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Effect of Welding Current on Energy Absorption of AISI 304 Resistance Spot Welds

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Abstract: In this study, the effect of welding current on the energy absorption capability of austenitic stainless steel AISI304 resistance spot welds during the quasi-static tensile-shear test is investigated. Results showed that there is a direct relationship between the fusion zone size and failure energy in expulsion free samples. However, when expulsion occurred, the energy absorption capability reduced significantly. Failure energy for samples experiencing expulsion is lower compared to expulsion free samples with identical or even smaller weld nugget size.

Keywords: AISI 304,failure energy, fusion zone size, resistance spot welding

INTRODUCTION

Car designers today seek the very best stiffness, mass-reduction and safety performance. The competition between different materials for structural applications in cars is intense. Choice centers on mass saving, formability, weldability, corrosion resistance, fatigue resistance, cost and environmental factors. Safety and crashworthiness, especially, should take priority (Schuberth *et al*., 2008).

Austenitic stainless steels are preferred materials for structural application in railway carriages. They are already widely accepted for use in structural frameworks and body paneling of buses and coaches (Snelgrove, 2009). Experience gained in these contexts can be readily transferred to the automotive sector. Stainless steels are excellent candidates for car body structural applications. Offering weight savings, enhanced "crashworthiness" and corrosion resistance, it can also be recycled. The material blends tough mechanical and fire-resistant properties with excellent manufacturability. Under impact, high-strength stainless offers excellent energy absorption in relation to strain rate. It is ideal for the revolutionary "space frame" car body-structure concept (Schuberth *et al*., 2008). Weldability of a material is one of the key factors governing its application in auto industry. Resistance spot welding is widely used to join sheet metals in the automotive industry (Khan *et al*., 2008). The quality and performance of the spot welds significantly affect the durability and safety design of the vehicles (Pouranvari *et al*., 2007; Pouranvari and Marashi, 2009).

Resistance spot welding is a process of joining two or more metal parts by fusion at discrete spots at the interface of workpieces. Resistance to current flow through the metal workpieces and their interface generates heat; therefore, temperature rises at the interface of the workpieces. When the melting point of the metal is reached, the metal will begin to fuse and a nugget begins to form. The current is then switched off and the nugget is cooled down to solidify under pressure (Feng *et al*., 2006; Goodarzi *et al*., 2009; Pouranvari, 2011).

There are generally three indexes for quality control of resistance spot welds:

- **Fusion zone size (FZS):** FZS which is defined as the width of the weld nugget at the sheet/sheet interface in the longitudinal direction is the most important factors in determining quality of spot welds (Pouranvari *et al*., 2008; Pouranvari and Marashi, 2009; Sun *et al*., 2008).
- **Weld mechanical performance:** Spot weld mechanical performance is generally considered under static/quasi-static and fatigue loading condition. The tensile-shear test is the most widely used test for evaluating the spot weld mechanical behaviors in static condition (Marashi *et al*., 2008; Hasanabadi and Pouranvari, 2010). Peak load, obtained from the tensile-shear load- displacement curve, is often used to describe spot welds mechanical behaviors. In addition to peak load, failure energy can be used to better describe the spot weld mechanical behaviors. Failure energy is a

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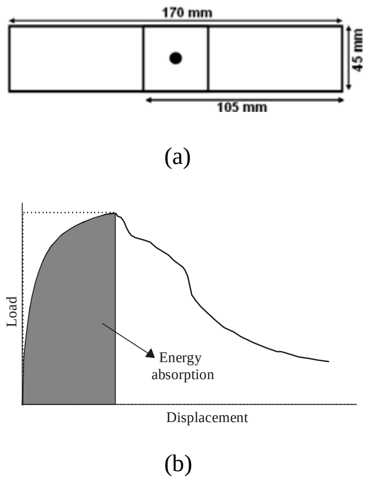

Fig. 1: (a) Sample dimensions of tensile-shear test (b) Load-displacement curve and the extracted parameter

measure of weld energy absorption capability and its higher value demonstrates the increase in weld performance reliability against impact loads such as accidents.

- **Failure mode:** Failure mode is the manner which spot weld fails. Generally, the Resistance Spot Weld (RSW) failure occurs in two modes: interfacial and pullout. In the interfacial mode, failure occurs via crack propagation through Fusion Zone (FZ); while, in the pullout mode, failure occurs via nugget withdrawal from one sheet. In this mode, fracture may initiate in Base Metal (BM), Heat Affected Zone (HAZ) or HAZ/FZ depending on the base metal and the loading conditions (Pouranvari and Marashi, 2010; Pouranvari and Marashi, 2011; Pouranvari *et al.*, 2011).

The objective of the research is to address the effects of weld attributes (i.e. fusion zone size and electrode indentation) on the energy absorption of austenitic stainless steel AISI 304 spot welds.

