Effect of weld time and weld current on the mechanical properties of resistance spot welded IF (DIN EN 10130–1999) steel

F. Hayat[1], B. Demir[1]*, M. Acarer[1], S. Aslanlar[2]

[1] *Materials Division, Metallurgy Education Department, Faculty of Technical Education, Karabük University, 78050, Karabük, Turkey*
[2] *Materials Division, Metallurgy Education Department, Faculty of Technical Education, Sakarya University, 54000, Sakarya, Turkey*

Received 6 November 2007, received in revised form 8 September 2008, accepted 14 October 2008

Abstract

In this study, the effects of weld current and weld time on the tensile peel strength and tensile-shear strength of 7114 grade IF (Interstitial Free) steel sheets joined by spot welding were investigated. Weld processes were performed by using 3, 5, 7, 9 kA weld current and 5, 10, 15, 20, 25, 30 weld cycles. The microstructure of the welded materials was evaluated. The hardness profiles were also determined. Experimental results showed that tensile shear loading bearing capacity and hardness of both weld and heat affected zones increased for increasing weld time and weld current. Weld nugget diameter extended by increasing weld time or/and weld current, so tensile shear load bearing capacity and tensile peel strength increased. Tensile fracture behaviour of the samples was evaluated. Weld lobe was constructed with respect to weld current and time.

Key words: Interstitial Free (IF) steels, welding, mechanical properties

1. Introduction

Resistance spot welding, one of the oldest of the electric welding processes, is the most frequently used joining technique, particularly in the car industry for sheet materials. The Body-in-White is assembled by means of spot welds in use by industry today [1, 2]. Advantages of the spot weld technique are that it is relatively fast, robust and economical. However, to apply spot welds and to fulfil user requirements, parts should be slightly oversized. Because of this, spot weld is expected to be increasingly replaced by laser weld or a combination of joining techniques in the future. This will enable the motor industry to make lighter constructions with improved rigidity and strength [1–4].

Resistance spot weld has evolved into a simple, straightforward manufacturing process. For automotive applications, it is imperative for the material to possess a good spot weldability and this is to a great extent dependent on the plate thickness, morphology of base metal and its mechanical properties [1, 2]. After spot weld, important changes occur in the mechanical and metallurgical properties of the spot welded areas and heat affected zones. The investigation of these changes is very important for the safety strength of the welded joints. The influences of the primary weld parameters affecting the heat input are weld time and weld current. Also they affect weld quality such as surface appearances, weld nugget size, weld penetration and weld internal discontinuities.

Ultra-low carbon IF steel sheet can offer both good formability and adequate strength for auto body panels. These steels combine excellent formability during press forming and an increased strength in the end product due to bake hardening [5–8]. This results in a better dent resistance of exposed automotive panels, which is the main application of these steels. Weld process of IF steel generally used in automotive industry is resistance spot welding [2, 8–13]. However, these modern steels may show many mechanical and metallurgical problems during the weld operations. For example, some certain grades of IF steels show grain growth problem in the HAZ [4, 9] and display

*Corresponding author: tel: +90-370-4338200/1177; fax: +90-370-4338204; e-mail address: bilge.demir@hotmail.com

Table 1. Chemical composition of IF steel sheet material (DIN EN 10130–1999, 7114 ERDEMIR grade) used in this study (wt.%)

C	Cr	Ni	Si	Mn	Mo	Al	Co	Cu	Nb	Ti	S	P	Fe
0.006	0.003	0.036	0.016	0.183	0	0.057	0.006	0.021	0.004	0.065	0.008	0.003	99.39

Table 2. Welding parameters of samples

Effective current (kA)	Holding time (cycle)*	Weld off (cycle)*	Electrode force (bar)	Squeezing time (cycle)*	Weld time (cycle)*	Hold on (cycle)*
3, 5, 7, 9	25	30	6 bar	30	5, 10, 15, 20, 25, 30	25

