International Symposium of Research Students on Materials Science and Engineering
December 20-22, 2004, Chennai, India
Department of Metallurgical and Materials Engineering Indian Institute of Technology, Madras

FRICTION WELDING OF AUSTENITIC STAINLESS STEEL AND OPTIMIZATION OF WELD QUALITY

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ABSTRACT

In friction welding, the joints are formed in the solid state by utilizing the heat generated by friction. The objectives of this study are obtaining friction weldment of austenitic stainless steel(AISI 304) and optimizing the friction welding parameters in order to establish the weld-quality. Similar austenitic stainless specimens were joined using the laboratory model friction welding machine. The processed joints were tested for their microstructure and strength related aspects. Acoustic emission emanated by the joints during tensile testing was acquired to assess the quality of the joints. Also a method to decide near optimal settings of the process parameters using Genetic Algorithm is proposed.

Keywords: Friction Welding, Tensile Strength, Optimization, Genetic Algorithm (GA).

1. INTRODUCTION

Stainless steel is an alloy, which is iron based and contains various combinations of other elements to give its characteristics suitable for a wide range of applications, in the areas such as chemical, petrochemical, food processing, pharmaceutical, cryogenic, heat exchangers and beverage sectors. Suitable welding techniques have to be developed to exploit the advantages of stainless steel. Friction welding is a solid state joining process that produces coalescence by harnessing the heat developed through controlled rubbing of faying surfaces. Due to the generated heat, the material reaches the softened state, at which the plasticized material begins to form layers that intervene with one another and results in good quality weld. Many researchers have investigated the effects of friction welding parameters on the quality of steel joints [1-4], and optimization of parameters using conventional techniques [5-8].However the literature on friction welding of similar stainless steel is scarce. Application of non conventional algorithms to optimize the parameters of welding is a novel idea. Kim.D.[9]used genetic algorithm to optimize the parameters of Gas Metal Arc welding(GMAW)process in order to obtain the desired weld bead geometry. In this present study, similar joints of austenitic stainless steel were processed. Through experiments, the optimal settings of the welding process parameters can be found. The input variables that control the joints are Heating Pressure(HP), Heating Time(HT), Upsetting Pressure(UP) and Upsetting Time(UT). The output variable is Tensile Strength. A generalized objective function was established using regression analysis for the process model.

2. EXPERIMENTAL DETAILS

A continuous drive friction-welding machine with a maximum 150 KN load was used for welding. Austenitic stainless steel (AISI 304) specimens of size 16 mm diameters and length

130 mm length were used as parent materials in this study. The base material composition is presented in Table.1. The friction and forge pressures in the range of 15-25bar and 35-45 bar respectively as presented in Table.2. The spindle rotating speed was kept constant at 1125rpm and the welding was performed under the specified friction upset distance. Similar austenitic stainless steel specimens were joined by friction welding process without any preheat. The welded joints were analyzed for their micro structural aspects through optical microscopy. The mechanical characteristics of friction welds were evaluated from tensile properties (at room temperature) measured by using a universal testing machine. During testing, acoustic emission signals emanated from the joints were acquired using Acoustic Emission set up (AET5500).The fractured surfaces were analyzed by scanning electron microscopy. We conducted micro Vickers hardness test on the welded specimen. The data were observed from the base metal-weld metal- base metal with a distance of 1mm. Theoretical optimization was carried out in order to maximize the tensile strength of the joint by genetic algorithm. The objective function was formulated by regression analysis method. The process was considered here as multi-input and single output system. The theoretical variation in tensile strength with friction time was predicted and it is validated experimentally.

3. FORMULATION OF OBJECTIVE FUNCTION and CONSTRAINTS

Regression analysis is applied to obtain an objective function in terms of predictor variables. In our problem we conducted 14 experiments in a random manner and tensile strength (T_o) was calculated for each set of data. Here T_o is the response obtained from four input parameters such as HP, HT, UP and UT. The objective function of this study is

T_O=0.4774*HP-12.0787*HT-0.5995*UP-1.2140*UT+658.1135 -------------(1)

The practical constraints imposed during the welding operations are stated as follows.
Bounds on Heating Pressure

$$HP_L \le HP \le HP_U \quad \text{--} (2)$$

where HP_L and HP_U are the lower and upper bounds of Heating Pressure respectively.
Bounds on Heating Time

$$HT_L \le HT \le HT_U \quad \text{--} (3)$$

where HT_L and HT_U are the lower and upper bounds of Heating Time respectively.
Bounds on Upsetting Pressure

$$UP_L \le UP \le UP_U \quad \text{--} (4)$$

where UP_L and UP_U are the lower and upper bounds of Upsetting Pressure respectively.
Bounds on Upsetting Time

$$UT_L \le UT \le UT_U \quad \text{--} (5)$$

where UT_L and UT_U are the lower and upper bounds of Upsetting Time respectively.

