The investigation of optimum welding parameters in connecting high alloyed X53CrMnNiN219 and X45CrSi93 steels by friction welding

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Abstract

In this study, different welding parameters are applied to two different steels with high alloys and mechanical and metallographical investigations were performed. Thus, the optimum welding parameters were investigated for these materials and working conditions. 12.30 diameter steel bars made up of 1.4871 (X53CrMnNiN219) & 1.4718 (X45CrSi93) steel were used as experimental material. The material loss increased with increase in friction and rotating pressure. The highest hardness and fracture energy were obtained in B5 group.

Keywords: Friction Welding, Welding Parameters, Microstructure.

1. INTRODUCTION

Joining has increasingly been used in the material technology because materials having different mechanical properties need to be efficiently joined to increase material's performance. The most suitable method of joiningtwo different alloyed steel is welding(Anık, 1983). After welding process, the properties of welding zone naturally becomedifferent from the properties of alloyed steels andthis difference maycause someproblems.The use melting welding methods, among many kinds of welding methods, has also increased these problems(Yılmaz, 1993). Phase diagrams and properties of joining materials are important factors in determining welding properties (Bargel and Schulze, 1988). Some problems also arise because the materials to be joined are different alloys and some additionalcomponents are needed to effectively join them. Many different zonesappear in connecting zone depending on composition and material properties (Yılmaz, 1993). Deposite remain of the melting welding methods,welding faults of porosity and inside tightens of cooling are the important disadvantages of these methods and they reduce the strength of welding. Therefore,solid statewelding methods are more suitable sincemelting welding faults do not significantly occur there(Tülbentçi and Yılmaz, 1989).

Vill(1962) has conducteda study to determine optimum conditions of friction welding parameters. He has determined that friction pressure coming from welding parameters are of great importance,the cycling number of turning component's sensitivity is the least paramaterand it can be fixed in a wide space depending on the materials used. Moreover,Tyleotehas determined that friction pressure affects the heat of space surface and supplies the required moment.He has also determined that forging pressure and cycling number are the most important parameters (Tylecote, 1968). It can be said that low welding periods have supplied the best welding zone in low carbon steels,which requires applying forging pressure of one second as well as applying high forging pressure (Lucas, 1971). Low welding periods andhigh forging pressure values forma thinner grainular structure for low carbon steels (Duffin and Crossland, 1971).In notch impact test results, better mechanical propertieshave been obtained onhigh cycling numbers between 1200 and 4200 rpm according to other constant parameters (Voinov, 1972). A friction pressure of 30-65 MPa, and a forgingpressure of 75-140 MPamust be applied for low carbon steels and a friction pressure of 70-210 MPaand a forging pressure of 100-420 MPa for medium carbon steels (Welding Handbook, 1980).

In another study, Ishibashi et al. (1993) determined that forging pressure value must be appliedtwice as much as that of friction pressure for stainless steels.Ina study on tool steels, it has been advised that the welding temperature and in turn friction pressure should be high enough so that no faults on welding zones will occur(Tanicheva, et al., 1989). Initally, conventional arc welding and then solid state joining methods were applied on welding processes of stainless steels (Gooch et al., 1996). Today, friction welding is one of the solid state joining techniques used widely for stainless steels. Bol'shokov et al.(1972) reported that friction welding on vacuum condition improved mechanical properties of joined materials.

With the technological development in the valve manufacturing industry, the exhaust valves of normal and diesel engines are manufactured from two different types of steels. The "handling" parts of exhaust valves are manufactured from 1.4718 (X45CrSi93) steel which is tough, ductile and resistant against wearing due to friction while the "head "parts are manufactured from 1.4871 (X53CrMnNiN219) steel which shows a very good resistance against oxidation, and hot corrosion caused by lead oxide and other burning products. Today, this steel couple is joined by friction welding(Uzkut, 1999). Friction welding is one of the methods which have some considerable share among the other conventional welding methods. The most important parameters in friction welding are friction time, friction pressure, forging time, forging pressure and rotational speed (Uzkut, 1999; Şahin and Akata, 2003).

Welding faults in the valve manufacturingmay occur due to thermal and mechanical stresses. Therefore, optimizing welding parameters are essential. The determination of optimum welding parameters and joining zones will minimize these faults on welded parts (Uzkut, 1999). In this study, optimum welding parameters of high alloyed X53CrMnNiN219 and X45CrSi93 steels used in automotive industry were determined by joining friction welding and by doing tensile, notch impact, metallography and microhardness tests.

