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The Influence of Friction Phase Parameters on the Joint Strength of High Speed Steel Welded to Medium Carbon Steel

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Abstract Friction Welding is a solid state bonding in which heat is generated by conversion of mechanical energy into thermal energy at the interface of the work pieces during rotation under pressure. Friction welding of high speed to carbon steels was carried out by many researchers and they couldn't reach 100% joint efficiency due to welding defects. This research is aimed at studying the influence of the friction phase parameters on the joint strength of the joint of samples consisting of high speed steel and medium carbon steel, welded by friction welding process. The parameters under question are: rotational speed, friction time and friction pressure. The forging pressure was fixed at 187 MPa and the forging time was fixed to15 seconds. The experiments were designed for the three parameters at three levels by Taguchi L_{27} array method with three replications. 81 samples were welded, heat treated and subjected to tensile tests. The results were analyzed for mean and S/N ratio in order to study the influence of the parameters on the joint strength, using Minitab 16.1 software. Results show that: time has significant effect and pressure comes next. Speeds have no significant effect. The maximum joint efficiency was found to be 83%.

Keywords Friction phase parameters, Joint efficiency, Taguchi L_{27} array method, Minitab 16.1 software, S/N ratio

1. Introduction

In the continuous drive friction welding process, investigated in this research, one of the parts that are to be welded is rotated at constant speed, while the other is pushed toward the rotated part by a sliding action. The components are brought together under axial friction pressure for a predetermined friction time. Then, the drive is closed, and the rotating part is seized while the axial pressure being increased to a higher upsetting pressure for a predetermined time. Various researchers carried out different studies about friction welding. In 1971, Jenning and Lucas investigated the properties of the dissimilar materials welded by friction welding and the process parameters on friction welding method [3, 4]. Friction welding of high speed to carbon steels was carried out by many researchers and they couldn't reach 100% joint due to welding defects. The main types of defects in the friction welded joints are considered due to the so-called shiny rings (carbides accumulations) on the side of the high–speed steel and a ferritic (complete decarburization) interlayer on the side of the structural steel .In 1970. Vill' V I et al , examined the defects of the type of shiny rings and is due to the deposition of the high-speed steel on the structural steel in the form of a layer at the initial moment of the process. [5]. In1977 A. N. Popandopulo and G. D. Tkachevskaya studied the nature of shiny rings. They concluded that the shiny non-fusion rings consist of high-carbon martensite, a large amount of retained austenite and dispersed carbides mainly vanadium carbides. [6]. In 1989 O. N. Tanicheva, N. E. Orlova, and L. A. Kyun studied the nature of the defect "bright ring" and the ways of eliminating it. They concluded that the defect "bright ring" in fracture is not due to incomplete fusion, as has been commonly assumed. Bright rings are due to overheating of high speed steel to temperatures causing the formation of eutectic melts at places where carbides accumulate (carbide lines). [7]. In 1990 I. O. Khazanov and N. I. Fomin, their work was to determine the mechanism of formation of carbide films and to work out regimes of friction welding that eliminate the possibility of bright rings forming in the welded joint of the semi products of high-speed and structural steels, and of the zone of complete decarburization forming in the structural steel. They concluded that Carbide films forming in welded joints and manifesting themselves in the form of "bright rings" are secondary structures originating as a result of internal restructuring of the surface layers of the friction pair. Friction welding of blanks of steels

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R6M5 and 45 with the use of the effect of superplasticity of high-speed steel eliminates the formation of bright rings at the contact of the welded joints and of a zone of complete decarburization in the structural steel [8]. Many recommendations on the welding conditions resulting in a decrease the 'shiny rings' in the welded joints have been suggested. The recommendations are: to reduce the frequency of rotation of one of the welded components, to increase the pressure and duration during the heating and forging stages, to carry out heat treatment after welding to dissolve the carbides and immediately after welding to prevent decarburization. The objective of this work is to study, experimentally, the influence of friction phase parameters on the joint strength of samples of high speed steel, friction welded to medium carbon steel.

2. Experimental Work

Friction welding was carried out to joint M2 high speed steel and AISI 1040 medium carbon steel specimens. The experiments were carried out by a lathe machine modified to work as continuous friction welding machine. The axial friction pressure was obtained by the hydraulic attachment. The friction times were set and varied by timers supplied with the electrical and the hydraulic circuits of the machine. Figure (1) shows the main features of the machine. The dimensions of the specimen before welding is shown in figure (2). Friction phase is affected by three factors (parameters): rotational speed, friction pressure and friction time. The three factors were chosen at three levels as shown in Table (1). The design of experiments was based on Taguchi L_{27} array method ,and using Minitab16 .1 Software, the experiment was designed to investigate the effect of friction phase parameters on the joint strength. The experiment was designed with 3 replications.