4. RESULTS AND DISCUSSION

Typical macrograph of the friction welded specimen is presented in Figure 1. Friction welding experiments were conducted with random choice of parameters. Microstructural aspects of good joints were analyzed by optical microscope. Typical micrographs of the friction joints are presented in Figure 2. The joint microstructure is classified into three distinct regions namely region I,II, and III. Region I can be termed as fully plastically deformed region. It can be observed on either side of the weld interface. This region contains small recrystallized grains. At region II, grains are partly deformed by the upset pressure. The grains are observed to be larger than region I. Undeformed base material microstructure is observed at region III. The processed joints were subjected to tensile testing to evaluate the strength related aspects of them. Typical tensile tested sample is presented in Figure 3. Figure 4 presents a macrograph view of fractured surface. By observing the fractured surface, it can be understood that the joints rupture mostly at the joint zone and partly through the parent material. Figure 5 shows the Scanning Electron Micrographs (SEM) of the fractured surface of the tensile tested specimen. From these micrographs, it can be understood that the joints had experienced a ductile mode of fracture, with the shear flow of material.

To determine the hardness across the weld zone, samples were prepared by milling a flat surface through the middle of the weld and the second surface was milled parallel to the first surface. Micro Vickers hardness was conducted on the prepared specimens by applying a load of 500 grams. The hardness values of the parent material and weld zone were tabulated in Table 3. The variation of micro hardness values across the welded joint is shown in Figure 6. This Figure shows the distribution of micro hardness in friction welded samples produced with friction time 3, 5 and 8 seconds. Micro hardness in Region-I was about 235,248 and 260 HV which is higher than the base material. The increase in hardness at the joint zone is attributed to the refinement of grains owing to heating of material at the weld region. This result shows that, the hardness increases with increase in friction time for all the specimens considered.

The proposed optimization problem is solved using Genetic Algorithm and the optimal maximum value for the tensile strength is obtained. The welding process parameters formed by the binary strings as much as population size, have been generated and then mapped into the search range. An efficient C program is generated which takes the parameters range as input and makes a number of iterations for optimality. Based on the above conditions, each iteration performs the four main steps of Genetic Algorithm: Decoding, Reproduction, Crossover, and Mutation. While executing the program, at each time the maximum tensile strength value and its corresponding parameters get updated. The program has been prepared to perform 5,000 iterations. The tensile strength values have been found to increase with the number of iterations, to a certain value and after the 145th iteration it starts to decrease. There is again no increase in tensile strength for a wide range. Table 4 presents the variation of experimental tensile strength and the predicted tensile strength values of the joints by GA, with the change in friction time. The percentage error between experimental values and predicted values is also presented in the same table. The relationship between the tensile strength and friction time is shown in Figure 7. This result shows that, the tensile strength decreases with increasing friction time for all the specimens considered. From Figure 8, the potential of GA technique for optimizing the welding parameters in order to maximize the tensile strength is realized. The predicted values of tensile strength by GA closely agree with the experimental values. By doing so, the maximum value for tensile strength is found as 608.551392 MPa and its corresponding optimized parameters are: Heating pressure 23.6666 bar, Heating Time3.0000 sec, upsetting pressure 5.03000 bars, upsetting time3.0000 sec.

During tensile testing, in addition to observing the mechanical strength related properties of joints, in-situ monitoring of emanated acoustic emission also was carried out. Acoustic Emission monitoring during the process of welding was carried out by many researchers [10-12]. Acoustic emission occurs as a release of a series of short impulsive energy packets. The energy thus released travels as a wave front and can be picked up from the surface using highly sensitive transducers. The picked up energy is converted into electrical signal and processed.

The joints when subjected to tensile loading emanate the acoustic emission. The emanated acoustic emission signals due to micro and macroscopic activities of joints during loading were acquired using the suitably integrated AE sensor and system. During tensile testing, for each 500 kg load, AE emanated were acquired. Typical AE power spectrums are presented in Figure 9. The AE spectrum is analyzed for its frequency & rms value. The variation of rms and frequency with load are presented in Figure 10. The dominant characteristic frequency for this combination of material and loading system is found to be around 80 KHZ. From the variation of rms value, it can be observed that, around 1000Kg load, burst signal emanated. The continuous increase in rms value confirms the continuous mode of fracture.

