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Adhesive weld bonding of interstitial free steel at spot welding for automotive application

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Abstract

In this study, the effect of adhesive bonding on strength and strength-ductility behaviour of welding joint in electrical resistance spot welding of 7315 grade IF steel sheets was investigated. 7315 grade (DIN EN 10130-1999) IF steels were adhesively bonded and different welding current and welding cycle conditions were performed in welding process. For adhesive bonding, Loctite Terostat 9120-Grey and Terostat 9220-Black grade adhesive bonders were used. Additionally, adhesively bonded joint samples were also performed without welding. Microstructure and tensile-shear tests of the adhesively bonded and welded materials were evaluated. Failure modes of the weld bonded tensile sheared samples were observed to be different from only welded samples. Experimental results have shown that with the increase in the weld time and weld current, the effect of the adhesive weld bonding on tensile performance also increases.

Key words: IF (Interstitial-Free) sheet steel, resistance spot welding, adhesive weld bonding, tension test

1. Introduction

Bonded structures can be of two types based on either purely adhesive or on an adhesive/mechanical connection. Purely adhesive bonding has been used for several decades in the construction of aircraft components. Lightweight sandwich construction and structural bonded joints form a major proportion of modern aircraft. Bonded patches are also used to repair sandwich panels, cracks in metallic structure or to reinforce deficient structures [1]. The combined connections (bonded-welded, bonded-riveted and bonded-screwed) ensure high strength of the structures and are extremely economical, because they do not require any fixtures for use during the cementing process. Similar or dissimilar sheets can be joined successfully using adhesive bonding technique. Since the adhesive bonding provides a smooth joining surface, the load can be transferred uniformly without local stress concentrations due to stress raisers encountered in the conventional joints, such as bolted, riveted joints [2]. Adhesive weld bonding not only improves strength but also prevents sudden fracture (catastrophic) and leaking [3–7].

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 [8–14]. Weld bonding is a modern and promising metal joining technology. The structural adhesive must have good wetting and flow characteristics in order to obtain a good quality bond of the faying metal surfaces, and premature curing, during or prior to spot welding, must be avoided since it can significantly increase the electrical contact resistance. High values of the electrical contact resistance may result in excessive heat generation in the vicinity of the interface followed by

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Table 1. Chemical composition of IF steel sheet material (DIN EN 10130-1999, 7315 Erdemir grade) used in this study (wt.%)

C	S	Mn	Ti	Cu	Co	Nb	Al	Fe
0.004	0.01	0.25	0.06	0.021	0.006	0.004	0.057	99.39

subsequent metal expulsion, or it may simply impede the current running through [4].

It can thus be concluded that the weld bonding technology has great advantages compared to alternative processes such as spot-welding and adhesive bonding. However, despite such advantages, most of the industrial applications are still restricted to aerospace applications. Its utilization by other industries (e.g. automotive and train industry) is still in an early stage and will most likely be much more widespread when more knowledge based on systematic investigations of the process has been obtained [4]. So far, descriptions of the experimental load-displacement behaviour of the weld-bonded joints have been found only in a few studies for automotive materials, and for IF steel [2, 4, 8]. Therefore, in this study, adhesive weld bonding behaviour of IF steel which is a very important material particularly for automotive industry has been investigated using different welding parameters and two different grade adhesive bonders. Ultra-low carbon IF steel sheet can offer both good formability and adequate strength for auto body panels [10, 15–17].

2. Materials and experimental methods

2.1. Materials and welding processes

Experimental tests were designed in order to evaluate the performance of weld-bonded joints against conventional spot-welded and adhesive bonded joints. In this study, 7315 (DIN EN 10130-1999) grade IF steel sheet whose chemical composition is given in Table 1 with 1 mm thickness was subjected to spot resistance welding.