* cycle = 0.02 s

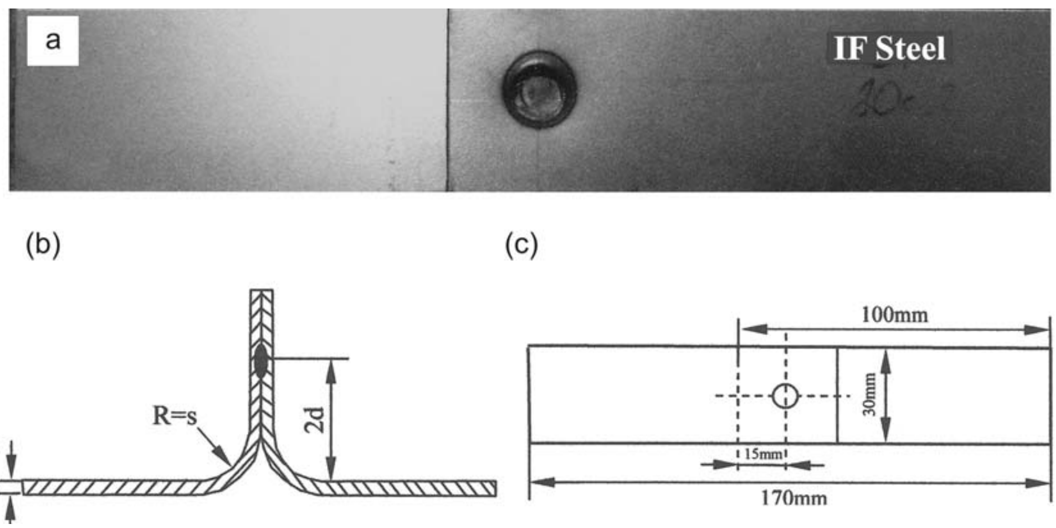

Fig. 1. Technical drawing of welded samples used in (a) tensile shear test, (b) tensile peel test and (c) macrograph of the spot welded samples.

intergranular fracture in that zone. The presence of such zone leads to a decrease in the fatigue resistance of welds by about 20 %. Additionally, impact tensile tests, with a notch localized in the grain growth zone, display fracture surfaces [9]. If it is considered that an ordinary car requires about 3000–4000 spot weld points, this will have a prohibitive effect on the manufacturing price [4]. However, the grain growth is not as big as for TIG and Laser welds [2].

In this study, a detailed work has been made to optimize weld parameters such as weld time and weld current, which determine weld lobe on the resistance spot welding of IF steel. For this aim, 7114 grade IF steel welded with resistance spot welding technique at different weld time and weld current were evaluated by mechanical tests.

2. Experiments

In this study, 7114 grade IF steel sheets were used with chemical composition given in Table 1 (DIN EN 10130–1999). The sheets with 0.85 mm thickness were subjected to spot resistance welding in a Baykal SPP60 installation. This installation is an AC machine for spot welding equipped with a device for pneumatic control of the phase shift of the AC current. The power of the installation is 60 kW. Before joining, the surface of the test pieces was cleaned mechanically and then welded using a conical water-cooled electrode from a Cu-Cr alloy. The diameter of the contact surface of the electrode was 8.0 mm. Welding was conducted for different times (5, 10, 15, 20, 25, 30 cycles) and weld current (3, 5, 7, 9 kA) by the method of linear overlapping (Fig. 1a). The specific force of pressing of the electrode was constant, i.e., $F_{sp} = 6 \times 10^5$ Pa. Parameters used throughout the weld processes and a schematic diagram of the resistance spot weld process are shown in Table 2 and in Fig. 2, respectively.

Transverse metallographic specimens of the IF steel and specimens passing through the central part of the welded pieces were prepared by a standard

