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Experimental Study of the Nugget Diameter Effect on Tensile-Shear Strength in AISI 1008 Spot Welding Specimens

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Abstract: The spot welding is widely used for joining thin sheets in different industries; such as automotive industry. This method of welding is very easy to automate and maintain. In this study, the effect of nugget diameter on the tensile-shear strength of the spot welding joints was investigated. The specimens were manufactured from AISI 1008 HR sheets with 1.0 mm thickness. The eight different electrodes with different active face diameters (3–10 mm) were employed. Tensile tests of the prepared specimens indicated that both ultimate tensile strength (UTS) and yield strength increased to a certain level and then remained constant. The comparison between specimen failure modes showed that in specimens with lower nugget diameter, tearing occurred in nugget. However with increasing the diameter, failure location moved to nugget edge with tearing in base sheet. Interestingly, the specimens with change in failure location were those that UTS and yield strength were remained almost constant. This was also the case where the elongations of these specimens were studied.

Keywords: Spot Welding, Nugget Diameter, Tensile-Shear Strength

1. Introduction

Spot welding is widely used in joining thin sheet parts in different industries, for example in ground vehicle industry has been the primary method of joining. A modern vehicle typically contains 2000 to 5000 spot welds. Therefore, the strength of the spot weld under quasi-static, impact, and fatigue loading conditions is extremely important because it affects the durability and safety design of automobiles. Although the spot weld has been used extensively, a simple failure criterion that is able to predict the failure strength of a spot weld subjected to various loading conditions does not exist. Conventional procedure in industry is to perform extensive tests to obtain sufficient data sets for reliable design purposes. The drawback of this approach is that there are too many variables to consider, e.g., welding parameters, sheet thickness, weld nugget size for a given material. Zuniga and Sheppard [1] performed failure test of spot weld on high strength steel and studied detailed failure mechanisms of lap-shear and coach peel samples. Barkey et al. [2] and Lee et al. [3] designed a test sample and a fixture such that a spot weld test sample can be loaded under pure shear, pure normal load and mixed shear-normal load by changing the loading position of the fixture. Ultimate strength data of spot welds using these tests were reported and after curve fitting to obtain the force based failure criterion for design consideration. Similarly, Lin et al. [4] reported another mixed mode test fixture and some test results.

In the spot welding process, two or three overlapped or stacked stamped components are welded together as a result of the heat created by electrical resistance. This is provided by the work pieces as they are held together under pressure between the two electrodes. Spot welding may be performed manually, robotically or by a dedicated spot welding machine [5, 6]. The similar spot welds

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having same property can be obtained in high production speeds by controlling welding current, electrode force and weld time automatically.

The required low voltage (5–20 V) and high current (2000–20,000 A) in welding are produced by trans-formators and the pressures are applied by hydraulic, mechanical and pneumatic devices [7–8]. Achieving good welding quality starts with a good process design that minimizes the variables encountered in welding. Electrode active face diameter, electrode force, current intensity and time are the most important welding parameters in electrical resistance spot welding. An electronically control unit is used in welding machines to pursuit the welding variables. The desired nucleus diameter can only be obtained by adjusting welding current intensity versus welding time properly. When time is held short, the nucleus diameter decreases. On the contrary, when it is held long the amount of molten metal increases and fused metal spurts out and as a result the strength of welding joint decreases. Since interfacial mode of failure in spot weld is generally not acceptable for automobile applications due to its low load carrying and energy absorption capability, the researchers first studied the effect of nugget diameter on failure mode of spot weld, i.e., under which diameter of a spot weld nugget the failure become no acceptable interfacial mode (or the acceptable nugget pullout mode) [9]. In addition the stress-strain pattern variations due to the nugget diameter alteration were studied. In this study, nugget diameter was the variable parameter which was considered and resulted in the investigation of other impressive parameters such as welding current and time.

2. Experimental procedure

2.1. Specimen preparation

AISI 1008 HR sheet was used for manufacturing the specimens. The sheet with 1mm thickness was cut into pieces and welded together. The specimen with one spot weld was chosen to investigate tensile-shear strength. Fig. 1 shows the general geometrical features of selected specimen. The chemical composition of AISI 1008 HR sheet is shown in Table 1. Also, the result of simple tensile test including mechanical properties of specimen is shown in Table 2.

