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Spot Welding between Stainless and Galvanised Steels with Microstructural Analysis

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Abstract:- In this paper, behaviour of dissimilar resistance spot welded joints of low carbon and Austenitic stainless steels was studied under tensile-shear test with attention focused on the failure mode. The experimental results show that in pullout failure mode, necking is initiated at nugget circumference and then the failure propagates along the nugget circumference in the sheet to final fracture. Necking location was low carbon steel side. Results showed that there is a critical fusion zone size to ensure pullout failure mode in shear tensile test, which is mainly controlled by ratio of fusion zone hardness and failure location hardness. In the case of dissimilar resistance spot welding, the hardness of the fusion zone which is governed by the dilution between two base metals, and fusion zone size of low carbon steel side are dominant factors in determining the failure mode of the joint.

Keywords:- Nugget, microstructure, RSW

I. INTRODUCTION

The quality and mechanical behaviour of resistance spot welds (RSW) significantly affect durability and crashworthiness of vehicle. Overload Failure mode of spot welds is a qualitative measure of the weld reliability. Generally, the spot weld failure occurs in two modes: interfacial and pullout. In the interfacial mode, failure occurs through nugget, while in the pullout mode, failure occurs by complete (or partial) nugget withdrawal from one sheet. Load carrying capacity and energy absorption capability for those welds which fail under the overload interfacial mode are less than those welds which fail under the overload pullout mode. To ensure the reliability of the spot welds during vehicle lifetime, process parameters should be adjusted so that the pull out failure mode is guaranteed [CHAO 2003, POURANVARI et al 2007].

Dissimilar resistance spot welding can be more complex than similar welding due to different thermal cycle experienced with each metal. Despite of various application of dissimilar RSW, reports in the literature dealing with mechanical behaviours of them are limited. The objective of this research is to investigate and analyse failure behaviour of dissimilar resistance spot welds between low carbon steel and austenitic stainless steel.

II. EXPRIMENTAL PROCEDURE

A 1.1 mm thick galvanized low carbon and 1.2 mm thick austenitic stainless steel sheets were used as the base metals, in this research. The chemical composition of galvanized steel (GS) and stainless steel (SS) is given in Table1. Spot welding was performed using a 120 kVA AC pedestal type resistance spot welding machine, controlled by a PLC. Welding was conducted using a 45-deg truncated cone RWMA Class 2 electrode with 7-mm face diameter.

The static tensile-shear test samples were prepared according to ANSI/AWS/SAE/D8.9-97 standard. Fig.1 shows the sample dimensions. Tensile-shear tests were performed at a cross head of 2 mm/min with an Instron universal testing machine. Peak load and failure energy (measured as the area under the load displacement curve up to the peak load) were extracted from the load-displacement curve. Failure mode was determined from the failed samples. The welding time, electrode pressure and electrode holding time were kept constant at 4 bar, 12 and 30 cycles ((1 cycle=50 Hz), respectively. Welding current was in the range of 7 to 13 kA.

Table1. Chemical composition of test materials (%Wt)

Element	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Nb	Fe
SS	0.035	1.08	0.038	0.004	0.388	18.47	9	0.561	0.462	0.016	Base
GS	0.065	0.404	0.018	0.017	0.095	0.017	0.032	0.004	0.053	0.001	Base

Samples for metallographic examination were prepared using standard metallography procedure. Optical microscopy was used to examine the microstructures and to measure physical weld attributes. After complete separation in the tensile-shear test failure location of samples was examined with optical microscope

Microhardness test, a technique that has proven to be useful in quantifying microstructure-mechanical property relationships, was used to determine the hardness profile in vertical (through thickness) and horizontal directions (50 µm away from weld center line for galvanized steel side and stainless steel side), using a 100g load on a Shimadzu microhardness tester.