5. CONCLUSIONS

(i) The microstructure of the friction welded AISI 304 stainless steel joints was classified into three distinct regions, namely the recrystallization zone (Region I) adjacent to the bonding interface, the region (Region II) where the grains partly deformed and grown, and the undeformed base material microstructure (Region III).

(ii) The tensile tests showed that the friction processed joints exhibited comparable strength with the base material and joint strength decreased with an increase in the friction time.

(iii) Fractured surface exhibits ductile mode of fracture with shear flow and small dimples.

(iv) The micro vicker's hardness increases with increasing friction time. The increase in hardness at the joint zone is attributed to the heating of material at the weld region.

(v) Genetic Algorithm has been found useful in reducing the number of trials necessary to optimize conditions for friction welding of similar materials (AISI 304-austenitic stainless steel) combination.

(vi) This paper describes an intelligent modeling i.e. optimization and classification of weld quality in the Friction Welding process. The objective function is formulated by regression analysis. Genetic Algorithm is then applied to the objective function for optimizing the process parameters.

(vii) Trials under optimum welding conditions resulted in good joint strengths, which were in fair agreement with the predicted results. The minimum difference observed between theoretical and the experimental values confirm the applicability of GA for the friction welding process.

(viii) In-situ monitoring of acoustic emission during tensile testing is useful in predicting the fracture mechanism of the joint.

REFERENCES

1. Dunkerton S B, *Toughness properties of Friction weld in steels, W*elding Journal (1986) 193_S .
2. Insu Woo, Masatoshi Aritoshi and Yaswshi Kikuchi, *Metallurgical and mechanical properties of high nitrogen austenitic stainless steel friction welds*, ISIJ International (2002) 401.
3. Lippold. JC and Odegard BC, *Microstructural evolution during inertia friction welding of austenitic stainless steels*, Welding Journal (1984) 35_S.
4. Mortensen K S, Jensen C G, Conrad L C And Losee F, *Mechanical properties and microstructures of inertia friction welded 416 stainless steel*, Welding Journal (2001) 268_S .
5. Murti K G K, Sundarasan S, *Parameter Optimization in friction Welding of dissimilar materials*, Metal Construction (1983) 331.
6. Kim I S, Son K J, Yang YS and Yaragada P K D V, *Sensitivity analysis for process parameters in GMA welding processes using a factorial design method*, International Journal of Machine Tools & Manufacture (2003) 763.
7. S.C.Juang and Y.S.Tarng *Process Parameter selection for optimizing the weld pool geometry in the Tungsten inert gas welding of stainless steel,* Journal of Materials Processing Technology (2002) 33.
8. Gunaraj V and Murugan N, *Application of response surface methodology for predicting weld bead quality in Submerged arc welding of pipes,* Journal a Materials Processing Technology (1999) 266.

9. Kim D and hee S R, *Optimization of Arc welding process parameters using a Genetic Algorithm*, Welding Journal (2001) 184-s.
10. Wang K K,Reif G R and Oh S K, *In-process quality detection of friction welds using acoustic emission technique*, Welding Journal(1982)312-s.
11. Sala A,Tonolini F and Villa G, *Monitoring of acoustic emission during the welding process*, Welding International(1987)655.
12. Chem C M and Kovacevic R, *Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding*, International journal of Machine Tools & Manufacture(2004)1205.

FIGURES

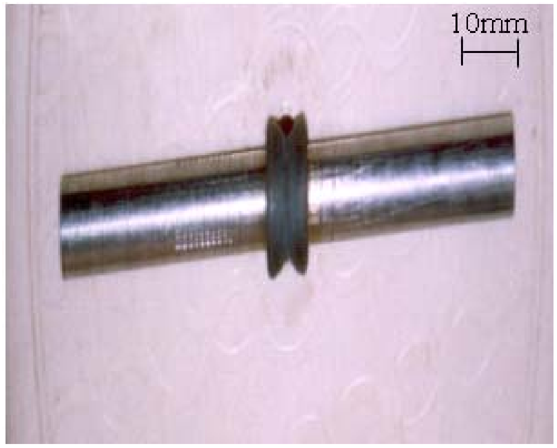
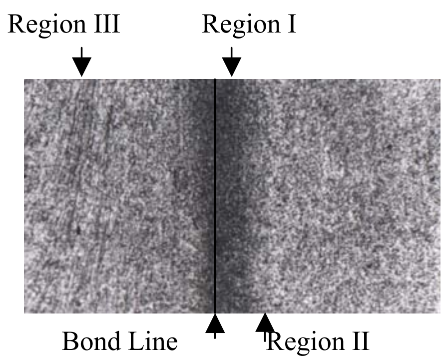
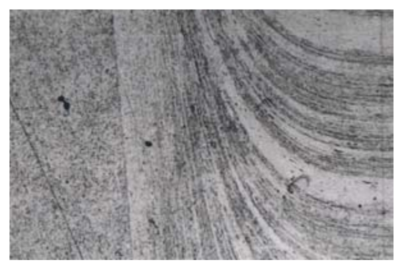


