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Experimental Investigation and Finite Element Simulation of Plasma Arc Welding Improve Current Rate Using Stainless Steel Material

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ABSTRACT

Welding is one of the important industrial processes commonly used in electronics, medical, automotive and aerospace industries due its high accuracy, finishing, ability of welding any hard materials. Plasma arc welding is high current rate using materials. The arc is fully formed the welding materials The current rate can be defined in terms of properties such as weld bead geometry welding pool and distortion. Therefore, mechanical properties should be controlled to obtain good welded joints. In this study, the weld current rate such as depth of penetration, bead width and tensile strength of the plasma arc welding butt joints made of austenitic stainless steel were investigated. A discussion is made on the process parameters such as plasma arc welding current rate. It turns out that high plasma arc welding speed is beneficial to complete joint penetration, but current rate parameters are good choice to improve the both the high weld quality and good joint penetration.

KEYWORDS

Current rate, welding pool, penetration

Introduction

Modern research trends on advanced supercritical (AUSC) boilers mainly focus on joining enhanced materials. AISI 304HCu, an emerging variant of stainless steel preferred in superheaters and reheaters. The resistance to corrosion and oxidation makes the austenitic steels a prime candidate; the steels owe superior creep properties at a temperature range of 650°C [1,2]. AISI 304 HCu fabrication involves Gas Tungsten Arc Welding (GTAW) either by constant current or pulsed mode with overmatching electrode. The selection of overmatching electrodes provides superior creep strength to the base material [3]. Conventionally, the joining of high alloyed stainless steels is by constant and pulsed Current GTAW Current GTAW processes. The heat dissipation in the fusion zone of TIG joints results in the segregation of micro alloying elements. Coarse columnar grains formed in the fusion zone of GTAW welds result in inferior mechanical properties. The efforts to control the pinning of temperature and precipitate could reduce the grain coarsening in the heat-affected zone (HAZ) of austenitic stainless steel. Grain coarsening of HAZ is because of the time available for growth during solidification of the weldment [4–6].

Segregation of elements is minimum in pulsed GTAW due to current pulsation [7]. To acquire a minimal width of HAZ choice of welding process with higher arc density can improve the mechanical properties. Plasma Arc Welding (PAW) is a welding process similar to the GTAW process. The arc density of PAW is higher than GTAW. PAW is intense; it provides a minimum weld region than GTAW. The lower capital cost of PAW makes it more suitable than LBW or EBW. Arc constriction provided through nozzle and plasma gas produces minimal bead geometry than GTAW. S.A. Rizvi optimized the parameters for Gas Metal Arc welded (GMAW) 304H and concluded that shielding gas rate influences the strength of the hardness of the joint. Arc voltage and wire feed rate had their impact correspondingly flowed by the gas flow [8]. TIG welding assisted with flux and provided complete penetration in a single pass. Complete penetration of AISI 304H weld by activated TIG (A-TIG) welding is possible. The use of flux increases the penetration by arc constriction by Marangoni’s convection effect. Equiaxed ferrite stringers form because of the arc constriction [9,10]. Huang et al. compared the joining of AISI 304 with TIG and PAW. The Fusion zone of PAW is narrow with refined grain because of the lower heat input of PAW [11].

PAW by keyhole mode on 304H results in defect-free joints with homogenous microstructure and a narrow weld zone. The arc constriction in PAW through the nozzle leads to a slender weld geometry [12]. The literature survey on joining AUSC materials by high energy density processes mainly, KPAW is scanty. Some works focus on the behavior of weld metal on the solidification of the weld pool. The effect of process variables on keyhole formation and evolution of microstructure is nil. Therefore, this work aims at delivering the impact of process parameters (welding current, plasma gas flow rate, and stand-off distance) that govern the stability of the keyhole in joining AISI 304HCu autogenously by KPAW.

Experimental Procedure

Plasma Arc Welding

The plasma process is basically very similar to the TIG process but has a number of critical advantages. In plasma welding, the arc is constricted by a cooled gas nozzle. The powerfully bunched arc that results does away with the need for time-consuming weld preparation work such as V- or U-type joint preparation. This saves as much as 30 % of the filler metal. In turn, the higher welding speed – around 20 % faster in soft-plasma welding, for example – saves time and costs at the same time as ensuring deeper penetration. Also, being enveloped in plasma gas, the tungsten electrode has a much longer service life. Here there are models for both manual and robot applications. On the manual torch, the handle-shells ergonomically shaped, making for precision torch guidance. The robot welding torch is flexibly mounted directly on the robot, in up to four positions. The tool centre point (TCP) is absolutely fixed and is the same as on TIG robot welding torches of identical construction.