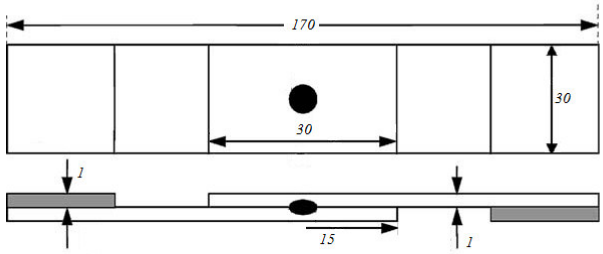

Fig. 1. Specimens' geometry of experimental tensile-shear tests for spot-welded joints (all dimensions are in mm).

A timer and current controlled electrical resistance spot welding machine with 120 kVA capacity and pneumatic application mechanism was used to weld the specimens. In addition to that, 8 different electrodes with different active face diameters (3–10 mm) were used. Welding current frequency was selected in range 9- 19 cycles and it was adjusted to increase by increasing from 6 kA to 18 kA and the amplitude of current steps variations were chosen by the machine catalogue tables. The applied electrode force fixed on 2.5 kN. Time and applied current for each nugget formation in the specimens is expressed in Table 3.

Table 1. Chemical composition of AISI 1008 HR

Cu	Co	Al	Ni	Mo	Cr
0.0229	0.0048	0.0429	0.0114	0.0050	0.0095
S	**P**	**Mn**	**Si**	**C**	**As**
0.0085	0.0633	0.3190	0.0050	0.0050	0.0059
Zr	**Ca**	**B**	**Sn**	**Pb**	**W**
0.0020	0.0001	0.0011	0.0020	0.0250	0.0150
V	**Ti**	**Nb**			
0.0020	0.0250	0.0253			

Table 2. Mechanical properties of material AISI 1008 HR

Mechanical properties	
Yield strength (MPa)	276
UTS (MPa)	401
Elongation (%)	28

2.2. Tensile-Shear tests

Prepared specimens were exposed to Tensile-Shear tests by means of a 60 kN servo-hydraulic INSTRON testing machine with strain rate which has been adjusted on 2 mm/min. The specimens were mounted in grips 4 cm from both ends. So the gage length was determined to be 9 cm. In order to provide symmetry and to prevent a moment being applied at the weld, 4 cm long pieces of same sheet were glued to both ends. Fig. 2 shows the specimen position between gripers.

3. Results and discussion

Welded specimens were different from testing uniform materials mainly because of the geometric characteristics of spot weldments. A weld is usually considered as a unit, and therefore, its strength is often expressed in terms of load instead of stress, and displacement instead of strain [10].

Results were obtained from tensile-shear tests were drawn together in a single diagram. Fig. 3 shows the final result for load-displacement curves. In Fig. 4, configurations of specimens are shown after testing. Corresponding on Fig. 4, the position and geometry of separation or tearing in the specimens depend on diameter of nugget. In specimens up to 6 mm nugget diameter, cross section of joint is small.

Table 3. Time and applied current for each specimen in pre-tests

Specimen Number	Electrode tip diameter used in welding process (mm)	Current (kA)	Welding cycles	Nugget diameter
1	3	6	9	2.6
2	4	7	9	3.5
3	5	10	9	4.3
4	6	12	13	5.3
5	7	14	15	6.1
6	8	16	15	7.0
7	9	17	17	7.9
8	10	18	19	8.5

Fig. 2. Specimen position between gripers.

