EFFECT OF ELECTRODE FORCE ON FRACTURE TYPE OF DQSK STEEL RESISTANCE SPOT WELDS

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Abstract
Failure mode is a qualitative measure of resistance spot weld performance. To ensure reliability of resistance spot welds during vehicle lifetime, process parameters should be adjusted so that the pullout failure mode is guaranteed. In this paper, the effect of electrode force on the failure mode of drawing quality specially killed (DQSK) steel resistance spot welds during the quasi-static tensile-shear test is investigated. Results showed that there is a minimum weld nugget size to ensure pullout failure mode. It was found that increasing electrode force decreases fusion zone size and therefore leads to transition of failure mode from pullout to interfacial mode.

Keywords: resistance spot welding, electrode force, failure mode, steel

1 Introduction

Resistance spot welding is considered as the dominant process for joining sheet metals in automotive industry. Typically, there are about 2000–5000 spot welds in a modern vehicle. Simplicity, low cost, high speed (low process time) and automation possibility are among the advantages of this process. Quality and mechanical behavior of spot welds significantly affect durability and crashworthiness of the vehicle [1-2].

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 one, failure occurs via complete (or partial) nugget withdrawal from one sheet. The Failure mode under which RSWs fail, can significantly affect their carrying capacity and energy absorption capability. Spot welds that fail in the nugget pullout mode provide higher peak loads and energy absorption levels than spot welds that fail in the interfacial fracture one. To ensure reliability of spot welds during vehicle lifetime, process parameters should be adjusted so that the pullout failure mode is guaranteed [2-10].

It is well established that the geometrical attributes of spot welds, particularly weld nugget size, are the most important controlling factors determining the mechanical strength of RSWs [8-15]. Welding parameters (e.g. welding current, welding time, electrode force, etc.) affect weld nugget size which in turn governs the failure mode and mechanical properties of spot welds. In this paper the effect of electrode force on the failure mode of a drawing quality specially killed (DQSK) low carbon steel resistance spot welds is investigated and analyzed.

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2 Experimental procedure

A 2 mm thick DQSK low carbon steel sheet was used as the base metal, in this research. The chemical composition of the steel is Fe-0.06C-0.17Mn-0.04Si. The yield strength, ultimate tensile strength and total elongation of the sheet are 190 MPa, 340 MPa and 45%. Spot welding was performed using a PLC controlled, 120 kVA AC pedestal type resistance spot welding machine. Welding was conducted using a 45-deg truncated cone RWMA, Class 2 electrode with 8-mm face diameter. The used welding schedule is given in **Table 1**.

Table 1 Welding parameters used in the present work

Squeeze Time (s)	0.6
Welding Current (kA)	13
Welding Time (s)	0.18
Electrode force (kN)	4.5-5-5.5-6-6.5-7
Holding time (s)	0.4

The static tensile-shear test samples were prepared according to ANSI/AWS/SAE/D8.9-97 standard [16]. Tensile-shear tests were performed at a cross head of 2 mm/min with an Instron universal testing machine. Peak load (measured as the maximum point in the load-displacement curve) was extracted from the load-displacement curve. Failure mode was determined from the failed samples.

For metallographic observation, samples were cut along the center of the spot weld nugget in the direction of the width of sample. Subsequently, standard metallographic procedure was applied for microstructural as well as macrostructural investigations. Optical microscopy was used to examine the microstructures and to measure physical weld attributes.

3 Results and discussion

Fig. 1 shows a typical macrostructure of the spot weld indicating three distinct microstructural zones in the joint region: (i) Fusion zone (FZ) or so called weld nugget, (ii) Heat Affected Zone (HAZ), (iii) Base Metal (BM).

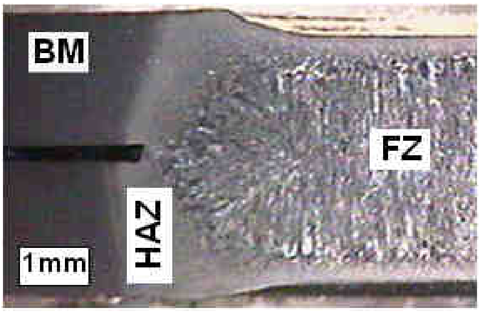

Fig. 1 A typical macrostructure of low carbon steel resistance spot weld

Two distinct failure modes were observed during the static tensile-shear test: interfacial fracture and nugget pullout. **Fig. 2** shows the typical fracture surface of spot welds failed in interfacial failure (IF) mode and pullout failure (PF) mode. As can be seen the pullout failure is a double failure (i.e. failure occurred in both sheets).

