Corrosion Studies And Optimization On Friction Welded Duplex Stainless Steel Tubes Using Design Of Experiment

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Abstract- *Corrosion studies on stainless steel are of great interest in the area tube welding. Duplex stainless steel (DSS) is used widely in the area of oil and natural gas pipe lines, marine etc due to its enhanced corrosive resistance compared to other stainless steels. Radiographic analysis is a common technique to analyze the quality of weldments for tubes or pipes. In this study the optimization of welding parameters is found by design of experiments (DOE). From DOE the parameter effects are analyzed using ANOVA and found that upset time is the most effecting parameter than other factors. The increase in upset time and upset pressure increased the tensile strength of the joint. The microstructure reveals that grains are finer at weld zone than other zones which lead to high tensile strength. The corrosion test results shows that joint were unaffected by pitting as well as intergranular corrosion.*

Keywords- Duplex stainless steel, Tube welding, Rotary friction welding, Design of experiment

I. INTRODUCTION

Duplex stainless steel (DSS) is well known for its excellent strength and corrosion resistance. However joining DSS plates by fusion welding causes a significant reduction in the mechanical properties, because of microstructure changes during weld solidification. It is essential to maintain the characteristics of the weld zone to use DSS in servicing highly critical environments, such as ocean-mining machinery, oil and gas pipe lines, desalination plants and chemical tankers of ships, etc. DSS has ferrite (□) and austenite (γ) in approximately equal proportions, which possess body centered cubic (BCC) and face centered cubic structure (FCC), respectively [1]. Design of experiments is used preferably to determine the feasibility and efficiency of the process. Taguchi methods is one of the methods developed by Genichi Taguchi for quality improvement of manufactured goods and more in recent times also applied to engineering biotechnology, marketing and advertising [2]. As usual, the benefits of these alloying elements invariably come with inevitable problems. The major problem is the thermodynamic micro-structural instability [3]. The □-ferrite phase is responsible for excellent pitting and crevice corrosion, whereas the γ -Austenite phase offers the superior toughness and strength. The ferrrite stabilizer such as: Cr, Si, Mo causes the formation of ferrite phase; the austenite phase leads to increased hardness and toughness as well as elongation [4]

Friction welding seems to be the only method that can eliminate the problems encountered during welding of materials with different chemical and physical properties. The method has several advantages: no melting, little energy consumed, and the completion of welding process within a very short period of time [5]. The inspection of welds is a very important task for assuring safety and reliability in several industrial sectors, e.g., ship and aircraft industry. For this purpose NDT techniques have been employed to test a material for surface or internal flaws without interfering in any way with its suitability for service [6]. The conventional method of inspection requires radiographic images to be of a high quality and is consequently subject to international standards. However, radiographic inspection by inspectors is done subjectively and requires great experience, keenness of vision and knowledge of the techniques employed [7]. The microstructural evaluation in the weld cross-section revealed different regions with acceptable phase ratio, although significant changes in microstructure have been observed. Departing from slight changes in effective grain size of both phases to major differences involving total reformation of the austenite crystals, the impact toughness is affected accordingly [8]. UNS S31803 duplex stainless steel displayed stronger resistance to pitting and general corrosion when compared to 410 martensitic stainless steel in HCl solution due to its higher percentage composition of chromium, nickel and other alloying elements [9]. As the corrosion degree increased, the strength of stainless steel bars decreased, and the ductility decreased significantly. Finally, the mechanical properties of the stainless steel bars after corrosion were compared with those of ordinary steel bars [10].

II. MATERIALS AND METHODS

2.1 Material: The material used for this study is duplex stainless steel grade UNS S31803 tubes. The specimen dimension is 30mm diameter and thickness of 3.4mm as shown in the figure 1. The material composition and mechanical properties are shown in table 1and table 2.

Table 1 Material composition

El	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
%	0.026	1.14	2.17	0.019	0.011	22.08	2.67	4.69	Bal

Table 2 Mechanical properties

PROPERTIES	METRIC
Tensile strength	585 MPa
Yield strength	338 MPa
Hardness	275 HV

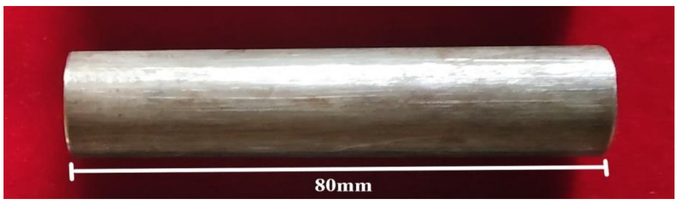

Figure 1 Specimen dimension

2.2 Method:

Design of experiment is used in this study for optimization of welding parameters. Taguchi method of design of experiment is chosen for this study for minimization of experiments. MINITAB software is used to design the experiment. Various trials were performed to fix the levels and ranges of welding parameters as in table 3. And for this study four factors and three levels are fixed. The parameters chosen for this study are heating pressure, upset pressure, heating time and upset time. The rotation speed is kept constant as 1400rpm. Figure 2 shows the friction welding equipment used in this study.