Figure 1. Friction welded sample





(a) Low magnification of friction weld (50X) (b) High magnification of region I(100X)

(c) High magnification of region II (100X) (d)High magnification region III(100X)

Figure 2. Optical Microstructures of friction joint of stainless steel (AISI 304)

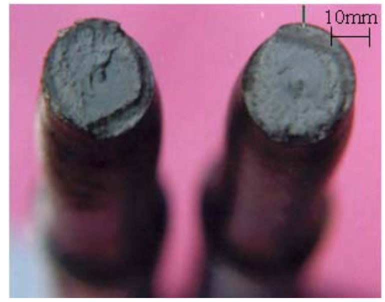


Figure 3. Tensile tested sample

Figure 4. Fracture surface of the friction welded tensile sample.

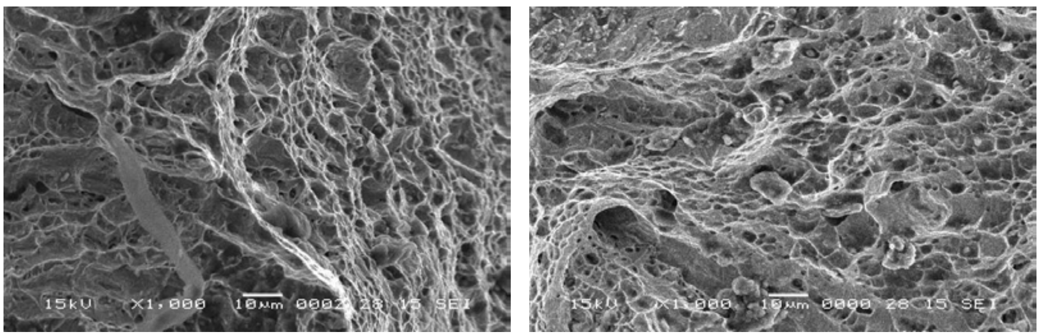


Figure 5. SEM Photograph of the fracture surface for Tensile Test Specimen (1000 X).

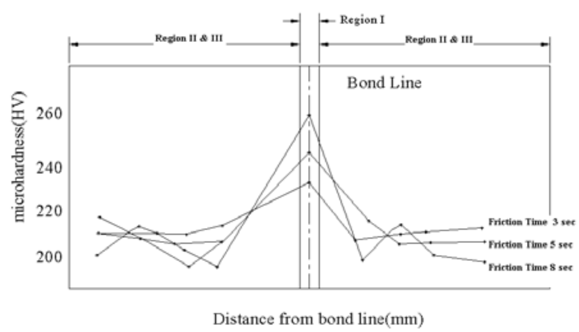


Figure 6. Distribution of micro hardness of friction welded stainless steel joints.

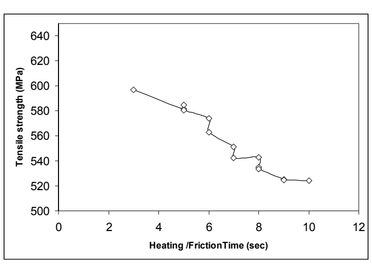


Figure. 7. Effect of Friction Time on the experimental Tensile Strength of Friction welded joints

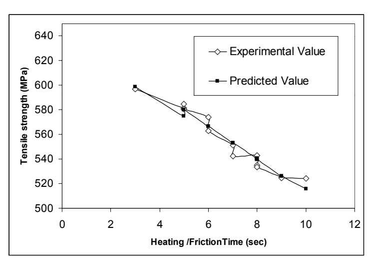


Figure 8. Experimental and Predicted Tensile Strength variation with Friction time.