The main arguments for deploying a plasma welding system are always the top-quality results which it reliably delivers, and its higher welding-speeds. This is true fall chrome-nickel materials, coated and uncoated steels, titanium and all nickel-based materials. Plasma welding is an interesting alternative for sheets of up to 8 mm in thickness. Not surprisingly, then, it has many and varied areas of use in the automotive vendor industry, for pipeline and tank construction, in mechanical engineering and structural steelwork, for rail vehicles and rolling stock, and in shipbuilding.

Figure1. Plasma Arc Welding Process

Mechanical Properties

In typical room temperature the properties of stainless steel is as follows,

Ultimate strength = 621 Mpa
Yield strength = 290 Mpa
Elongation = 55 mm
Rockwell hardness = B82

Oxidation Resistance

The maximum temperature to which Types 304 and 304L can be exposed continuously without appreciable calling is about 1650°F (899°C). For intermittent exposure, the maximum exposure temperature is about 1500°F (816°C).

Heat Treatments

Type 304 is non- harden able by heat treatment. Annealing: Heat to 1900 - 2050°F (1038 - 1121°C), then cool rapidly. Thin strip sections may be air cooled, but heavy sections should be water quenched to minimize exposure in the carbide precipitation region. Stress Relief Annealing: Cold worked parts should be stress relieved at 750°F (399°C) for 1/2 to 2 hours.

Formability

Types 304 and 304L have very good drawing ability. Their combination of low yield strength and high elongation permits successful forming of complex shapes. However, these grades work harden rapidly. To relieve stresses produced in severe forming or spinning, parts should be full annealed or stress relief annealed as soon as possible after forming.

Weldability

The austenitic class of stainless steels is generally considered to be weld able by the common fusion and resistance techniques. Special consideration is required to avoid weld “hot cracking” by assuring formation of ferrite in the weld deposit. Types 304 and 304L are generally considered to be the most common alloys of this stainless class.

Alloying Systems

Carbon = 0.08 %

Manganese = 2.00 %

Phosphorus = 0.045 %

Sulfur = 0.030 %

Silicon = 0.75 %

Chromium = 18.00-20.00 %

Nickel = 8.00-12.00 %

Nitrogen = 0.10 %

Incomplete penetration

It is also called as lack of penetration. This is usually occurs at the root of the weld or between the deposits made from both sides of a joint. In double welded joints lack of penetration may occur with internal wall thickness as a buried defect. Incomplete penetration root is more severe. Lack of penetration beyond a limit is one of the most critical defects and this can cause service failures. These types of defects are easily detected by fluoroscopic test.

Figure 2. Incomplete Penetration

Crack

This can occur due just too thermal shrinkage or due to a combination of strain accompanying phase change and thermal shrinkage. In the case of welded stiff frames, a combination of poor design and inappropriate procedure may result in high residual stresses and cracking. Where alloy steels or steels with a carbon content greater than about 0.2% are being welded, self-cooling may be rapid enough to cause some (brittle) martensite to form. This will easily develop cracks. To prevent these problems a process of pre-heating in stages may be needed and after welding a slow controlled post cooling in stages will be required. This can greatly increase the cost of welded joins, but for high strength steels, such as those used in petrochemical plant and piping, there may well be no alternative.

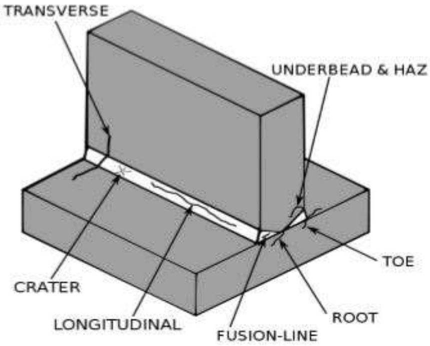

Figure 3. Cracks in Welding

Gas hole

Porosity is the presence of gas pockets or voids caused by the entrapment of gas evolved during weld metal solidification porosity is caused due to improper shielding rust the weld face, too much generation of gas in the weld pool and sudden cooling slag etc., Sometimes elongated tabular gas pockets are also described as worm holes or piping large isolated gas pockets.