Experimental procedure: An austenitic Stainless Steel (SS) sheet 1.2 mm thick was used as the base metal. The chemical composition of the base metal was Fe-18.47Cr-9Ni-1Mn-0.462 Cu-0.016 Nb-0.388 Si-0.035C-0.038P-0.004S corresponding to AISI 304 stainless steel. Spot welding was performed using a PLC controlled 120 kVA AC pedestal type resistance spot welding machine. Welding was conducted using a 45º truncated cone RWMA Class 2 electrode with 7-mm face diameter. Welding current was varied from 5 to 10.5 kA and welding time, electrode pressure and holding time were fixed at 12 cycles, 4 bar and 30 cycles, respectively. All experiments were done in Welding Lab, Iran University of Science and Technology, in March 2010.

Table 1: The effect of welding current on weld nugget size, expulsion and failure mode

Welding current (kA)	5	6	7	8	9	10	11	12	13	14
Failure mode	IF	IF	IF	PF	PF	PF	PF	PF	PF	PF
Nugget size (mm)	3	3.6	4.5	5.7	5.8	6	6.8	6.5	6.7	6.6
Expulsion	No	No	No	No	No	W	M	M	H	H

IF: Interfacial Failure; PF: Pullout Failure; W: Weak; M: Medium; H: Heavy

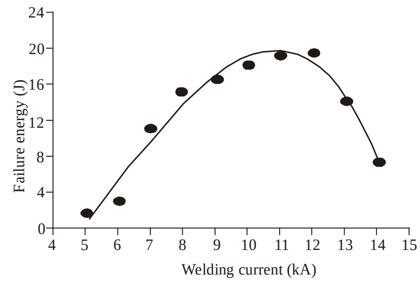

Fig. 2: Effect of welding current on peak load

The static tensile-shear test samples were prepared according to American Welding Society (2007) (AWS) standard. The sample dimensions are shown in Fig. 1a. The tensile-shear tests were performed at a cross head of 2 mm/min with an Instron universal testing machine. Failure energy was calculated as the area under the load displacement curve up to the peak load (Fig. 1b). The Failure mode was determined from the failed samples.

RESULTS AND DISCUSSION

Energy absorption capability of spot welds depend on their physical attributes especially fusion zone size, failure mode and failure location mechanical properties. Table 1 shows the effect of welding current on the FZ size, failure mode and expulsion.

The experimental results indicate that welding current has a significant effect on the failure energy of spot welds under the tensile-shear static test. As in Fig. 2, weld energy absorption capability rises by increasing welding current, however, it sharply decreases by heavy expulsion. Increasing welding current increases the probability of expulsion occurrence as well as its severity (Table 1).

To examine the relationship between the energy absorption and the weld nugget size, a scatter plot of peak load vs. weld size was constructed and a trend line was added to the scatter plot to show the general trend (Fig. 3). Before expulsion, there is a positive relation between failure energy and the weld nugget size. The peak point in load-displacement plot of tensile-shear test corresponds to the point of crack propagation through the weld nugget for interfacial mode and to necking point at failure location for pull out mode. Failure mode is a qualitative

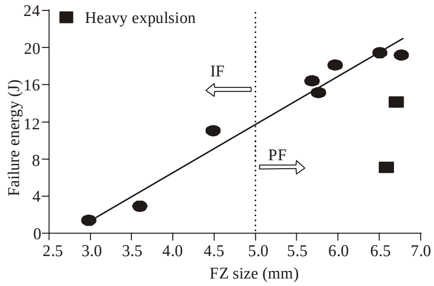

Fig. 3: Effect of fusion zone size on the peak load

criterion for weld reliability which is widely used in the manufacturing environment. As in Fig. 3, for small weld nuggets, the dominant failure mode is interfacial. However, increasing weld nugget diameter to more than a critical value, the failure mode changes to the pull out one. In the present investigation the minimum nugget diameter required to ensure pullout mode is about 5.7 mm (Fig. 3). As can be seen in Fig. 3, the failure energies have smaller value in the interfacial failure mode compared to the pull out mode. This is due to the fact that in the interfacial failure mode, almost no plastic deformation is occurred, while pull out mode accompanied by considerable plastic deformation. For interfacial mode, the bigger the nugget size the higher is the interfacial resistance to shearing. For pull out mode, increasing nugget diameter increases the nugget resistance against rotating and therefore, increases the required force and energy for necking at failure location. In both cases, increasing weld nugget diameter increases the required force and energy for failure to occur. Therefore, it is concluded that before expulsion weld nugget diameter is the main controlling factor of energy absorption capability of the welds. Similar conclusion was obtained for galvanized low carbon steel (Goodarzi *et al*., 2009), TRIP800 steel and DP800 spot weld (Sun *et al*., 2008). In summary, it can be concluded that the weld FZ size is the main controlling factor of the RSW mechanical properties in terms of the peak load and energy absorption. This can be attributed to:

- Transition of the failure mode from interfacial to pullout by increasing the FZ size
- Increasing the overall bond area in both failure modes by increasing the FZ size

It has been proved that the FZ size is the most important parameter controlling the mechanical properties of the spot welds.