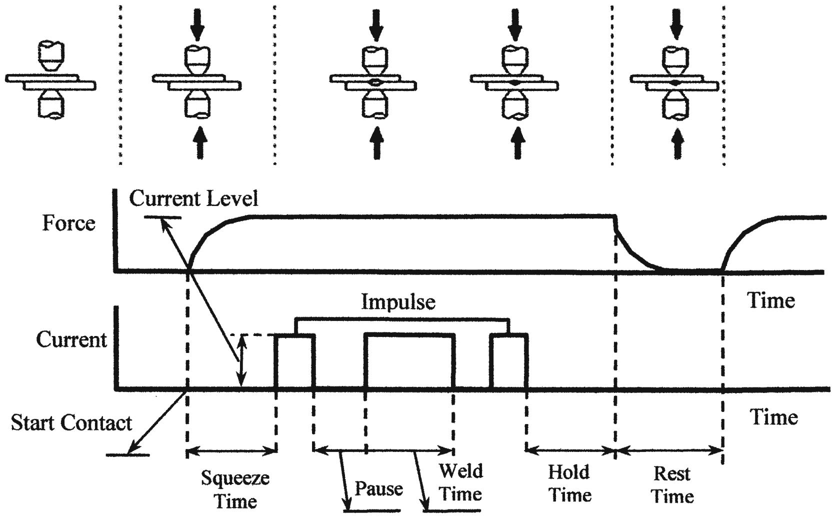

Fig. 2. Schematic diagram of the resistance spot weld process.

method. The microstructure was analysed and the diameter of the spot weld nugget was determined using a Nikon Epiphot 200 light microscope.

The microhardness measurements were carried out using a SHIMADZU type Vickers hardness machine under the 200 g load. On each sample, measurement was made in one direction, which is along the radius of the nugget.

The tensile peel and tensile shear strengths of the welded test pieces were determined using a SHIMADZU UH 5000 kN at deformation rate of $1 \mathrm{m\,min^{-1}}$ at room temperature. Tensile peel and tensile shear test samples were shown in Fig. 1b and 1c, respectively. The test samples conform to the specification DIN 40 120 [2].

3. Results and discussion

3.1. Microstructure

The most important factors that affect weld quality are surface appearance, strength and ductility, weld nugget size, weld penetration, sheet separation, and internal discontinuities. Surface appearance of the welded IF material is shown in Figs. 1 and 3. Normally the surface appearance of a spot weld should be relatively smooth; round or oval in the case of contoured work; and free from surface fusion, electrode deposits pits, cracks and deep electrode indentation [14–21]. In this study, the smooth weld surface appearance is almost achieved (Figs. 1 and 3).

As seen in Fig. 4, grain growth was observed in weld metal and heat affected zones. Two different evolutions can be seen for weld nugget zone from this figure. Firstly, equiaxed grains were seen at the centre of the weld, which corresponds to a zone, which is heated up to 1200 ℃, and equiaxed grains can be attributed to the electrode pressure. As known pressure on the electrodes is maintained for a hold or forging time while the weld solidifies during the processes of spot weld [1, 9]. Secondly, highly elongated grains were seen at vicinity of these equiaxed grains, which resulted from heat transfer from weld metal zone to base metal [9, 18–21].

As noted earlier, this is explained through the heat input that increases with rising weld time. Depending on the heat input, an increase in the grain size in heat affected zone (HAZ) and crispness in the weld region were observed [1, 2, 6, 8, 9].

In this study, weld discontinuity, mentioned in literature [1, 2, 8], was not observed in the weld interface. It can be explained with currency of weld processes and steady low alloy content of IF steel.

3.2. Microhardness

The microhardness measurement was performed on the weld nugget, HAZ and the base metals of weldment as seen in Fig. 5. As can be seen, there is a profile of microhardness, which is similar to those seen in previous studies/researches [2, 8, 13]. However, it is observed that in the case of low weld time and weld current, the hardness emerges as a peak rather than as a homogeneous dispersion. The lowest hardness values are observed in 5 cycles and 3 kA. This result can be interpreted as the weld process not being completed entirely in the whole of nucleus with the low values of weld current and weld time [2, 6]. These cycle values can be used by taking into consideration tensile load bearing capacity and other production factors (i.e. economical) as well.