2. EXPERIMENTAL STUDIES

X53CrMnNiN219 (1.4871) and X45CrSi93 (1.4718) high alloyed steels were used in the experiments. Standards of materials are shown in Table 1,chemical composition of materials in Table 2-3,standard measurements of welded tensile samples in Table 4, mechanical properties of materials in Table 5.Rotation number (n) and forging time (t2) werekept constant and friction time (t1), friction pressure (P1), and forging pressure (P2) had different levels. Constant parameters and values for 12.3 mm diameter were determined as follows:

Constant parameters and values are as follows: experimental bar diameter is12.3 mm (H9), during welding process,rotation number of spining parts is 3000 rpm, during machining process,rotation number of spining parts is 1500 rpm, friction contact time is 0.4 s, brake delaying time is 0.1 s, forging delaying time is 0.8 s, forging time is 2 s, friction pressure rising time is 1 s, forging pressure rising timeis 1 s, and waiting time at the end of forging time is 1 s. The levels of studied parameters were as follows: friction time (2.70, 3.70, or 4.70 s), friction pressure (138, 207, or 276), and forging pressure (345, 414, or 480 MPa).The specimens subjected to friction pressureof 138 MPa is called group A, and friction pressure of 207 MPa group B, and friction pressure of 276 MPa group C.

Tensile test, one of mechanical tests, was carried on by 5 tone capacity universal 1114 model, INSTRON type depending on TS-138 (Turkish Standard). Tensile velocity was taken as 1 mm/min at tensile test. Notch impact test was carried on at 25 0C depending on TS-269. Notch was opened on welding line as standart. Some suitable standart measurements were applied on specimen.

1.4871 materials were etched for 10 s and 1.4718 materials at 3 s by 5 % nital on optical tests. These tests were carried on in CARL ZEISS JENA type optical microscope atDokuzEylül University laboratories (Izmir, Turkey). A 1360 pyramide point Vickers type was used for microhardness tests. Microhardness tests were carriedout at distance of 10 μm to welding and parallel to welding cross-section on this study 80 g load was used for these tests; however, a load from 25 g to 100 gcould be applied on microhardness tester. Microhardness tests were carried out in CARL ZEISS JENA type microhardness tester at DokuzEylül University labaratories. SEM tests were carried out on by using JEOL JXA-733 type at DokuzEylül University laboratories (Izmir, Turkey).

Table 1. Standards of materials.

Material	X53CrMnNiN	1,4871	Z52CMN21-	~349S52	X53CrMnNiN219
	X45CrSi93	1,4718	Z45CSİ10	~401S45	X45CrSi8

Table 2. Chemical composition of 1.4871 material.

Material	Chemical composition (% wt)							
	C	Si	Mn	Cr	Ni	N	P	S
1.4871(theor	0.48-	≤	7-	20 -	3.25 -	0.38 -	Max.	Max.
1.4871	0.50	0.27	8.1	20.11	3.90	0.4	0.025	0.001

Table 3. Chemical composition of 1.4718 material.

Material	Chemical composition (% wt)					
	C	Si	Mn	Cr	P	S
1.4718	0.40 - 0.50	2.70 -	≤ 0.80	8 - 10	Max.	Max. 0.030
1.4718	0.42	2.73	0.47	8.71	0.017	0.001

Table 4. Standard measurements of welded tensile samples.

d_0 (mm)	d_1 (mm)	h (mm)		$(l = 10 d)$	
			l_0 (mm)	l_v (mm)	l_t (mm)
6	8	25	60	66	125

Table 5. Mechanical properties of 1.4871 and 1.4718 materials.

