bead weld. The main advantage of the heat input is that it controls the cooling speeds in the welds and, therefore, affects the exact structure of the welding metals. The change in the microstructure directly affects the mechanical properties of the weld. Therefore, the control of heat input is very important in arc welding in terms of quality control.

The high heat input causes a thick microscopy compared to the low heat input. The increase in thermal inputs highlights the appearance of more than the proeutectoid ferrite and the widmanstatten ferrite, which affect the low durability.

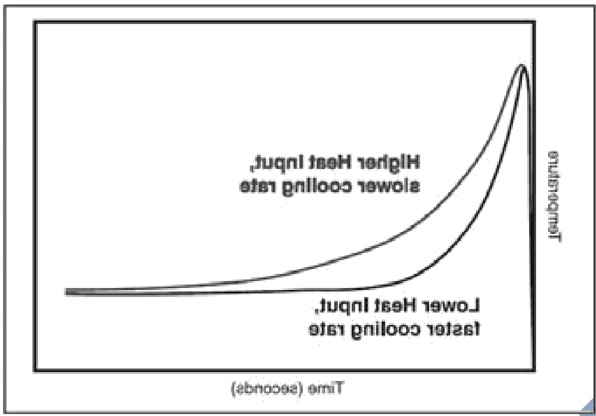

Fig 8: Effect of Heat Input on cooling rate

The change in durability is not only related to heat input, but is also significantly affected by the size of the weld bead. With the increase in cord size, which corresponds to the high inlet temperature, the inclination resistance tends to decrease. In multi-line welds, part of the previous welding path is improved and durability improved. The heat emitted from each step cuts the metal below. If the grains are smaller, the grains will improve better, which will lead to better stiffness [20].

Type of product	**Type of material**	**Tested Thickness (T)mm**	**Qualified Thickness mm**
Strip, plate, pipe, tube and wrought fittings	High alloyed austenitic SS + SS type 25Cr duplex	T ≤ 40	T + 25%
		T > 40	Maximum 40 T
	SS type 22Cr duplex	T ≤ 60	T + 25% Maximum 60
		T > 60	T

There are additional requirements laid down by NORSOK standard like low temperature toughness, pitting corrosion resistance. So to meet such requirements, we needed to be assuring before going for an actual welding for the qualification purpose. As we had to qualify this manufacturing of duplex stainless steel for UNS S31803 and UNS S32205, we have taken two trials on UNS S32205 plate [23].

12. CONCLUSION

Stainless steel has always been a fascinating area of interest for researchers, manufacturers and end-users. They face many challenges and very attractive service characteristics. In addition, Duplex Stainless Steel enjoys an excellent cost / ownership ratio in vital markets including: Oil & Gas, Chemical Industry, Paper & Cellulose, Chemical Oil Tankers, Desalination Plants, Water Networks. Underwater arc welding allows very large welds to be deposited less time compared to a larger number of passes with less deposition per pass. For large constructions and large straight welding operations, SAW is a relatively profitable and satisfactory way of welding stainless steel.In the current investigation, SAW machine was used to manufacture double stainless-steel tubes.

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