Table 3: Factors and levels

Factors and Levels	1	2	3
Heating pressure Hp, MPa	1000	1100	1200
Upset pressure Up, MPa	1000	1100	1200
Heating Time, H_t ,s	20	22	24
Upset Time, U_t ,s	2	3	4

Figure 2 Friction welding machine

Table 4: Design matrix

Ex N0	Heating pressure Hp, MPa	Upset pressure Up, MPa	Heating Time, H_t , s	Upset Time, U_t , s
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

As per design of experiment the welding parameters are designed and design matrix is shown in table 4. And the welding parameters are to be welded are shown in table 5. The specimens are welded with respect to the parameters as shown in figure 3 and the fabrication of tube joints are performed for 9 sets of parameters. The burn-off length for the welded samples are observed and shown in table 6. The burn-off length of about 10mm is found to be higher and it shows that the joints are sound weld.

Table 5: Welding parameters

Exp no.	Heating pressure Hp, MPa	Upset pressure Up, MPa	Heating Time, H_t , s	Upset Time, U_t , s
1	1000	1000	20	2
2	1000	1100	22	3
3	1000	1200	24	4
4	1100	1000	22	4
5	1100	1100	24	2
6	1100	1200	20	3
7	1200	1000	24	3
8	1200	1100	20	4
9	1200	1200	22	2

Figure 3 Typical flash showing burn-off length

Figure 4 Weld joints

III. RESULTS AND DISCUSSION

3.1 Tensile test:

Tensile test were done for all the sets as per standard and the values are shown in table 7. From the tensile values it is found that experiment no.6 has highest strength of about 612 MPa this is due to effect of high upset pressure & upset time. Experiment no.7 has the least value of about 386 MPa because of lesser upset pressure.

Table 7: Tensile strength

Exp. No.	Heating pressure Hp, MPa	Upset pressure Up, MPa	Heating Time, Ht, s	Upset Time, Ut, s	Ultimate tensile strength, MPa (Experimental)	Ultimate tensile strength, MPa (calculated)
1	1000	1000	20	2	433	407
2	1000	1100	22	3	440	480
3	1000	1200	24	4	447	421
4	1100	1000	22	4	418	457
5	1100	1100	24	2	409	416
6	1100	1200	20	3	612	586
7	1200	1000	24	3	386	350
8	1200	1100	20	4	590	587
9	1200	1200	22	2	581	610

Table 8: ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	62500.5	15625.1	8.43	0.031
Hp	1	9520.2	9520.2	5.14	0.086
Up	1	27068.2	27068.2	14.60	0.019
Ut	1	170.7	170.7	0.09	0.777
Ht	1	25741.5	25741.5	13.89	0.020
Error	4	7415.5	1853.9		
Total	8	69916.0			

A regression equation (1) is developed and adequacy checking is done for tensile strength. Figure 5 shows the comparison of experimental values and calculated value for tensile strength.

$$TS = -1420 + 0.398\,Hp + 0.672\,Up + 2.67\,Ut - 32.75\,Ht \quad \text{---------------- (1)}$$

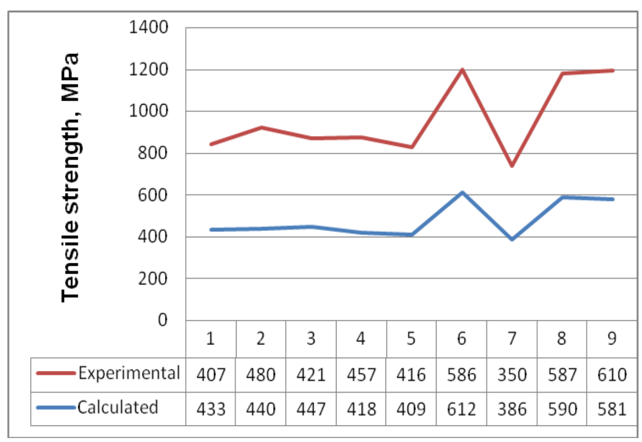

Figure 5 Comparison of tensile values

From table 8 it is observed that P values are calculated for all factors and found that Up and Uthas least value of p which is less than 0.05. So upset pressure and upset time is the most affecting parameter compared to other factors.

3.2 Microstructural analysis:

The microstructure analysis is done to reveal the distinctive zones like weld zone (WZ), parent metal zone (PM) and partially deformed zone (PDZ). The figure 6(a,b) shows the macrographs and figure 7 shows the microstructure for three samples, joint with high strength [exp. No. 6], joint with lowest strength [exp. No. 7] and optimized parameter. In figure 7a&b shows that grains are coarser at PDZ and finer at weld zones due to the effect of upset pressure. The figure 7c&d shows finer at both PDZ and WZ this is due to low upset pressure.