Material	Diameter	Length	Circularry (mm)	Surface Roughness	Hardness	Tensile Strength
1.4871 (standard)	12.258-12.300	3.5-4.0	Max. 0.03	Max. 0.8	Max. 40	950-1250

1.4871 (test)	12.280- 12.290	4.0	0.005- 0.02	0.3-0.8	37-40	1120
1.4718 (standard)	12.258- 12.300	3.5- 4.0	Max. 0.03	Max. 0.8	29-35	950-1125
1.4718 (test)	12.280-	4.0	0.005-	0.6-0.8	29-32	1030

3. RESULTS AND DISCUSSION

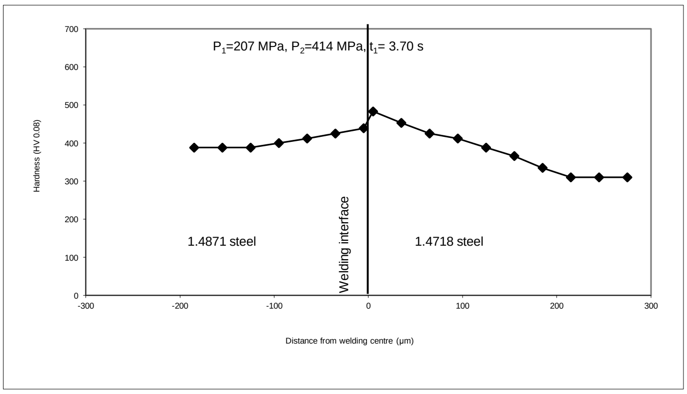
3. 1. Mechanical Properties

When tensile tests results were examined, mechanical properties of group B were betterthan those of group A or C. The basicrepresentative property of groupB is that friction pressure is 207 MPa. Break out did not occurin welding zone on B4, B5, and B6. Common determining characteristic of this group is that friction pressure (P1) and forging pressure (P2)values were takenconstant whereas friction time is variable on these groups. Yield and tensile strength were similar. As a result, it can be seen that friction time is a determining parameter among these three groups. In determining optimum welding parameters,breaking point in tensile bar, the suitability of post-tensioning yield and tensile strength values for acceptable values of materials and percentage of extent quantity havesignificance.Fractures in 1.4871 materialoccurred out of welding zone in group B5. Yield strength was 854 MPa, tensile strength value was1081 MPa.

When notch impact tests results are examined,it has been determined the energy quantities spent to break the samples of group B are more than those of the other two groups and the samples of B5 in group B spent the highest energy quantity.

Based on microhardnessresuts,microhardness values did not increase ingroup B5 samples, but microhardness valuessignificantly increased 4 mmaway from centre. The microhardness value was 400 HV in outer cross section for 1.4871 materials,while it was 439 HV in centre. Microhardnesswas 483 HV in the centrewhile it was 439 HV in outer cross section for 1.4718 materials. The cooling was the slowestin the centre of materials. Consequently, element diffusion in materials centretakes much longer time. In addition, movement and mechanical orientationwere alsominimalin the center due to material deformation. Therefore, it is determined that the highest microhardness value is in the center of materials.The variations of microhardness values depending on distant are shown in Fig. 1.The hardnessdistributions were determined by using optical and scanning electron microscope.

Fig.1. Variation of hardness of B5 sample in welding zone.



Length shortening quantities on post welding and effects of parameters on length shortening are explained by graphics depending on parameter groups in Fig. 2. As seen in figures, variation on length shortenings depending on welding parameters is linear. A significant material loss due to burning occurs in 1.4718 materialson friction welding joints. Total material loss reaches the highest values in the parameter groups having the highest friction time. When we regard all these criteria; A9, B3, B5, B6, B8, B9, C4, C7 and C8, parameter groups differ from other groups according to the length shortening quantities. Efficient length shortening quantities can notbe obtained for 2.7 s friction time. By increasing friction pressure and forging pressure values it is determined that there is much more material loss in the groupssubjected to4.7 s friction time. Length shortening quantities could not be obtained at low friction time in group B samples. In the light of these results, group B5 can be considered ideal for length shortening.

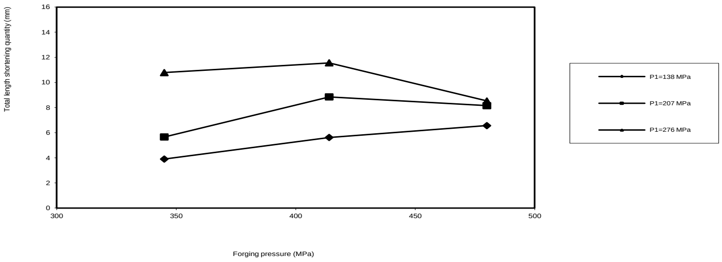


Fig.2. Quantities of total length shortening depending on friction pressure for varry friction time (P2= 414 MPa).