However, after a critical point, energy absorption capability sharply decreases due to high electrode indentation depth. Reduction of failure energy at points

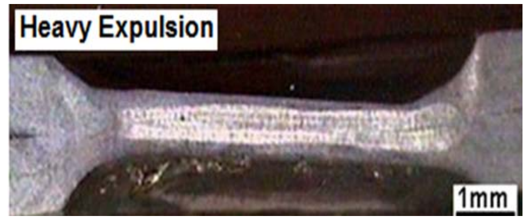

Fig. 4: Macrograph of a spot weld with heavy expilsion

higher than the critical welding current can be assigned to severe electrode indentation. Figure 4 shows macrograph of welds made at welding current of 14 kA. In this welding condition, welding is accompanied with heavy expulsion. As in Fig. 4, heavy expulsion leaves a severe electrode indentation in the sheets. Therefore, it could be concluded that despite constant weld nugget size, the energy absorption capability is significantly reduced upon expulsion. As in Fig. 3, those spot welds experiencing expulsion have lower failure energy even compared to expulsion free spot welds of smaller nugget size.

CONCLUSION

Understanding the influence of RSW parameters on the mechanical performance of the spot welds is a prerequisite for the development of optimum welding conditions which ensure high levels of joint quality in autobody manufacture. Results showed that in addition to the weld nugget size, electrode indentation can significantly affect weld performance. There is a direct relationship between the fusion zone size and failure energy in expulsion free samples. However, when expulsion occurred, the energy absorption capability reduced significantly. Failure energy for samples experiencing expulsion is lower comparing to expulsion free samples with identical or even smaller weld nugget size.

REFERENCES

American Welding Society, 2007. Specification for Automotive Weld Quality Resistance Spot Welding of Steel. AWS D8:1M, American National Standard. New York.

Feng, J.C., Y.R. Wang and Z.D. Zhang, 2006. Nugget growth characteristic for AZ31B magnesium alloy during resistance spot welding. Sci. Technol. Weld. Joining, 11: 154-162.

Goodarzi, M., S.P.H. Marashi and M. Pouranvari, 2009. Dependence of overload performance on weld attributes for resistance spot welded galvanized low carbon steel. J. Mat. Process. Tech., 209: 4379-4384.

Hasanabadi, M.M. and M. Pouranvari, 2010. Correlation between macro/micro structure and mechanical properties of dissimilar resistance spot welds of AISI 304 austenitic stainless steel and AISI 1008 low carbon steel. Metalurgija-J. Metallurgy, 16: 133-146.

Khan, M.I., M.L. Kuntz and Y. Zhou, 2008. Effects of weld microstructure on static and impact performance of resistance spot welded joints in advanced high strength steels. Sci. Technol. Weld. Joining, 13: 294-304.

Marashi, P., M. Pouranvari, S.M.H. Sanaee, A. Abedi, H. Abootalebi and M. Goodarzi 2008. Relationship between Failure Behavior and Weld Fusion Zone Attributes of Austenitic Stainless Steel Resistance Spot Welds, Mater Sci. Techno, 24: 1506-1512.

Pouranvari, M., H.R. Asgari, S.M. Mosavizadeh, P.H Marashi and M. Goodarzi, 2007. Effect of weld nugget size on overload failure mode of resistance spot weld. Sci. Technol. Weld. Joining, 12: 217-225.

Pouranvari, M., A. Abedi and M.P. Goodarzi, 2008. Effect of expulsion on peak load and energy absorption of low carbon resistance spot welds. Sci. Technol. Weld. Joining, 13: 39-43.

Pouranvari, M. and S.P.H. Marashi, 2009. Similar and dissimilar RSW of low carbon and austenitic stainless steels: Effect of weld microstructure and hardness profile on failure mode. Mater Sci. Technol., 25: 1411-1416.

Pouranvari, M. and S.P.H. Marashi, 2010. Key factors influencing mechanical performance of dual phase steel resistance spot welds. Sci. Technol. Weld Joining, 15: 149-155.

Pouranvari, M., 2011. Prediction of Failure mode in AISI304 resistance spot welds. Metallurgija-J. Metallurgy, 17: 23-30.

Pouranvari, M. and S.P.H. Marashi, 2011. Failure mode transition in AHSS resistance spot welds, Part I: controlling factors. Mat. Sci. Eng. A., 528: 8337-8343.

Pouranvari, M., S.P.H. Marashi and D.S. Safanama, 2011. Failure mode transition in AHSS resistance spot welds. Part II: Experimental investigation and model validation. Mat. Sci. Eng. A., 528: 8344-8352.

Schuberth, S., E. Schedin, T. Frohlich and E. Ratte, 2008. Next Generation Vehicle-Engineering guidelines for stainless steel in automotive applications. Proceedings of the 6th, Stainless Steel Science and Market Conference, Helsinki (Finland), 10-13 June.

Snelgrove, P., 2009. Stainless steel automotive and Transport Developments, International Stainless Steel Forum, 1-5, Reterived from: http://www.worldstainless.org/.

Sun, X., E.V. Stephens and M.A. Khaleel, 2008. Effects of fusion zone size and failure mode on peak load and energy absorption of advanced high strength steel spot welds under lap shear loading conditions. Eng. Fail. Anal., 15: 356-367.