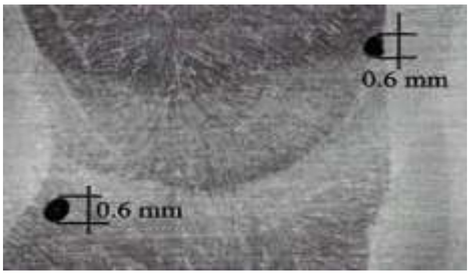

Figure 4. Gas Hole

Lack of fusion

In completes fusion involves lack of complete melting and fusion of some portion of the metal in a weld joint. It may occur either between weld beads are between weld and base metal. This occurs in fusion welding and pressure welding.

Figure 5. Lack of Fusion

Testing

Butt Joint

A butt joint is a joinery technique in which two members are joined by simply butting them together. The butt joint is the simplest joint to make since it merely involves cutting the members to the appropriate length and butting them together. Usually, a butt-welding joint is made by gradually heating up the two weld ends with a weld plate and then joining them under a specific pressure. This process is very suitable for prefabrication and producing special fittings. Afterward, the material is usually ground down to a smooth finish and either sent on its way to the processing machine, or sold as a completed product. This type of weld is usually accomplished with an arc or MIG welder. It can also be accomplished by brazing. With arc welding, after the butt weld is complete, the weld itself needs to be struck with a hammer forge to remove slag before any subsequent welds can be applied.

Figure 6. Butt Joint

Micro Testing

This is performed on samples either cut to size or mounted in a resin mold. The samples are polished to a fine finish, normally one micron diamond paste, and usually etched in an appropriate chemical solution prior to examination on a metallurgical microscope. Micro examination is performed for a number of purposes, the most obvious of which is to assess the structure of the material. It is also common to examine for metallurgical anomalies such as third phase precipitates, excessive grain growth, etc. Many routine tests such as phase counting or grain size determinations are performed in conjunction with micro-examinations.

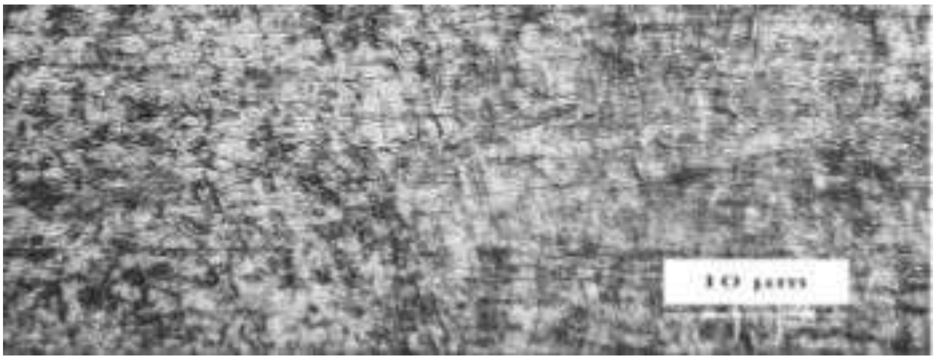

Figure 7. Micro Testing

Macro Testing

The Macro etching is the procedure in which a specimen is etched and evaluated macro structurally at low magnifications. It is a frequently used technique for evaluating steel products such as billets, bars, blooms, and forgings. There are several procedures for rating a steel specimen by a graded series of photographs showing the incidence of certain conditions and is applicable to carbon and low alloy steels. A number of different etching reagents may be used depending upon the type of examination to be made. Steels react differently to etching reagents because of variations in chemical composition, method of manufacturing, heat treatment and many other variables. Macro-Examinations are also performed on a polished and etched cross-section of a welded material. During the examination, a number of features can be determined including weld run sequence, important for weld procedure qualifications tests. As well as this, any defects on the sample will be assessed for compliance with relevant specifications. Slag, porosity, lack of weld penetration, lack of sidewall fusion and poor weld profile are among the features observed in such examinations. It is normal to look for such defects either by standard visual examination or at magnifications of up to 50X. It is also routine to photograph the section to provide a permanent record. This is known as a photo macrograph.

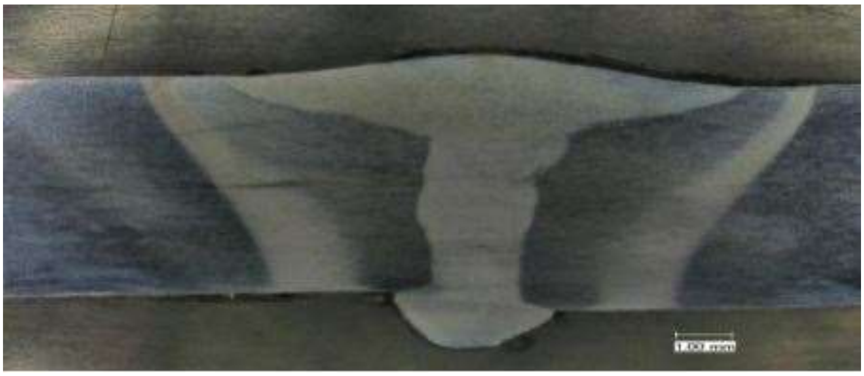

Figure 8. Macro Testing

Material

The stainless steel material has been purchased from Mumbai. The material is a stainless steel plate of thickness 6mm. The size of the plate comprises of length 1000 mm and breadth of 300 mm.