The profile of hardness peaks with the low cycle values in the weld nucleus can be explained by the

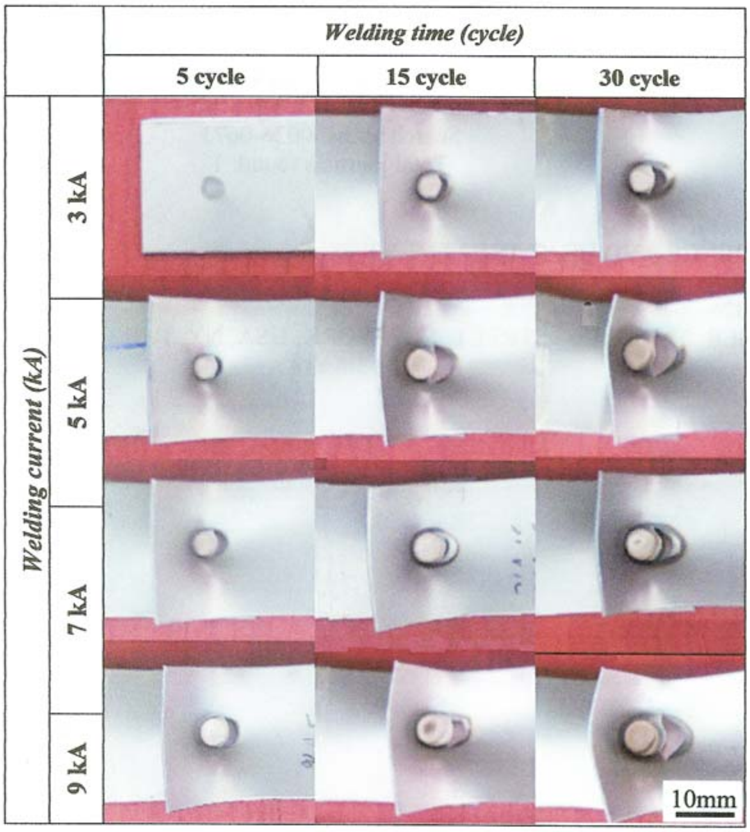

Fig. 3. Coalescence types of failure in resistance spot welded tensile shear samples.

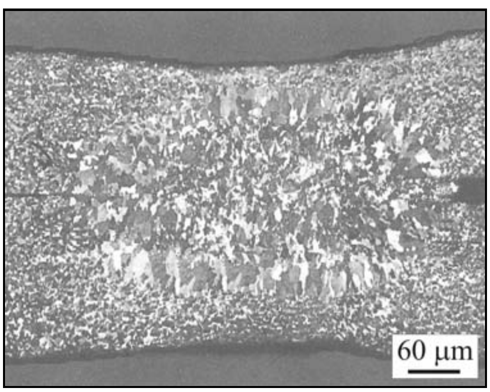

Fig. 4. Microstructures of welded samples (7 kA, 30 cycles).

coarse columnar grains, appearing in the sample weld nucleus, but not coarsening completely towards the surroundings.

Microhardness test results also showed that important differences in hardness distributions are observed between weld metal, HAZs and the base metal. However, when the weld current and weld time were increased to grow the nugget diameter, an important increase was not observed in the hardness distributions. It was observed that there is no significant increase in the hardness at the centre of weld, depending on the increase of weld nugget size.

3.3. Tensile shear performance

The strength of weldment is a very important factor for spot weld quality. Structures employing spot weld are usually designed so that the welds are loaded in shear when the parts are exposed to tension or compression loading. In some cases, the welds may be loaded in tension, where the direction of loading is normal to the plane of the joint, or a combination of tension and shear [13].

Tensile shear load bearing capacity of weldment showed increase with increasing peak weld current or weld time (Figs. 6 and 7).

The enhancement in tensile shear load bearing capacity of weldment with increasing of peak weld current and time is primarily attributed to the enlargement of nugget size so enlargement of the area to be exposed to the stress. In this study, the highest tensile shear strength was obtained in 25 cycles weld time for a 7–9 kA current range. It is expected that the samples welded at 30 cycles and 9 kA have the highest strength. However, the tensile shear load bearing capacity of weldment tended to decrease after welding at 7 kA weld current up to 25 cycles weld time. Further increase in weld time to 30 cycles caused a decrease