IF steel samples were welded using a Baykal SPP60 model. Spot welding was carried out using a water-cooled conical Cu-Cr alloy electrode having contact surface of 8.0 mm in diameter. For the process of joining, 10, 20, 30 cycles (1 cycle: 0.02 s) weld time and effective weld current (5–9 kA) were applied while other weld parameters such as electrode pressure (6 × 10^5 Pa) and holding time of electrode (25 cycles) were kept constant. The test samples conform to the specification DIN 40 120. The geometry and dimensions of the test samples are shown in Fig. 1a. These test samples were bonded using adhesive before spot welding was carried out as shown in Fig. 1b.

The weld-bonded specimens have been prepared as

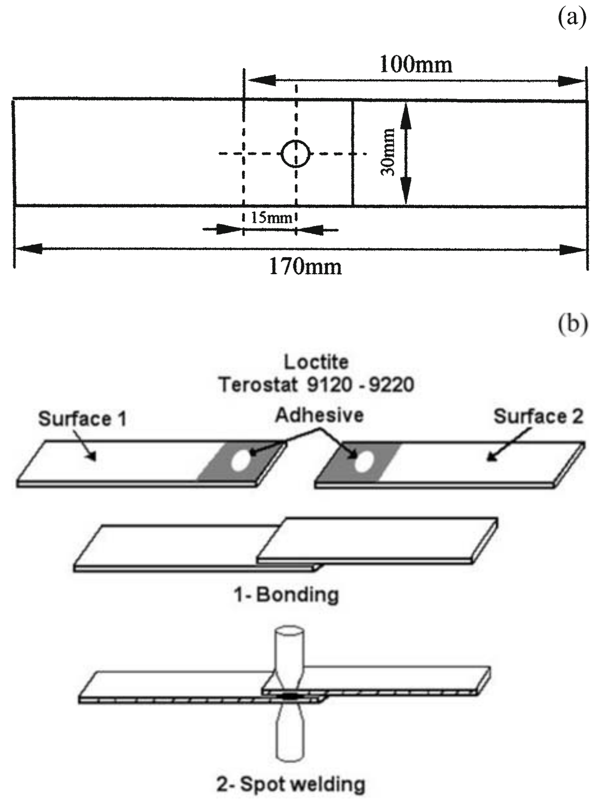

Fig. 1. Geometry and dimensions of the test specimen (a) and schematic outline of the weld bonding process (b).

follows: (1) Clean and dry surface is a necessary prerequisite for adhesive bonding. Therefore, the mechanical and chemical treatment of the surface was performed just prior to the bonding process. Lap joint samples were grinded until they were 1000 mesh grinder and then were cleaned with alcohol and dried with hot pressurized air; (2) The adhesive was applied on both of the two contact surfaces through a hand-held injection gun; (3) The curing time was 30 min in an oven at room temperature, as suggested by the manufacturers. After curing, the adhesives acted as electrical insulators impeding the current to run through, so they were removed from electrode contact surface. The remaining layer of adhesive was about 1 mm; (4) Bringing the metal sheets together; (5) Positioning them with a fixture to form required adhesive thickness; (6) Spot welding the specimen; and the only adhesive bonded specimens described in Section 2 were prepared in a similar process except the welding step [14].