In joining A6061 alloy and SUS304 stainless steel by friction welding, it has been observed that high forging pressures affect the joining strength positively and tensile strength of notched samples increaseswith forging pressure and maximum effectiveness of joining is seen as 87-93 %percent (Ochi etal., 1996).

In another study, energy absorption of normalized welding joining is rather more than a normalized one, and energy transition temperature has been determined at about 24 0C at normalized welding joining. This temperature is harmonious with temperature on fracture surface. Crack proceeding strength of normalized welding joining is higherthan that of a normalized one. Impact bending strength of normalized welding joining is almost the same as hot processed metal (Kato et al., 1996).

Şahin et al.(1996)conducted tensile and microhardness tests, heat and SEM studiesin welding zone to determine heat affected zone (HAZ)metalurgical variations on Al-Al, Al-Steel, and steel-steel using different parameters of friction welding.They reported that welding parameters significantly affected yield, tensile and fracture strength and HAZ zone near the Al was wider on Al-steel joinings. Preperation measures of welding joining must be taken as

1-10 mm per welding joining by considering length shorteningduring surface preperationin welded joints (Anık, 1983).

Ogawa et al.(1993)reported high material lossin friction welding of S45C steel, so it has to be examinedfor its economical impact. In this study, low hardness thin grained ferrite, and pearlite layer occured on HAZ. Slope of hardness distribution on joining zone has been determined to be low at wider space.

Şahin(2005)determined optimum welding parameters as follows: friction time (4 s), friction pressure (110 MPa) and tensile strength (600 MPa) on high-speed steel (HSS-S6) and medium carbon steel (AISI 1040). He determined hardness of welding zone as 700 HV. Şahin(2007) determined that optimum welding parameters as friction time 9 s, friction pressure 60 MPa and tensile strength 800 MPa on stainless steel (AISI 304). He determined hardness of welding zone as 200 HV. In these studies, the tensile strength of the joints increased with the friction time and pressure, and it raised a maximum, but it decreased for more friction time and pressure (Şahin, 2005; Şahin, 2007). Ateş et al. (2003) determined friction time as 6 s, friction pressure 70 MPa, and tensile strength 850 MPa on MA 956 iron-based superalloy. They determined hardness of welding zone as 700 HV. In this study, tensile strength increased with forging pressure and with friction pressure up to a certain value in HAZ.

Özdemir(2005) and Özdemir et al. (2007)determined that hardness of welding zone as about 1000 HV on AISI 304 and AISI 4340 steel.In these studies, for excellent welding parameters "the friction time was held as short as possible, while the rotational speed, friction and forging pressure was chosen as high as possible. Satyanarayana et al.(2005)determined that hardness of welding zone as about 270 HV, and notch tensile strength 690 MPa on AISI 304 and AISI 430 steel.The differences in our results and those of other previous studies may be attributed to the fact that their materials and welding parameters were different from ours.

3. 2. Microstructure Properties

When microstructure results are examined, it has been observed that friction time does not cause any noticeable differences in inner microstructure due to low friction pressure ingroup A samples. Heat affected zone (HAZ) is observed to be thicker ingroup C samples. These zones are seen to be much wider especially in the groups, belonging to the values of increasing forging pressure and friction time. Mechanical orientation and wider HAZ are observed on group C5 and 1.4871 materials. Mechanical orientation of grains is certainly seen from central to outer on grains. Certain microstructure and standart thickness HAZ were observed on group B samples (Fig. 3).

Fig.3. Mechanical orientation and Fe2C carburs of B5 sample in welding central (x45).

When forging pressure resuts are examined; in the inner structure of groups the high forging pressure values from central to outer mechanical orientation in grains, coming out due to deformation during welding is observed (Fig. 3). This orientation is possible for each of thetwo materials. Standart thickness and more obvious HAZ are seen ingroup B samples (Fig. 4).

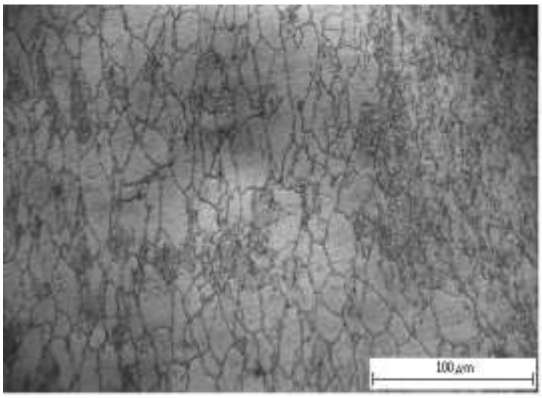


Fig.4. Grain flattening of B5 sample in HAZ of 1.4871 material (x450).