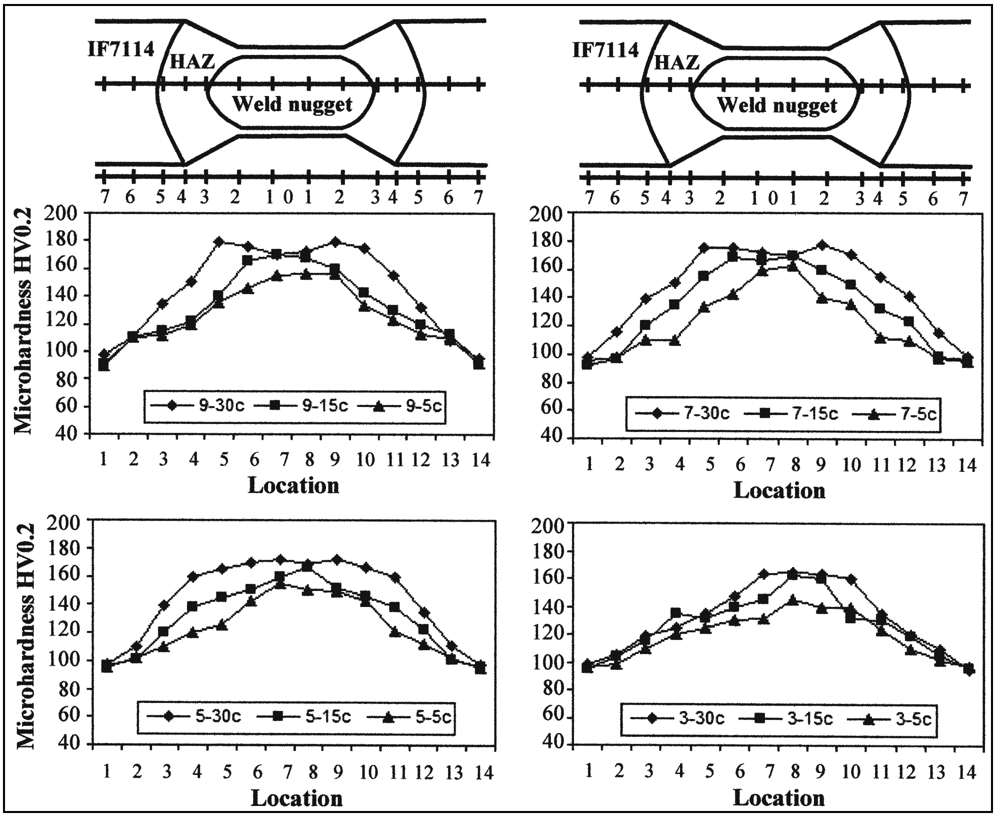

Fig. 5. Hardness profile of spot welded samples.

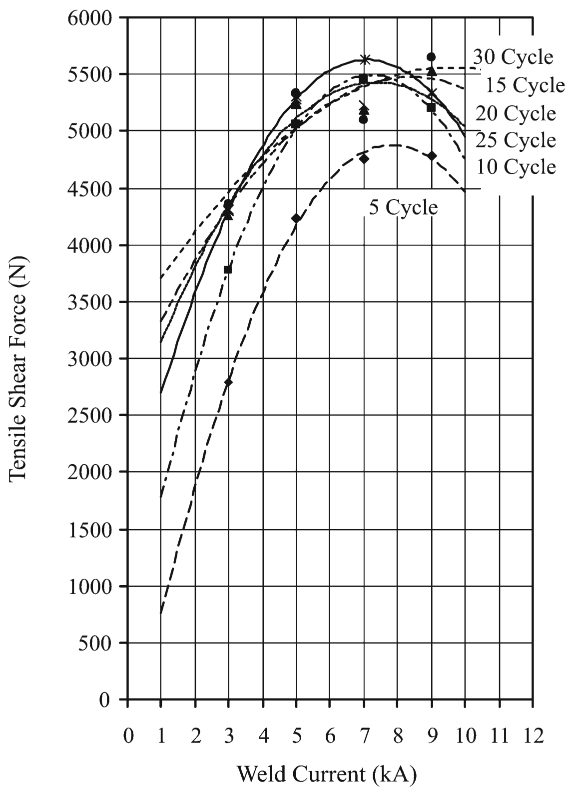

Fig. 6. Effect of weld current on tensile shear force of weld joints.