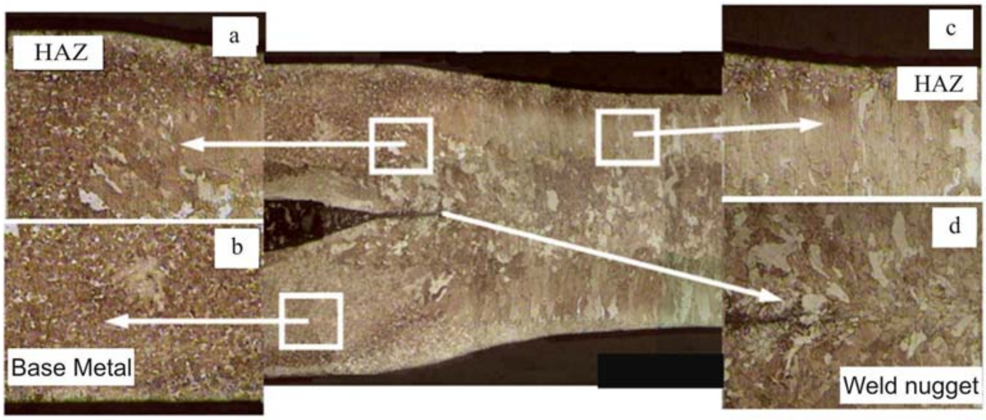

Fig. 2. Microstructure of the adhesive resistant spot weld bonded (ARSW) sample (welded at 7 kA-30 cycle).

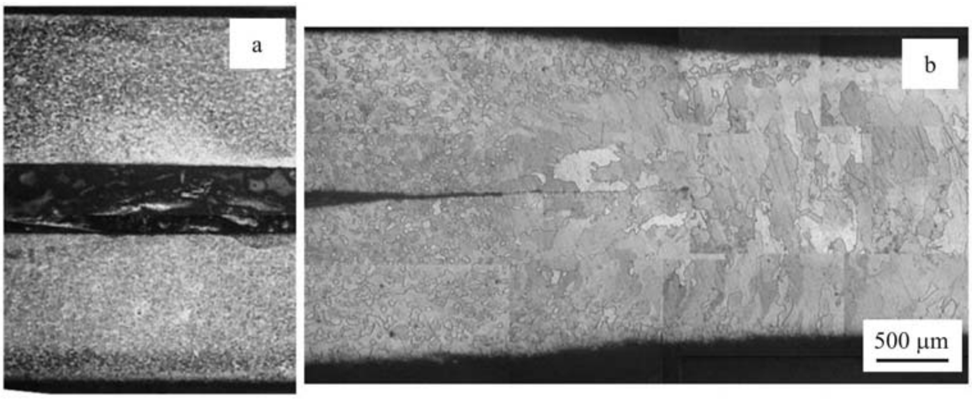

Fig. 3. Microstructure of the a) only adhesively bonded (AB) with 9120-Grey (without welding) and b) only spot welded (RSW, without adhesive) sample (welded at 7 kA-30 cycle).

Micrographs of cross-sections through the weld nugget and macrographs of the weld nugget of the spot-welded and weld-bonded specimens were made to determine the nugget diameter and penetration.

The spot-welded samples were exposed to tensile shear test in Shimadzu UH 5000 kN type testing machine in laboratory conditions. The crosshead speed was kept constant 2 mm min^{-1} during tests.

Table 2. Changing of nugget diameter dependent on effective weld current and weld time

Weld current (kA)	Weld time (cycle)		
	10	20	30
5	6.3 mm	7.2 mm	7.4 mm
7	6.7 mm	7.5 mm	7.6 mm
9	7.2 mm	8.4 mm	7.8 mm

3. Results and discussion

As seen from Table 2, at the end of the welding procedure, nugget diameter changed between 6.3 mm and 7.8 mm with different welding parameters. Nugget size increased when weld time and weld current were enhanced. It is known that the increase in energy input caused by an enhancement in effective current and weld time increased the nugget size of the weld [8–14]. Similar studies on galvanized interstitial free (cold formable) steel sheets with austenitic stainless steel sheets were carried out by Vural and Akkus [18]. They reported that the enhancement of peak current increased the nugget size of the welded metals, particularly IF steels.