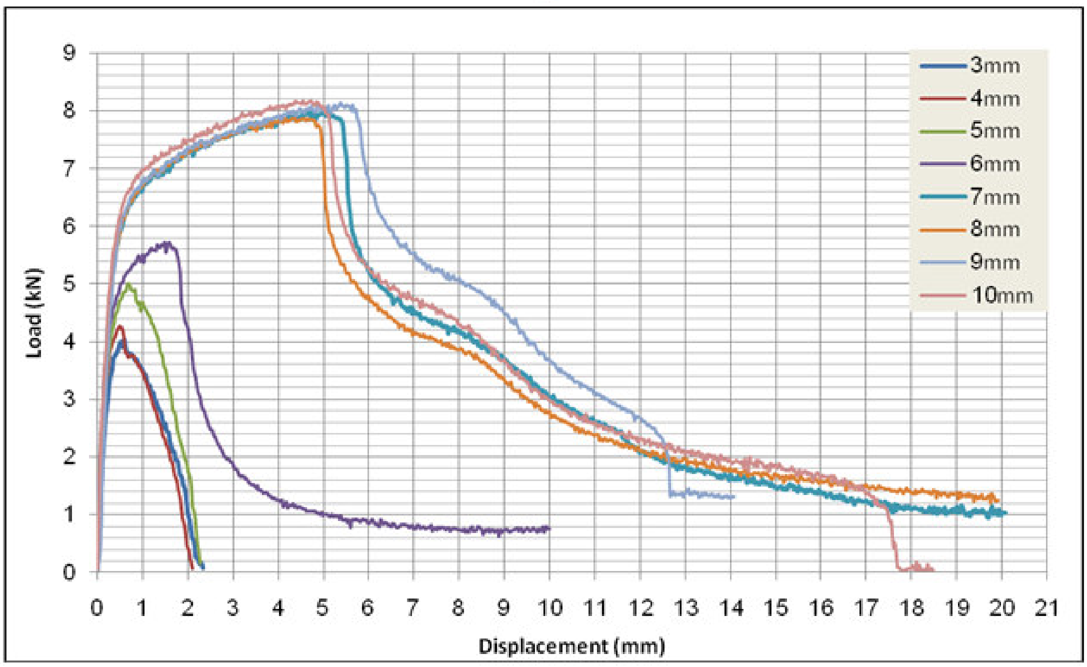

Fig. 3. Tensile-shear tests results.