in tensile shear load bearing capacity (Fig. 7). The result shows that the weld current and weld time are fairly effective on mechanical properties. These results are compatible with Vural and Akkuş [8], Campos et al. [4], and Gupta et al. [15]. The decrease in the tensile shear load bearing capacity that was observed over 7 kA and 25 cycles can be explained by excessive heat input. The electrodes may react to work piece due to their excessive heating, which cannot be compensated by cooling water. As a result, excessive heat input caused grain growth in HAZ and weld nugget so tensile shear load bearing capacity of weldment decreased. The strength would have been even higher if the grain growth had not taken place [1, 2, 9] on the microstructure of samples welded at 30 cycles and 9 kA. In addition, the decrease in the tensile shear load bearing capacity can also be attributed to the decrease in cross-section area. The cross-section area decreases because of the excessive metal melting and splashing in the interlayer due to high heat input relative to weld current and weld time.

The tensile shear load bearing capacity increasing can also be attributed to the electrode pressure. As known pressure on the electrodes is maintained for a hold or forging time while the weld solidifies during the processes of spot weld. When the current and time is switched off (automatically) the weld solidifies under pressure. During this period, stress hardening takes

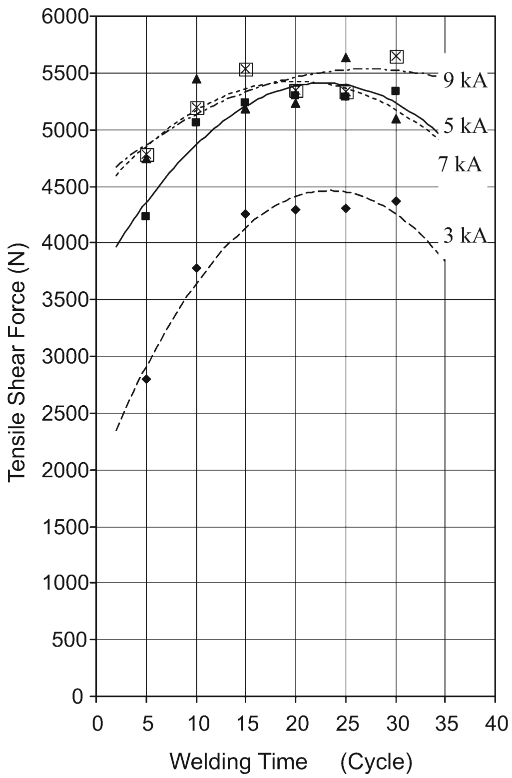

Fig. 7. Effect of weld time on tensile shear force of weld joints.

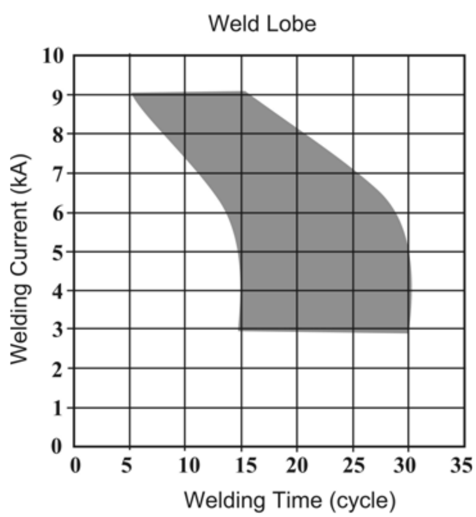

Fig. 8. The weld current vs. weld time diagram (weld lobe).

place in the weld zone due to the rapid cooling of weld metal. Increasing peak current and weld time, electrode force increases deformation hardening so the tensile shear strength of weld nugget may increase [1, 2, 8, 10–17].

The failure types of tensile shear test samples were also determined. Results were shown in Fig. 3 as photographs. Three types of failure modes were observed [1, 2, 6, 12, 13]. They were described as (1) separation, (2) knotting and (3) tearing.