Figures 2 and 3 show microstructure of the adhesive weld bonded (ARSW) sample (welded at 7 kA-30 cycle) with 9120-Grey, only adhesive (AB, without welding) and only spot welded (RSW) sample at 7 kA-30 cycle (without adhesive), respectively. The increase in energy input also coarsens the microstructure of weld nugget. For example, grain size of the 7 weld current – 10 cycle and 7 weld current – 30 cycle samples are shown at Table 3. Two different evolu-

T a b l e 3. Change of the grain size in weld area by weld time

Sample (explained with spot welding parameter)	Grain size (μm)			
	Base metal (IF steel)	Electrode centre	HAZ	Weld centre
7 weld current – 10 cycle	18	106 (length 170 – width 42)	100	65
7 weld current – 30 cycle	18	118 (length 186 – width 50)	110	89

T a b l e 4. Results of the tensile shear test of the samples: Adhesively (both of 9120-Grey and 9220-Black) resistant spot weld bonded (ARSW), Resistant spot welded (RSW)

Weld parameters	Times	10 cycle		20 cycle		30 cycle	
Currents	Samples code	TLBC** (N)	Disp.* (mm)	TLBC (N)	Disp.* (mm)	TLBC (N)	Disp.* (mm)
5 kA	RSW	**5574**	6.735	**5937**	8.332	**6069**	8.676
	(ARSW, 9120-Grey)	**6446**	7.974	**7003**	8.8375	**6594**	8.0635
	(ARSW, 9220-Black)	**6875**	8.508	**6950**	8.386	**7394**	9.94
7 kA	RSW	**5800**	7.831	**5975**	9.09	**6108**	9.753
	(ARSW, 9120-Grey)	**6792**	8.154	**6730**	9.488	**7072**	10.719
	(ARSW, 9220-Black)	**7030**	8.857	**7312**	10.1	**7304**	11.168
9 kA	RSW	**5796**	6.9245	**5706**	6.851	**5620**	7.0055
	(ARSW, 9120-Grey)	**7079**	8.274	**7100**	10.014	**7162**	11.152
	(ARSW, 9220-Black)	**7100**	9.1115	**7200**	9.4855	**7495**	11.973

*Disp.: Displacement, **TLBC: Tensile load bearing capacity

tions can be seen for weld nugget zone from this figure. Firstly, as seen in Fig. 2 and Fig. 3a,b, equiaxed grains were seen at the centre of the weld, which corresponded to a zone, heated up to 1200 ℃ and attributed to the electrode pressure. Secondly, the grains in the weld nugget were found to be elongated in parallel to the electrode compression direction.

The micrograph depicted in Fig. 2 representing experiments with adhesive 9120-Grey confirms that no significant differences were observed in the weld nuggets when comparing only spot-welded samples in Fig. 3b. The penetration of the weld nugget into the base material is almost adequate and no defects such as porosities in the adhesive due to burning off, or metal particles inside the bonding area due to expulsion of the nugget have been observed.

In 10, 20 and 30 cycles and in effective current from 5 to 9 kA, ultimate tensile shear load bearing capacity (TLBC) of the weld (produced by spot-welding and adhesively weld bonding using two different adhesives) is shown in Table 4. The highest TLBC (6108 N) for spot-welded parts was obtained in 30 cycles welding time for a 7 kA current range. However, the highest TLBC (7495 N) for adhesively weld bonded using two different adhesive parts, also the highest TLBC value of this study, was obtained in 30 cycles welding time for a 9 kA in ARSW 9220-Black samples. The effective current and weld time are the primary welding parameters affecting the weld thermal cycle. The increase in energy input caused by an enhancement in effective current and weld time increased the nugget size of the weld resulting in increase in the tensile shear load bearing capacity (Figs. 2, 3 and Tables 2, 4). Hayat [10, 11], Kocabekir [12], Vural and Akkus [18], Hasanbaşoğlu et al. [19], Gupta [20], and Sharma et al. [21] reported that the TLBC of spot-welded materials increased due to an enlargement of nugget size.

The increase in the tensile shear load bearing capacity of welded samples 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 are switched off (automatically), the weld solidifies under pressure. During this period, stress hardening takes place in the welding zone due to the rapid cooling of weld metal. Increasing peak current and welding time and electrode force increase deformation hardening, so the tensile shear strength of weld nugget may increase [9–11].