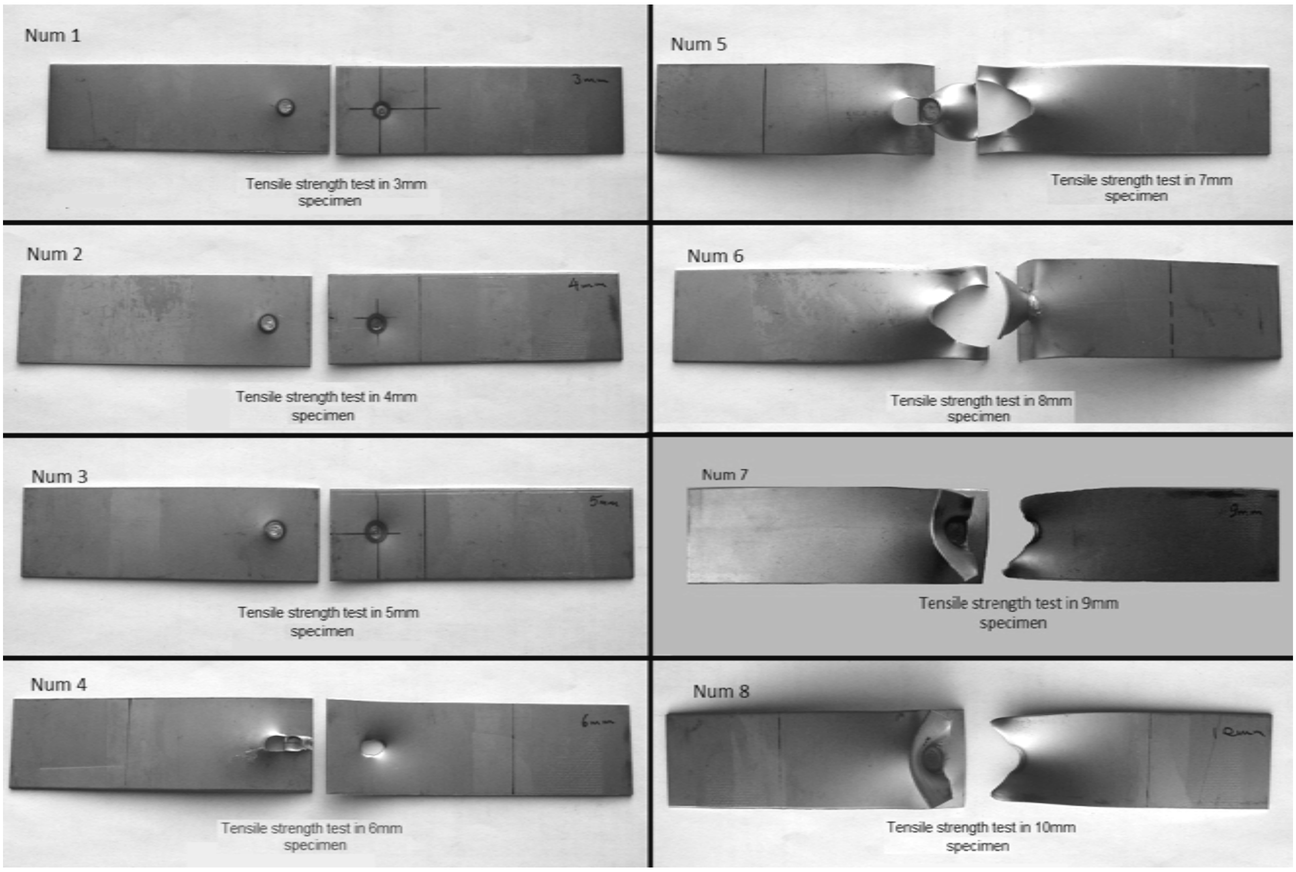

Fig. 4. Specimen's failure mode.

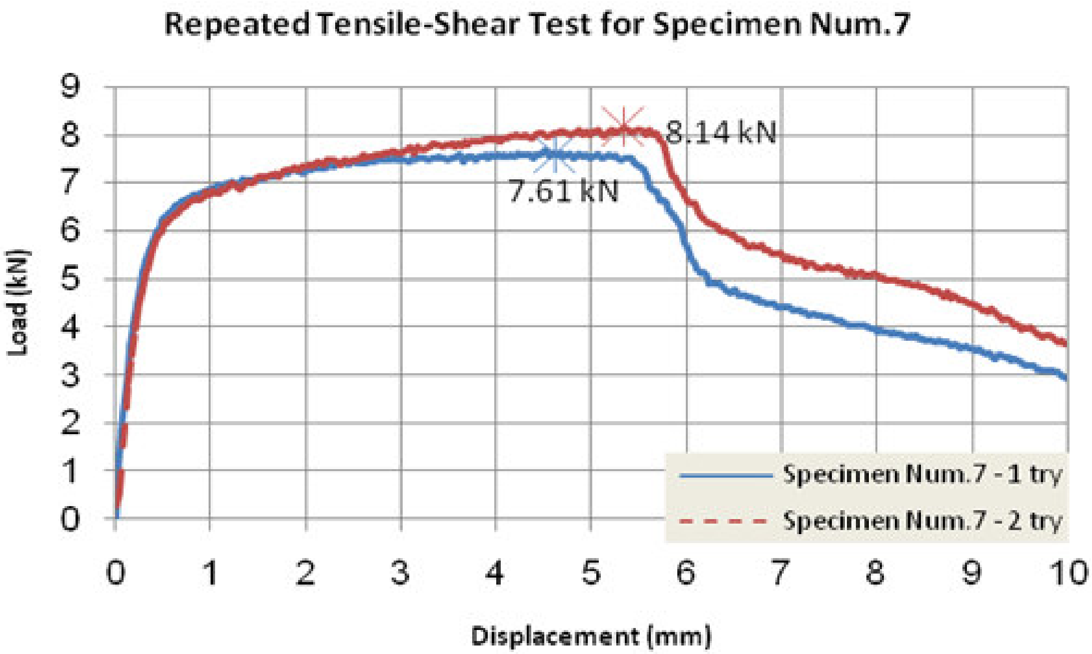

Fig. 5. Testing results accuracy verification.