When tensile and notch impact tests results are examined, better mechanical were obtained in group B5 samplesas compared with the other groups. When optical microscope images of group B5 are examined; martensitic microstructure of 1.4718 materials waspresent at a distant zone of welding. Austenitic microstructure of 1.4871 materials is seen at a zone way from welding. Black zones occured in microstructures are Fe2C carburs on austenit grain boundaries and some austenit grains. SEM image of 1.4718 and 1.4871 material microstructure in a zone away from welding was shown as 4000 times magnified in Fig. 24. SEM image of welding interface in two materials was shown as 4000 times magnified in Fig. 5.

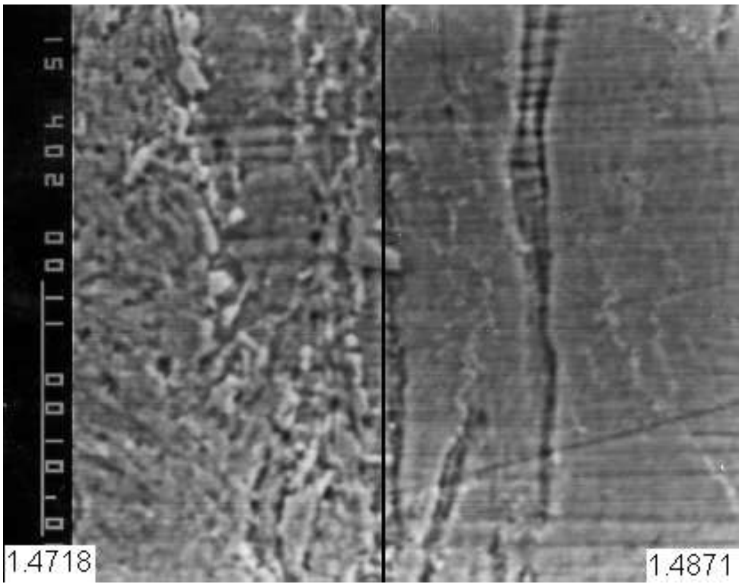


Fig.5. SEM image of welding interface in two materials (x4000).

Şahin(2005; 2007), Ateş et al. (2007), Özdemir(2005) and Özdemir et al. (2007), and Satyanarayana et al. (2005)observed thin grained structure in welding zone, and observed grain orientation in HAZ in medium carbon steels, and stainless steels.Ateş et al. (2007) reported that HAZ and grain orientation in microstructure increased with increasing friction pressure. They reported that HAZ and grain orientation in microstructure decreased with increasing forging pressure. In our study, similar microstructure results were obtained.

4. CONCLUSIONS

In this study, the optimum welding parameters were determined in materials during the connection of X53CrMnNiN219 and X45CrSi93 steels by friction welding.Based on the findings of this research, the following conclusions can be drawn:

1. Efficient length shortening quantities can not be obtained in the samples in which friction time is applied as 2.7 s. It has been determined that there has been more material loss with increased friction pressure and forging pressure in the groups where the highest friction time was 4.7 s. While the ideal length shortening is 7-10 mm, it is 8.85 mm for B5.

2. Break from welding zone is not observed on the samples of group B5 on tensile tests. For tensile properties, B5 parameter group has been determined as an ideal parameter group.

3. The highest fracture energy (toughness) on tensile tests was observed in group B5.

4. Profiles hardness of A group occured on near 1.4871 material of welding zone, and the highest value of hardness of these samples occured near 1.4718 material of welding zone. The slope of hardness profile on group B and C was much higher than that of group A in the welding zone.

5. Carbur formations were clearly observed along direction lines of HAZ and mechanical orientations on group B5 optical micrscope images. Austenitic structure occured on microstructure distant welding zone 1.4718 and martensitic structure occured on 1.4871 material on distant welding zone. Next to welding zone, gain shortening and grain flatness occured as perpendicular deformation in 1.4871 materials.

6. Optimum welding parameters;friction time(t1) was determined as 3.7 s, friction pressure (P1) was determined as 207 MPa, forging pressure (P2) was determined 414 MPa on B5 group and joining by friction welding 1.4871 and 1.4718 materials.

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