In low weld current and weld time application (3 kA, 5 cycles), small weld nugget diameters were obtained resulting of lower tensile shear load bearing capacity and separation mode. Any deformation in nugget and HAZ was not observed. Results indicate that joint strength can not be acceptable for industrial applications.

Some of the tensile shear test samples welded under condition of 5, 10 cycle weld time and 5 kA weld current showed knotting fracture type. It can be attributed to the excessive heat input and depth of electrode indentation.

In general, the maximum shear strength was obtained, when the nugget was separated by tearing from the sheet [7]. Results showed that the failure did not take place within the weld interface. The separation of welded samples started from the outer region of the HAZ. Aslanlar et al. [2] reported that with increasing in energy input, the region of failure shifted from the interface to the outer region of the HAZ. They also determined the relationship between fracture's modes and penetrations. Their results indicated to the weld lobe, which shows an ideal weld parameter. The relationship between the weld parameters and fracture mode was also determined as a weld lobe in this study (Fig. 8).

3.4. Tensile peel force

Effects of weld current and weld time on tensile peel strength are shown in Figs. 9 and 8, respectively. As seen on Figs. 9 and 10, the tensile peel strength increased with increasing weld current and weld time. It is obvious that tensile peel strength starts to decrease after critical weld current values such as 25 cycle weld time and 5 kA weld current. This is explained by excessive heating and growing of weld nugget diameter and also decreasing of nucleus size ratio couples because of spurts out of the materials [2, 8, 15].

4. Conclusions

In this study, mechanical behaviour of resistance spot welded IF steel was investigated under different weld time and weld current conditions. The conclusions resulting from this study are given as follows:

1. Grain coarsening was observed in the weld nugget and HAZ of the spot welded samples.

2. Sample spots welded at low weld time and weld current have the highest microhardness at the centre of the weld nugget. However, it showed a continuous decrease from the centre of the weld nugget to the base materials.

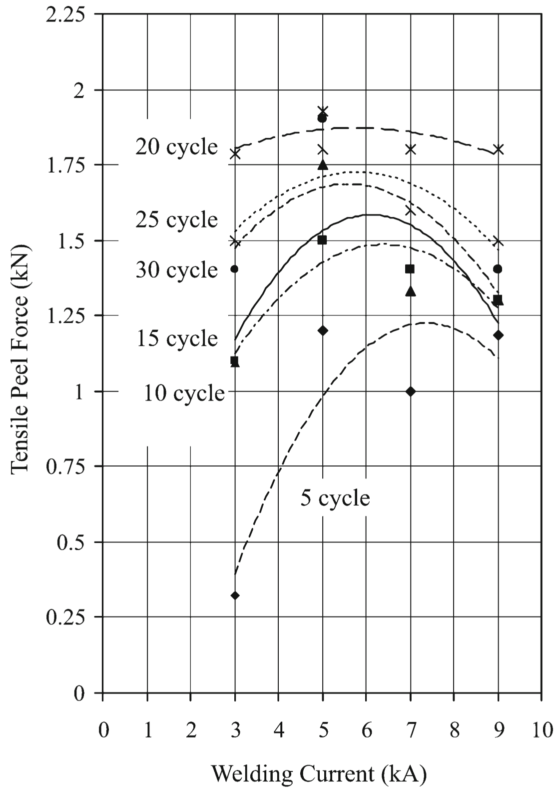

Fig. 9. Effect of weld current on tensile peel force of spot welded samples.