Figure 9. Material

Machining of Material

The stainless steel material of above size has been cut into the dimensions of 80 mm length and 60 mm breadth. The cutting process is done with hydraulic machinery without any heat involvement to avoid thermal distortions. Then the material is faced at all the surfaces. So that the stainless steel pieces are of dimensions 75 mm length and 55 mm breadth. The thickness of the material is maintained in 6 mm.

Figure 10. Stainless steel after machining

Welding

The material is welded by plasma arc welding method. The butt joint is made without any gap between the two stainless steel plates. The stainless steel filler material is used as a powder feed and argon gas as a shielding gas. After the welding process is completed the stainless steel plates are left to cool in atmospheric air.

Figure 11. Stainless steel materials during welding process by plasma arc method

Testing

The material is then tested for measuring the depth of penetration, presence of cracks in the weld area and keyhole in the welded portion

Figure 12. Stainless steel material to be tested after welding

Data Collection

The data collected when the welding process is carried out is as follows, the information is shown in a table.

Table 1. Data Collection

Sl.No.	Pilot Arc Current	Welding Speed	Voltage	Temperature
1	6	150	1.5	5093
2	6	200	1.5	5142
3	6	250	1.5	5330

Results and discussion

Micro Analysis Result

Micro examination of the specimen did not reveal any cracks or other defects. It has been observed that there is a complete weld fusion takes placed at all the examined areas.

Figure 13. Micro image of weld

Macro Analysis Result

Macro examination of the specimen also does not reveal any cracks or other defects. The complete fusion of weld takes placed completely all over the areas examined.

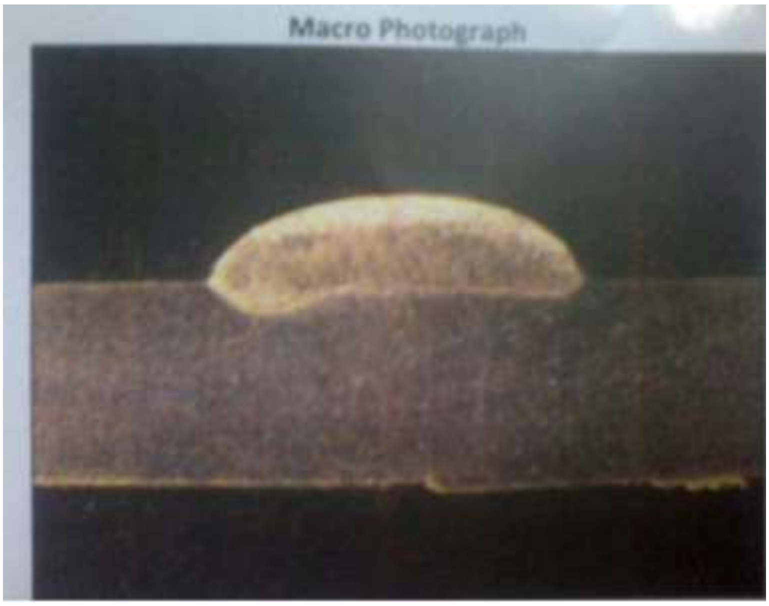

Figure 14. Macro image of weld

Analysis Results on Ansys

This analysis shows the amount of heat dissipated near and on the weld and parent material respectively.