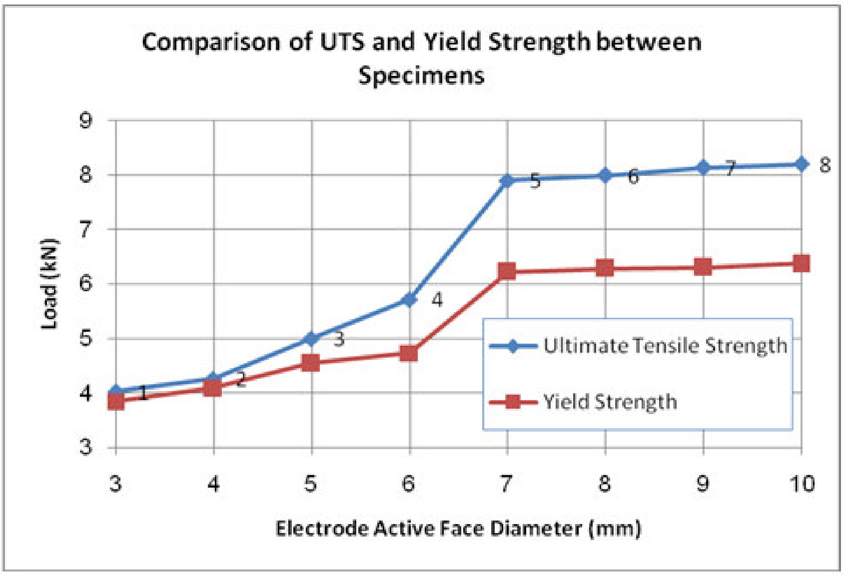

Fig. 6. Changing pattern in UTS and yield Strength values.

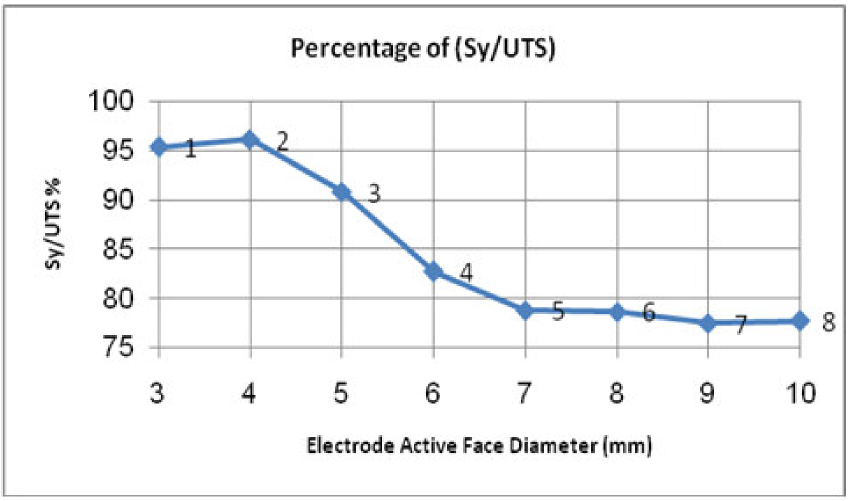

Fig. 7. Effect of active face diameter on S_y / UTS .

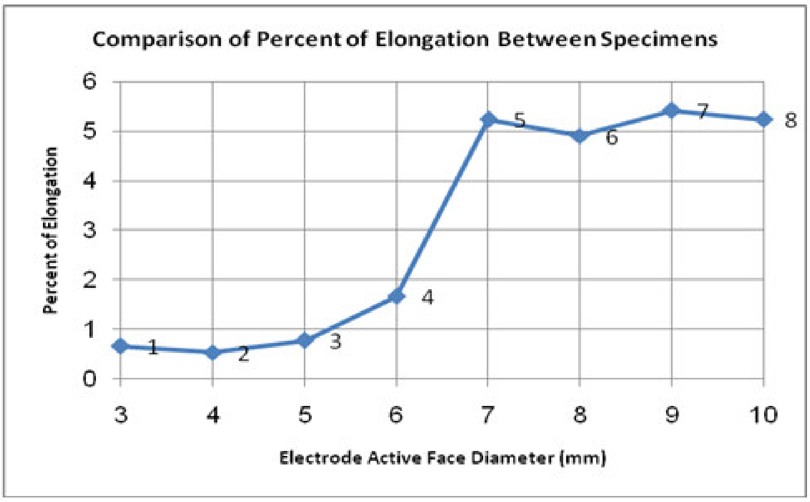

Fig. 8. Effect of active face diameter on elongation percentage.

Therefore failure mode occurred in nugget as shearing. It causes decreasing of load capacity and energy absorption capability. In specimens with nugget diameter 7 to 10 mm, failure location moved to base sheet. With increasing of nugget diameter, the joint cross section increased. It leads to the strength rise of joint. Thus failure occurred in the base sheet as tearing. In specimen with nugget diameter specimen equaled 6 mm, failure mode occurred in the edge nugget as tearing. This is an average case between the two previous modes.