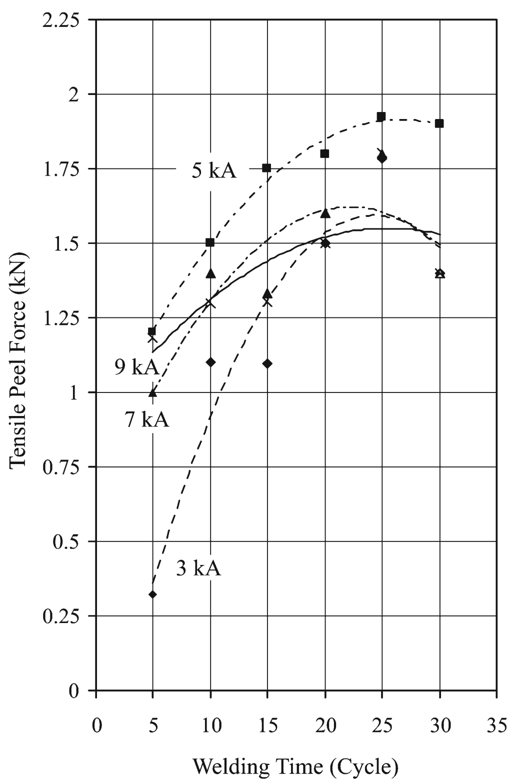

Fig. 10. Effect of weld time on tensile peel force of spot welded samples.

3. Tensile shearing and peel strength of the resistance spot welded samples showed an increase with increasing weld time or/and weld current, nugget diameter.

4. Three types of breaking failure were observed in the tensile shear tested samples: (1) separation, (2) knotting, (3) tearing.

Acknowledgements

The authors wish to acknowledge the materials support of the Eregli Iron and Steel Plant (Erdemir, A. Ş.), Turkey, for this study.

References

[1] KOCABEKIR, B.—KAÇAR, R.—GÜNDÜZ, S.—HAYAT, F.: Journal of Materials Processing Technology, *195*, 2008, p. 327.
[2] ASLANLAR, S.: Materials & Design, *27*, 2006, p. 125.
[3] CHOU, Y.—RHEE, S.: Welding Journal, *82*, 2003, p. 95.
[4] CAMPOS, C. A.—GUERRERO-MATA, M. P.—COLÁS, R.—GARZAI, R.: ISIJ International, *42*, 2002, p. 876.
[5] Corus Research, Development & Technology Automotive Applications JON/02-2002.
[6] KAHRAMAN, N.: Materials and Design, *28*, 2007, p. 420.
[7] BAKKALOGLU, A.: Engine and Metal Tech./Turkey, July 2001, p. 1.
[8] VURAL, M.—AKKUS, A.: Journal of Materials Processing Technology, *153–156*, 2004, p. 1.
[9] BAYRAKTAR, E.—KAPLAN, D.—DEVİLLERS, L.—CHEVALİER, J. P.: Journal of Materials Processing Technology, *13*, 2007, p. 114.
[10] ASM Metals Handbook, Resistance Spot Weld, *6*, 1993.
[11] AVTAR, R.—GHOSH, P. K.—GUPTA, P. C.: Metallkd., *30*, 1990, p. 233.
[12] KAİEDA, K.—OKAMOTO, S.: Prediction Weld in the World, *48*, 2004, p. 39.
[13] HASANBASOGLU, A.—KACAR, R.: Materials and Design, *28*, 2007, p. 1794.
[14] SHARMA, P.—GHOSH, P. K.—NATH, S. K.: Metallkd., *84*, 1993, p. 513.
[15] GUPTA, P.—GHOSH, P. K.—NATH, K.—RAY, S. Z.: Metallkd., *81*, 1990, p. 502.
[16] ZHOU, M.—ZHANG, H.—HU, S. J.: Weld J. AWS, *84*, 2003, p. 72.
[17] HAYAT, F.—DEMIR, B.—ACARER, M.: Metal Sci. and Heat Treat., *49*, 2007, p. 484.
[18] ZUNİGA, S. M.—SHEPPARD, S. D.: Model. Simul. Mater. Sci. Eng., *3*, 1995, p. 391.
[19] ASLANLAR, S.—OGUR, A.—OZSARAC, U.—ILHAN, E.—DEMIR, Z.: Materials and Design, *28*, 2007, p. 2.
[20] HAYAT, F.—DEMIR, B.—ASLANLAR, S.: IV. Iron and Steel Congress. Eds.: Tmmob council, Karabuk, Turkey 2007, p. 243.
[21] TANG, H.—HOU, W.—HU, S. J.—ZHANG, H.: Weld J. AWS, *79*, 2000, p. 175.