The load-displacement curves obtained by tensile shear tests of adhesively weld bonded (both of Loctite 9120-Grey and 9220-Black) and spot-welded samples at 9 kA and 30 cycles are plotted in Fig. 4. As seen in Fig. 4 and Table 4, adhesive weld bonded samples

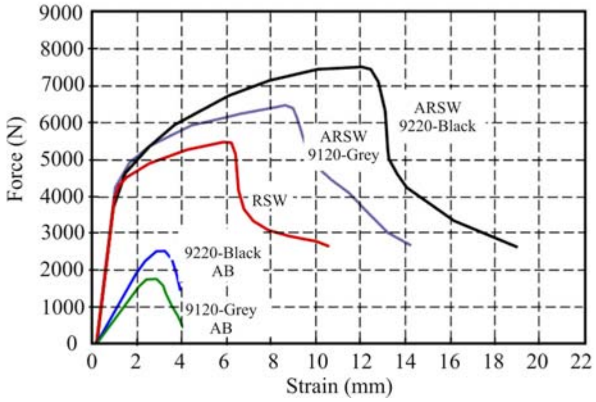

Fig. 4. Tensile shear curves of ARSW and RSW samples at 9 kA and 30 cycle and AB sample.

showed higher load bearing capacity and displacement value (4 and 8 mm, respectively) than that of spot-welded samples with the same welding parameters.

Tensile shear test results also showed that classic spot-welded 7 kA-30 cycle samples had higher load bearing capacity (6108 N) and displacement (9.7 mm) than that of the 9 kA-30 cycle samples (5620 N and 7 mm). This can be explained by the increase of the weld current and the weld time, which is the cause of excessive heat input and so, of such failures as splashing and over grain size. Bayraktar [22] et al. reported that excessive grain growth depended strongly on the value of the local thermal gradient in the vicinity of the austenite to ferrite transformation temperature and the mobility of austenite-ferrite interface. In the case of a high thermal gradient, the grain growth occurs in the direction of the fusion zone, along the thermal gradient. However, adhesive weld-bonded samples did not show these failures. So it can be said that adhesive weld bonding retards the failure to such high welding parameters as 9 kA--30 cycles. This proves an important advantage that welding mechanical properties can be enhanced by increasing excessive heat input without welding failure.

3.1. Microhardness

Hardness or ductility is one of the most important factors that affects the spot weld quality. The ductility of a resistance spot weld is determined by the composition of the base metal and effect of high temperatures and subsequent rapid cooling on that composition. The nearest thing to ductility measurement is the hardness test since the hardness of metal is usually an indication of its ductility [12, 13]. Therefore, the hardness measurement was performed on the weld nugget, HAZ and the base metals of weldment as seen in Fig. 5. The effect of heat input related with weld time, weld current and on the hardness of weldment was also determined and results are shown in Fig. 5. As can be seen, there is a profile of microhardness that is similar to those seen in previous studies/researches [7, 10]. In addition, as seen in Fig. 5, there were no distinctive differences between RSW and ARSW samples' hardness profile.

Microhardness test results have also shown that there are important differences in hardness distributions between weld metal, HAZs and the base metals. 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 was no significant increase in the hardness at the centre of weld, depending on the increase of weld nugget size [10]. Identical differences between RSW and ARSW samples' hardness profile were not observed, so one group hardness profile was shown.

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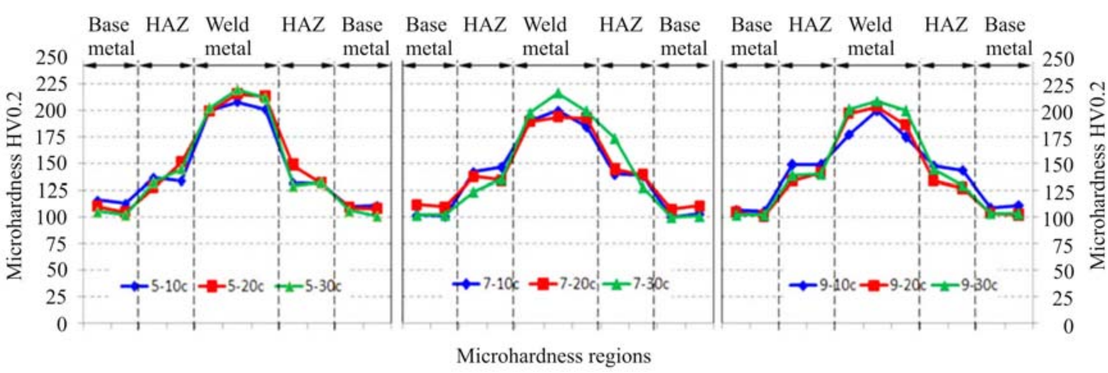