Table 1. Factors and their levels and values

Factors	Code	Levels			Unit
		1	2	3	
Rotational	X1	1000	1400	20	Rpm
Friction Time	X2	25	35	45	Second
Friction	X3	62.5	87.5	11	M Pa

3. Results

Samples were welded at constant forging pressure of 187 MPa and 15 second forging time .The surface temperatures were measured by an infrared device, and was found to be in the range of (1000 – 1100℃). The samples were tempered and annealed before being tested for strength. A Sample consisting of 27 pieces, was selected from each welded group, then checked for internal welding defects using x-ray techniques. The specimens were, then, loaded in tension up to fracture using a ZAPADPRIBOR tensile testing machine model MP-200, the ultimate tensile strengths were calculated and recorded as shown in Table (2).

Figure 1. The lathe machine modified into a friction welding machine

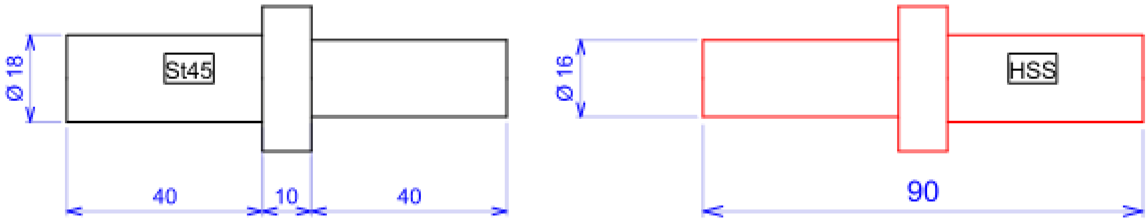

Figure 2. Dimensions of welding sample

Table 2. The matrix of factors and response

	X1	X2	X3	Tensile Strength (MPa)		
				Y1	Y2	Y3
1	1000	25	62.5	338.232	298.44	298.44
2	1000	25	87.5	**109.428***	363.102	**89.532***
3	1000	25	112.5	258.648	258.648	363.102
4	1000	35	62.5	288.492	288.492	258.648
5	1000	35	87.5	258.648	174.09	218.856
6	1000	35	112.5	348.18	353.154	323.31
7	1000	45	62.5	238.752	**139.272***	248.7
8	1000	45	87.5	407.868	**149.22***	437.712
9	1000	45	112.5	397.92	417.816	343.206
10	1400	25	62.5	248.7	298.44	253.674
11	1400	25	87.5	358.128	353.154	313.362
12	1400	25	112.5	**189.012***	-	338.232
13	1400	35	62.5	328.284	397.92	358.128
14	1400	35	87.5	**64.662***	149.22	238.752
15	1400	35	112.5	333.258	397.92	**104.454***
16	1400	45	62.5	363.102	338.232	358.128
17	1400	45	87.5	407.868	492.426	502.374
18	1400	45	112.5	437.712	397.92	432.738
19	2000	25	62.5	189.012	174.09	109.428
20	2000	25	87.5	338.232	353.154	308.388
21	2000	25	112.5	253.674	368.076	293.466
22	2000	35	62.5	248.7	338.232	392.946
23	2000	35	87.5	213.882	**139.272***	338.232
24	2000	35	112.5	382.998	338.232	353.154
25	2000	45	62.5	397.92	378.024	333.258
26	2000	45	87.5	363.102	373.05	437.712
27	2000	45	112.5	348.18	338.232	-

Note: Highlights indicate odd readings, attributed to experimental errors

4. Analysis of Results

The results of the experiments were analysed using the Taguchi method of analysis in order to estimate the contribution of individual factors, and to estimate the response under the optimum conditions. Minitab 16.1 software was used to analyse Taguchi approach for the mean and S/N ratio. The average S/N ratios, the larger-the-better characteristics, were used to maximize the tensile strength (Y) of the joint and the significant interactions. Minitab was also used to study the contribution of each factor on the tensile strength. The results are shown in tables (3), (4), (5), (6), and figure (3).