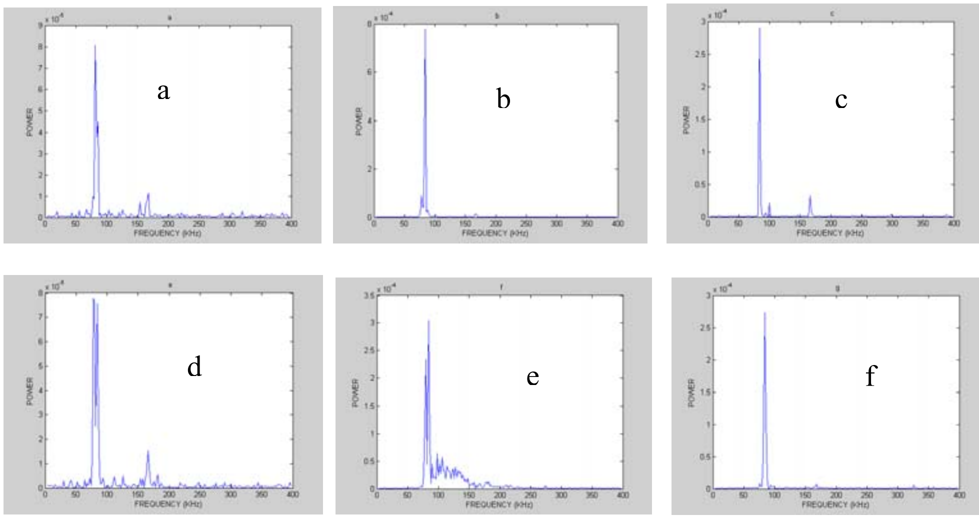
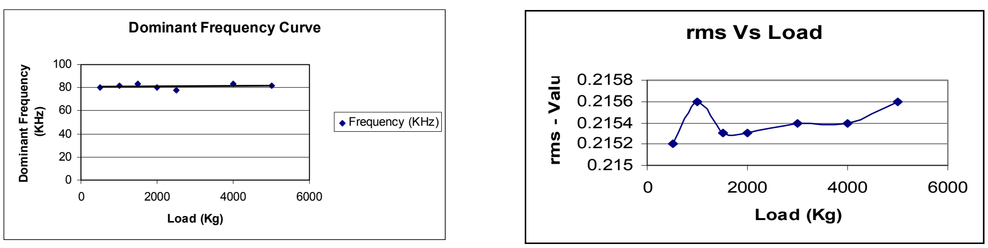


Figure 9 Typical AE power spectrum (a = at 500 Kg, b = at 1000Kg, c = at 1500 Kg, d= at 2500 Kg, e= 4000 Kg and f = at 5000 Kg)



(a) (b)

Figure 10 AE characteristics (a) Variation of Dominant Frequency (b) Variation of rms value

TABLES

TABLE 1: BASE MATERIAL CHEMICAL COMPOSITION

Element	C	Si	Mn	P	Cr	Ni	Co	Mo	As	Pb	Ti	Fe
%	.0468	.3446	1.313	.0182	17.87	8.289	.0785	.010	.0152	.0007	.0355	Balance

TABLE 2 INPUT VARIABLE RANGE

Sl. No.	Input Variable	Range
1	Heating Pressure	15-25 bar
2	Heating Time	3-10 sec,
3	Upsetting Pressure	35-45bar
4	Upsetting Time	3-7sec.

TABLE 3: MICRO HARDNESS TEST RESULTS

Friction Time (sec)	Distance From The Bond line (HV) Region III 1	2	3	4	Region II 1	2	3	4	Hardness for Weld Metal (HV) Region I
3	208	207	206	204	203	205	207	208	235
5	202	200	204	208	206	204	203	202	248
8	200	208	205	202	200	207	205	202	260

TABLE 4 COMPARITIVE TENSILE TEST RESULTS AND PERCENTAGE OF ERROR

Sl.No.	Friction / Heating Time(sec)	Experimental Tensile Strength (MPa)	Predicted Tensile Strength (MPa)	Error (%)
1.	3	596.7	598.9884	0.38
2.	5	581.3	574.7900	-1.12
3.	5	585.0	580.2565	-0.81
4.	5	580.7	580.1344	-0.10
5.	6	574.0	566.7196	-1.27
6.	6	562.7	566.5975	0.09
7.	7	551.3	553.1827	0.34
8.	7	542.3	553.0606	2.04
9.	8	542.7	540.4124	-0.42
10.	8	535.0	539.6458	0.87
11.	8	533.7	539.5237	1.09
12.	9	525.0	526.1089	0.21
13.	9	524.8	525.9868	0.23
14.	10	524.0	515.7860	-1.95