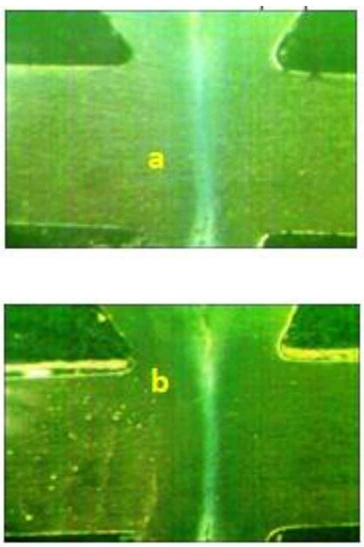

Figure 6 Macrographs

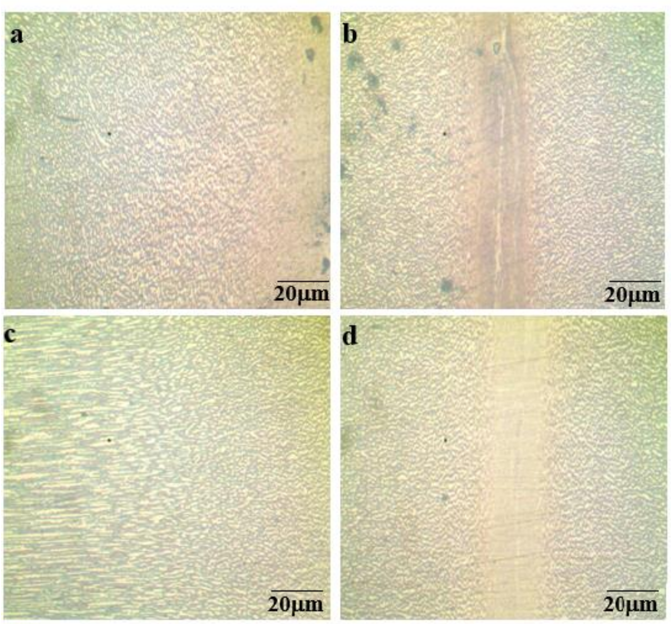

Figure 7 Microstructure analysis

(a-b) Joint with high strength [exp. No. 6], (c-d) Joint with lowest strength [exp. No. 7]

3.3 Corrosion behaviour:

The samples are subjected to corrosion test as per standard ASTM G-48 Method A. both samples are tested for pitting corrosion and intergranular corrosion. During the pitting corrosion all the machined surfaces of the specimen were ground finished Using 1200 grit paper and 100gm of Reagent Grade Ferric Chloride ($FeCl_3.6H_2O$) in 900 ml of Reagent Water (6% $FeCl_3$ by Wt) are added as test solution. In the observation it was observed that No Pitting observed on all surfaces as in the figure 8. Figure 9 shows the unaffected area by the intergranular corrosion.

Figure 8 Macrograph of pitting corrosion tested joint

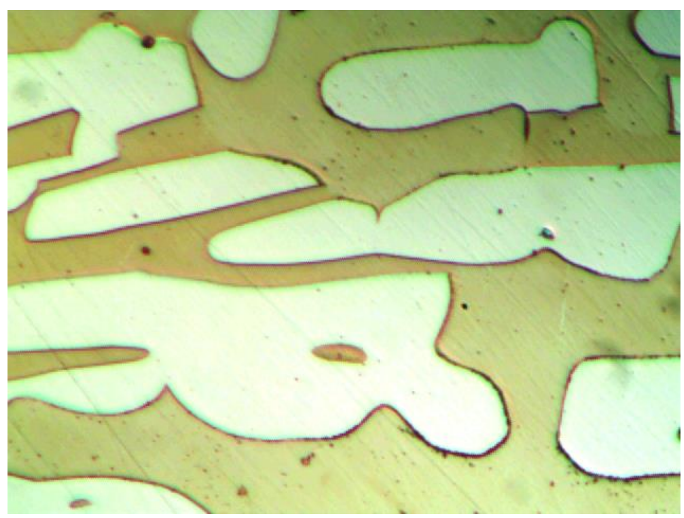

Figure 9 Unaffected area of the joint

IV. CONCLUSION

- The friction welding of duplex stainless steel tubes are welded successfully using design of experiment.
- The tensile strength value is found to be high of 612 MPa for Hp-1100, Up-1200, Ht- 20, and Ut-3.

- The ANOVA results show that upset pressure is found to be effective parameter than other parameters.
- The macrographs showed three distinctive zones WZ, PDZ, PM without any defects.
- The Microstructural analysis showed coarser at PDZ and finer for WZ due to the effect of upset pressure.
- The corrosion studies reveal that joints were not corroded due to the joint optimization. Both pitting and intergranular corrosion are not observed.

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