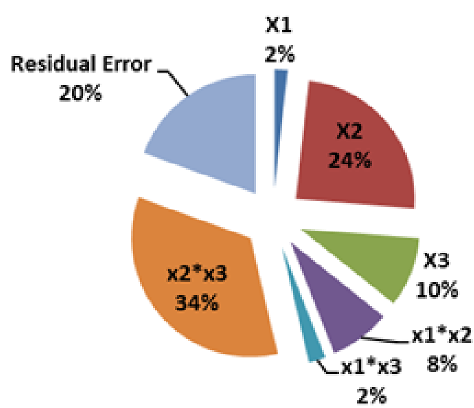

Figure 3. Contributions of the process factors in the joint strength

Table 3. Taguchi analysis results for MEANS and SN ratio

x1	x2	x3	y1	y2	y3	SNRA2	MEAN2
1000	25	62.5	338.232	298.44	298.44	49.83017615	311.704
1000	25	87.5	-	363.102	-	55.97178537	363.102
1000	25	112.5	258.648	258.648	363.102	49.03313757	293.466
1000	35	62.5	288.492	288.492	258.648	48.86296868	278.544
1000	35	87.5	258.648	174.09	218.856	46.39400307	217.198
1000	35	112.5	348.18	353.154	323.31	50.64935893	341.548
1000	45	62.5	238.752	-	248.7	49.49352301	243.726
1000	45	87.5	407.868	-	437.712	54.26717366	422.79
1000	45	112.5	397.92	417.816	343.206	51.64657765	386.314
1400	25	62.5	248.7	298.44	253.674	48.44308002	266.938
1400	25	87.5	358.128	353.154	313.362	50.62168411	341.548
1400	25	112.5	-	-	338.232	55.35550642	338.232
1400	35	62.5	328.284	397.92	358.128	51.08064591	361.444
1400	35	87.5	-	149.22	238.752	46.81565293	193.986
1400	35	112.5	333.258	397.92	-	52.91874398	365.589
1400	45	62.5	363.102	338.232	358.128	50.94691866	353.154
1400	45	87.5	407.868	492.426	502.374	53.27979986	467.556
1400	45	112.5	437.712	397.92	432.738	52.49876253	422.79
2000	25	62.5	189.012	174.09	109.428	43.17261264	157.51
2000	25	87.5	338.232	353.154	308.388	50.4136933	333.258
2000	25	112.5	253.674	368.076	293.466	49.38893774	305.072
2000	35	62.5	248.7	338.232	392.946	49.80394876	326.626
2000	35	87.5	213.882	-	338.232	49.91381946	276.057
2000	35	112.5	382.998	338.232	353.154	51.04641718	358.128
2000	45	62.5	397.92	378.024	333.258	51.28478133	369.734
2000	45	87.5	363.102	373.05	437.712	51.76311654	391.288
2000	45	112.5	348.18	338.232	-	52.46927335	343.206

Table 4. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
x1	2	4.060	2.948	1.474	0.44	0.664
x2	2	44.826	31.328	15.664	4.67	0.060
x3	2	5.250	16.705	8.353	2.49	0.163
x1*x2	4	9.049	13.458	3.364	1.00	0.474
x1*x3	4	7.064	7.682	1.920	0.57	0.694
x2*x3	4	34.696	34.696	8.674	2.58	0.144
Residual Error	6	20.145	20.145	3.357		
Total	24	135.089				

Table 5. Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution
X1	2	5568	2264	132.2	0.37	0.708	2%
X2	2	39443	31379	15689.7	5.07	0.051	24%
X3	2	12309	2201	6100.6	1.97	0.220	10%
x1*x2	4	6630	10643	10643	1.97	1.97	10%
x1*x3	4	1929	2967	741.7	0.24	0.906	2%
x2*x3	4	43923	43923	10980.8	3.55	0.081	34%
Residual Error	6	18553	18553	3092.2			20%
Total	24	128355					100%

Table 6. Response Table for Means

Level	X1	X2	X3
1	317.6	301.2	296.6
2	345.7	302.1	334.1
3	317.9	377.8	350.5
Delta	28.1	76.6	53.9
Rank	3	1	2

5. Discussion

From table (4) result for S/N ratios, shows only the time (X2) (p = 0.06) is significant at a-level of 0.10, because their p-values are less than 0.10. From table (5) result for means, shows the time (X2) (p = 0.051), and the interaction between the time and pressure (X2X3) (p = 0.081), are significant at a-level of 0.10, because their p-values are less than 0.10.

The Percentage Contribution of the Process Parameters of graph of figure (3) shows that the time has the highest contribution (24%), then the pressure (10%) and eventually the speed (2%) on the strength of the joint. The response of table (6) shows the average of the response characteristic for the mean for each level of each factor. For the mean, the ranks indicate that time has the greatest influence; pressure has the next greatest influence, and the speed is last.

6. Conclusions

The following could be concluded:

- Time has significant effect on the strength of the joint, Pressure has next effect on the joint and Speed has less effect
- To maximize the joint strength, the trend is to increase the time and pressure and hold the speed at specific value
- The analysis show that x1 (the speed) has no significant effect on the model
- The optimal value of the joint strength was obtained at the highest value of the time and the pressure and middle value of the speed. This emphasis that the effect of speed is not significant

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