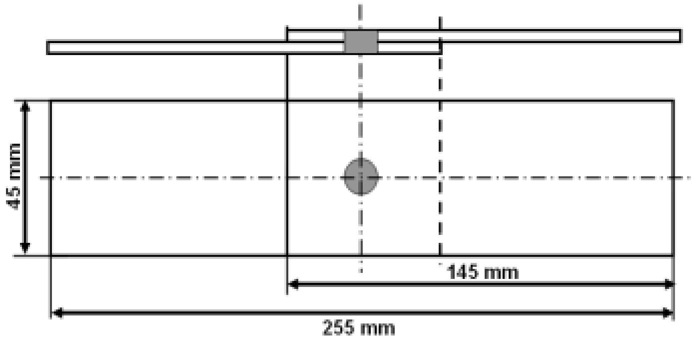

Fig.1 Tensile-shear test sample dimension

III. RESULTS AND DISSCUSION

3-1-Microstructure and Hardness profile of the joint

Fig.3 shows a typical macrostructure of a dissimilar resistance spot weld between galvanized low carbon steel and austenitic stainless steel. As can be seen, the joint region consists of three distinct structural zones: i)
Fusion Zone (FZ) or weld nugget, ii) Heat Affected Zone (HAZ), and iii) Base Metal (BM).

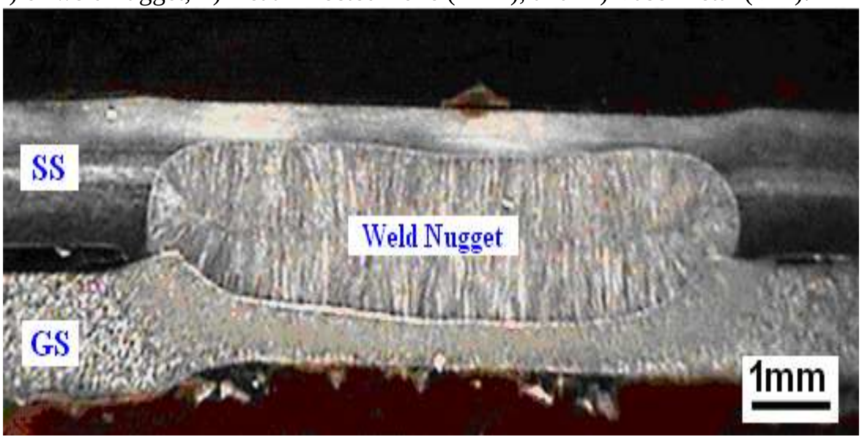

Fig.2 Macrostructure of dissimilar RSW between galvanized steel and stainless steel

One of the important features of the weld nugget is its asymmetrical shape such that fusion zone size (FZS) and penetration depth of stainless steel side are larger than those of galvanized steel side. Electrical resistance and thermal conductance control heat generation and heat dissipation which in turn, affect weld nugget formation and its growth. Differences in the thermal conductivity and electrical resistivity of two steel sheets lead to an asymmetrical weld nugget in dissimilar metal joints. Lower electrical resistance of carbon steels, which is even lower for low carbon galvanized steel sheet, and its higher thermal conductivity compared to stainless steel leads to smaller fusion zone in the former.

HAZ in the galvanized steel side is wider than that in the stainless steel side, which can be related to higher thermal conductivity of galvanized steel.

Fig. 3 shows variation of physical weld attributes as a function of welding current. As can be seen, the FZS of both stainless and galvanized steel sides increases with the welding current at a decreasing rate with the exception of really high currents (more than 11 kA) which show a decrease in the FZS due to expulsion.