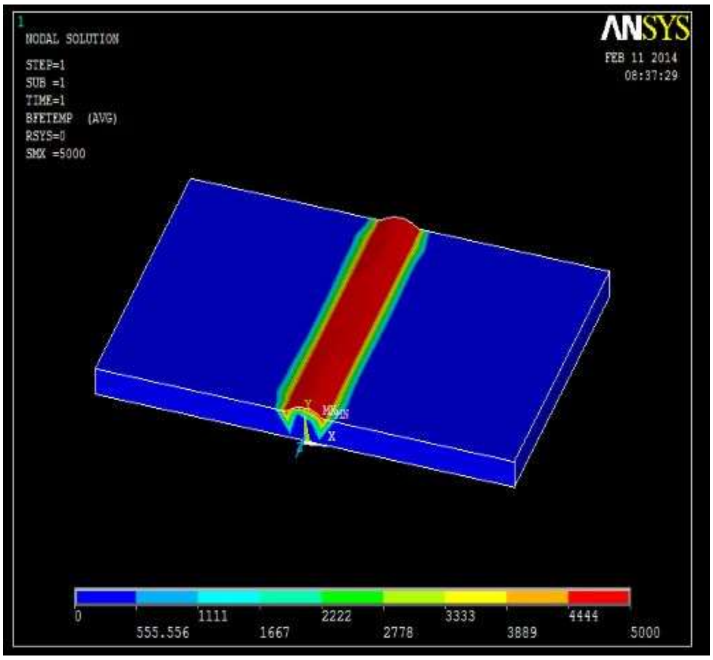

Figure 15 (a). Analysis of a welded stainless steel material

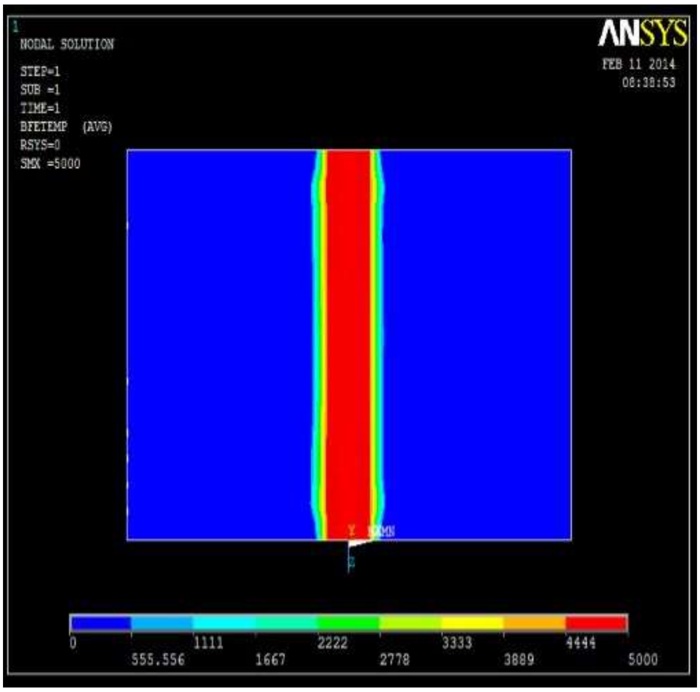

Figure 15 (b). Front view of the analysis

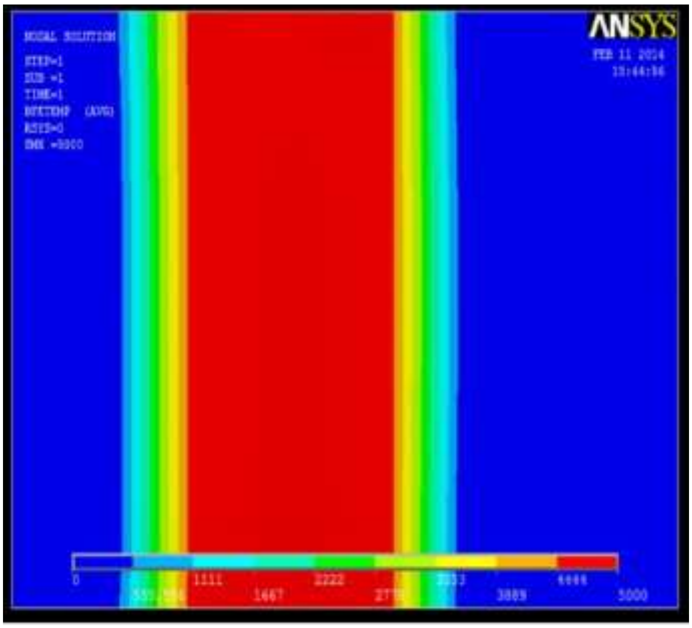

Figure 15 (c). Zoomed view of the material

Conclusions

The various destructive and non-destructive testing have been carried out for this experiment, as a result the properties of the stainless steel material during the process of welding has been studied. From the test results it has been observed that through plasma arc welding process the welding depth has been increased in the absence of root gap between the two specimens. Due to the particular plasma arc welding process the welding defects like cracks which are eliminated to 100%, there is no lack of fusion in the welded portion and the gas holes or porosity on the weld are eliminated. This shows that the perfect welding can be done for stainless steel material through plasma arc welding process.

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