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Fig. 3 shows the effect of electrode force on the FZ size and failure mode. As can be seen increasing electrode force decrease the FZ size. The amount of heat generated at the sheet-to-sheet interface during the spot welding process is mainly responsible for nugget formation and its strength. Generated heat during resistance spot welding can be expressed as follows:

$$Q = R\,I^2 t \tag{3.}$$

Where, Q, R, I and t are generated heat, electrical resistance, welding current and welding time, respectively. Static electrical resistance (i.e. contact resistance) is mainly governed by the electrode force which in turn controls the weld nugget formation [8]. In a ductile material, as normal force is applied across the contact interface, the number of surface asperities supporting the applied load gradually increases due to their successive yielding. In other words, the true contact area will initially be a relatively small fraction of the macroscopic or apparent contact area. The true contact area will increase with the application of load and, in the limit, will approach the apparent contact area. Therefore, increase in electrode force, decreases the electric resistance and thus reduces the generated heat at the sheet/sheet interface.

(a) (b)

Fig. 2 Observed failure modes during tensile-shear test a) interfacial failure mode b) pullout failure mode

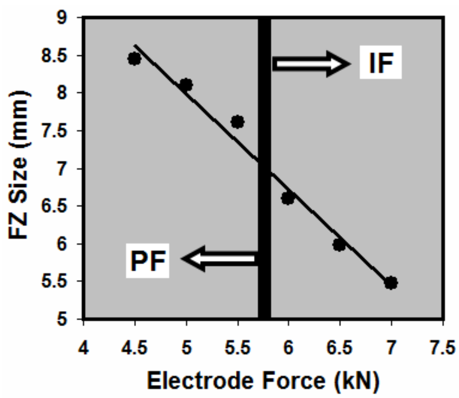

Fig. 3 Effect of electrode force on the FZ size and failure mode

According to **Fig. 3**, increasing electrode force leads to transition in failure mode from pullout to interfacial failure mode. This can be explained as follows:

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During the tensile-shear test, the shear stress at the sheet/sheet interface and the tensile stress created in the nugget circumference are the driving force for the interfacial and pullout failure mode, respectively. Each driving force has a critical value and the failure occurs in a mode in which the driving force reaches its critical value, sooner. Physical weld attributes particularly weld nugget size are the most important governing parameters of the failure mode of resistance spot welds. Weld nugget size is the most important parameter determining stress distribution.

For those welds with small weld size, the shear stress reaches its critical value before tensile stress causing failure in the circumference of the FZ (BM or HAZ). Therefore, failure tends to occur under interfacial failure mode. Increasing FZ size, increases the weld nugget resistance against interfacial (i.e. shear) failure. Therefore, there is a critical FZ size above which pullout failure mode is ensured. The existence of a critical FZ size is reported in the literature [8-13].

The deriving force for the interfacial failure mode is the shear stress at the sheet/sheet interface in the weld nugget centerline which depends on the area of the weld nugget in the plane of sheet/sheet interface. The shear stress at sheet/sheet interface can be approximated using following relation:

$$\tau = \frac{4F}{\pi D^2} \qquad (4.)$$

Where, F is the applied force and D is the weld nugget size.

Accordingly, as the weld nugget size decreases, the shear stress experienced by sheet/sheet interface increases. Therefore, increasing electrode force beyond a critical limit increases the risk of the interfacial failure mode due to the small weld nugget size. **Fig. 4** shows the effect of electrode force on the peak load.

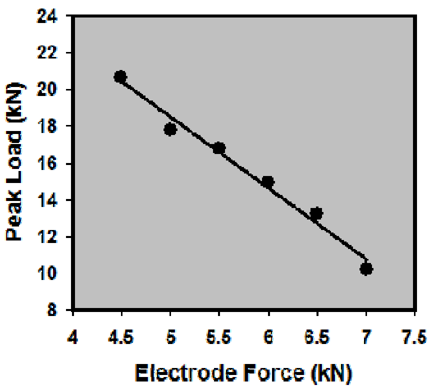

Fig. 4 Effect of electrode force on the peak load

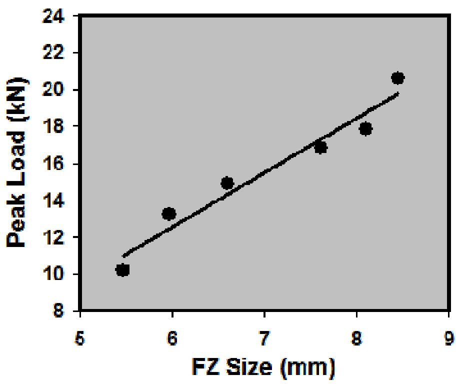

Fig. 5 Effect of FZ size on the peak load of DQSK resistance spot welds under tensile-shear test

As can be seen increasing electorde force decreases peak load of the spot welds. **Fig. 5** shows the effect of FZ size on the peak load. As can been there is a direct relation between FZ size and load bearing capacity of the spot welds. It can be concluded that the weld FZ size is the main controlling factor of the RSW mechanical properties.

This can be attributed to

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

4 Conclusions

The following conclusions can be drawn from this study:

(1) Increasing electrode force decreases fusion zone size due to reducing the contact resistance.
(2) Increasing electrode force leads to change in failure mode from pullout to interfacial failure mode.
(3) Increasing electrode force beyond a critical limit increases the risk of the interfacial failure mode due to the small weld nugget size.
(4) Increasing electrode force leads to failure of spot welds at lower load.

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