Fig. 5. Hardness profile of spot welded samples.

Fig. 6. Failure modes of ARSW and RSW samples with respect to weld time and weld current.

3.2. Fracture mode

In literature [12, 19, 23, 24], for spot welded sheet steel, three different fracture modes such as separation, knotting and tearing, have been reported. As can be seen in Fig. 6, knotting and tearing type fracture modes were observed, but separation was not observed. Knotting and tearing fracture modes are results of the coalescence of the void. Hayat et al. [10] reported that the failures occurred by tearing and knotting of interstitial free steel sheet metals of spot-welded materials. They explained that the primary cause of weakening of the weldment was identified as the excessive grain growth region of HAZ in IF steel. Depending on the heat input, an increase in the grain size in HAZ and crispness in the weld region was observed. For IF (DIN EN 10130-1999) sheet steel, the same fracture place was also observed in this study. Adhesive weld bonding not only increases strength but also provides sealing to prevent abrupt failure due to fatigue. So this joining technique has an important advantage especially for automotive industry [4–7].

Yong et al. [14] studied the modelling of the fracture of the weld bonded parts and reported for HSLA340 sheet steel, that weld-bonded structure, the adhesive-bond and the spot-weld failed at different stages and had little coupling effect, but they supplemented each other. Therefore, it is anticipated that one can develop appropriate modelling methods for adhesive-bonded and spot-welded joints and then combine them to model the weld-bonded joint.

When failure locality after tensile shear test was investigated, it was also seen that tearing formed in the HAZ. Besides, on the adhesive weld bonded samples failure localities are different from spot welded samples without adhesive (Fig. 6). On the spot welded samples without adhesive, corners of the materials formed towards outside and weld nugget torn. However, on the adhesive weld bonded samples, flexion formed. This confirms that there is extra elongation on the adhesive weld bonding. As mentioned above, it can be said that since the adhesive bonding provides a smooth joining surface, the load can be transferred uniformly without local stress concentrations due to stress raisers [2].

In general, the maximum shear strength was obtained when the nugget was separated by tearing from the sheet (e.g., 9 kA-30 cycle sample at Fig. 6). Results, as seen in Fig. 6, 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 [9] and Hayat et al. [10] also reported for IF sheet steel that with the increase in energy input, the region of failure shifted from the interface to the outer region of HAZ. They also determined the relationship between fracture's modes and penetrations. Their results indicated the weld lobe, which showed to be an ideal weld parameter.

4. Conclusions

The paper focused on the assessment of weld-bonded joints assembled with two commercial adhesives using different welding parameters. The following main conclusions could be drawn based on the results of the experiments:

1. Increasing weld time or/and weld current increased nugget diameter. So, tensile-shearing strength of the resistance spot welded and adhesive weld bonding samples increased.

2. Generally, grain coarsening was observed at the weld centre and HAZ of spot-welded samples.

3. Tensile-shearing strength and displacement of the adhesive weld-bonded samples have higher values than those of resistance spot-welded ones.

4. Terostat 9220-Black grade adhesives showed higher tensile shear strength in comparison to Terostat 9120-Grey.

5. Both weld samples without adhesive and adhesive weld-bonded samples showed that two types of breaking failure were observed at tensile shear tested samples: knotting and tearing.

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