To verify the accuracy of results, the tensile-shear test for random one of the specimens was repeated. In this case specimen No. 7 specimen put under tensile test conditions again. The results are as shown in Fig. 5. Highlighted points are shown the UTS in first and repeated tests. The error percentage of UTS was:

$$\%\,error = \left|\frac{7.61-8.14}{8.14}\right| \times 100 = 6.5\% \tag{1}$$

The amount of this error showed the results were sufficiently accurate and acceptable.

The results which were obtained from tensile-shear tests, give us some specifications like yield strength and UTS. As mentioned before, all of figures expressed in terms of load-displacement instead of stress-strain. The values of yield strength and UTS in specimens with different nugget diameters were calculated and shown in a single diagram (Fig. 6). The values of yield strength, S_y, and UTS increased with increasing of nugget diameter in range 1-4 mm. With increasing of nugget diameter from 6 mm to 7 mm, both yield strength and UTS increased sufficiently, but after 7 mm diameter of nugget they approximately remained constant.

By determining the ratio of S_y /*UTS* for each specimen, a comparison between the ranges of plastic strain was carried out. Results are expressed in Fig. 7. Also, the effect of nugget diameter on elongation is shown in Fig. 8. Based on Figs. 7 and 8, it is observed that the ratio of S_y / *UTS* and elongation in specimens, after No. 5 specimen or after specimen with 7 mm nugget diameter were constant and did not vary with increasing of nugget diameter. Thus, the optimum nugget diameter for having the highest ratio of S_y / *UTS* was 7 mm.

4. Conclusions

In the present study, the effect of nugget diameter on tensile-shear strength of 1 mm thickness AISI 1008 spot welding specimens was investigated and the following results were obtained:

1- Comparison between UTS and yield strength amplitudes showed that with increasing the nugget size both parameters increased up to a certain level and then remained constant which means that load capacity of weld also depends on specimens conditions.

2- The comparison between configurations of specimens failure showed that in specimens with lower nugget diameter, tearing occurred in nugget which is an unwanted occurrence because it resulted in decreasing load carrying and energy absorption capability. Therefore, it is essential to choose an acceptable nugget diameter in design. However with increasing the diameter, failure location moved to nugget edge with tearing in base sheet.

3- Interestingly, the specimens with change in failure location were those that UTS and yield strength, and elongation were remained almost constant.

References

[1] Zuniga, S.; Sheppard, S. D., "Resistance spot weld failure loads and modes in overload conditions", Fatigue and Fracture Mechanics, 1997, 27, 469–489.

[2] Barkey, M. E.; Kang, H., "Testing of spot welded coupons in tension and shear", Experimental Techniques, 1999, 23(5), 20–22.

[3] Lee, Y.; Wehner, T.; Lu, M.; Morrissett, T.; Pakalnins, E., "Ultimate strength of resistance spot welds subjected to combined tension and shear", J. Test. Eval., 1998, 26(3), 213–219.

[4] Lin, S.H.; Pan, J.; Wu, S.R.; Tyan, T.; Wung P., "Failure loads of spot welds under combined

opening and shear static loading conditions", Int. J. Solids Struct., 2002, 39, 19–39.

[5] Yang, Y. S.; Lee, S. H., "A study on the joining strength of laser spot welding for automotive applications ", J Mater Process Tech., 1999, 94, 151–156.

[6] Nong, N.; Keju, O.; Yu, Z.; Zhiyuan, Q., "Research on press joining technology for automotive metallic sheets", J Mater Process Tech., 2003, 137, 159–163.

[7] Anık S., "Welding technique handbook, processes and equipments", Turkey: Kansu Printed, 1991.

[8] Eryu¨rek, B., "Electrical resistance welding", Mech. Eng. Mag., 1983, 279, 22–31.

[9] Chao, Y. J., "Failure of Spot Weld: A competition between crack mechanics and plastic collapse, Recent advances in experimental mechanics", Kluwer Academic Publishers, 2002.

[10] Pouranvari, M.; Marashi S.P.H., "On the failure of low carbon steel resistance spot welds in quasi-static tensile–shear loading", Materials and Design, 2010, 31(8), 3647-3652.