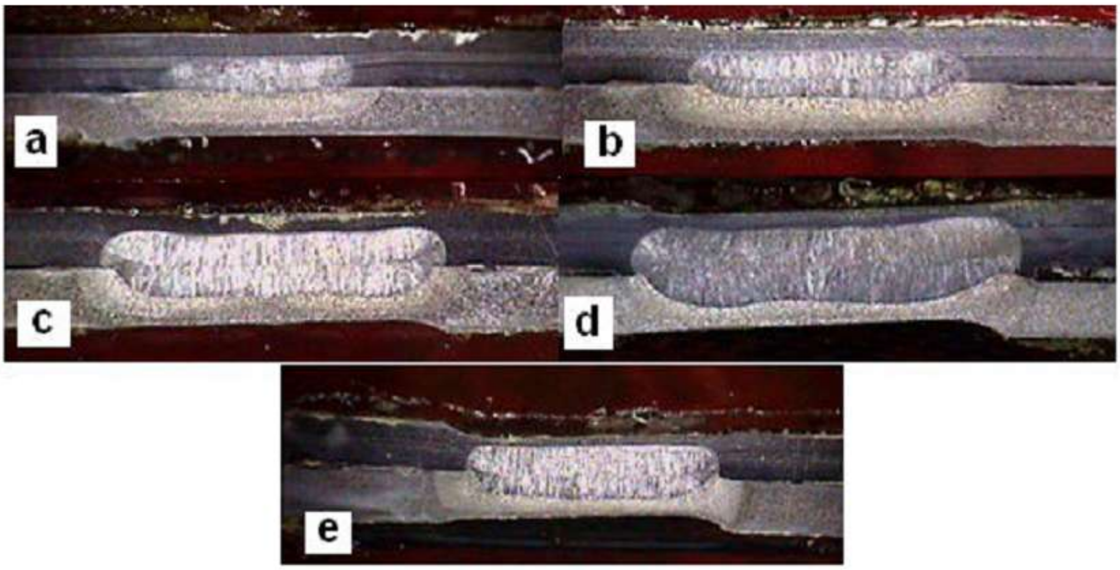

Fig.3 Effect of welding current on the weld nugget growth: a) 8kA b) 9kA c) 10 kA d) 11kA

In this study two different types of hardness profile were observed as a function of welding current. Effect of welding current on the average hardness of the fusion zone is shown in Fig.4.

Typical vertical hardness profile for spot welds made with IW>8kA is shown in Fig.5a. As it can be seen, the hardness of the weld nugget is much higher than the hardness of both base metals. Higher hardness of the weld nugget can be attributed to martensite formation in this zone. Microstructure of fusion zone of dissimilar metal joint between low carbon and stainless steel can be predicted using constitution diagrams, e.g., Schaeffler diagram. It should be noted that the application of this diagram might be inaccurate due to very high cooling rates of RSW process. The predicted microstructure of the weld nugget of a dissimilar joint between galvanized and stainless steel using Schaeffler diagram is fully martensite (Fig.4), when volum fraction of galvanized steel in weld nugget is 60%. It should be noted that changing of the welding current in this range (>8 kA) has no

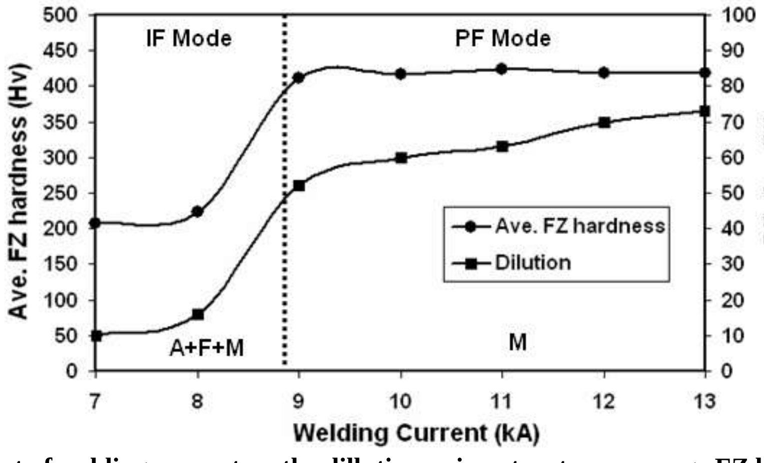

Fig.4 Effect of welding current on the dillution, microstructure, average FZ hardness and Failure mode of the dissimilar joint

Significant effect on the weld nugget hardness (See Fig.4). Welding current affect geometrical characteristics of weld nugget e.g. FZS, and hence changes the dilution is (defined as galvanized to weld nugget volume ratio) (Fig.4). However, as it can be seen from Schaeffler diagram (Fig.6) changing the dilution in 30%-90% range has no effect on the predicted microstructure which can explain weak dependence of the weld nugget hardness on the welding currents greater than 8kA.Different hardness profile for spot welds made with welding currents of 7 and 8 kA was observed. Fig.5b shows the hardness profile of the spot welds made with 8kA welding current which illustrates that the weld nugget hardness is much lower than that of the spot welds made with IW>8kA.

Macro structural examination of spot welds made with 7kA and 8kA welding current showed that dilution is about 10% and 16%, respectively. In both conditions Schaeffler diagram predicts an austenitic structure plus some amount of ferrite and martensite which justifies lower hardness of the weld fusion zone in these cases.

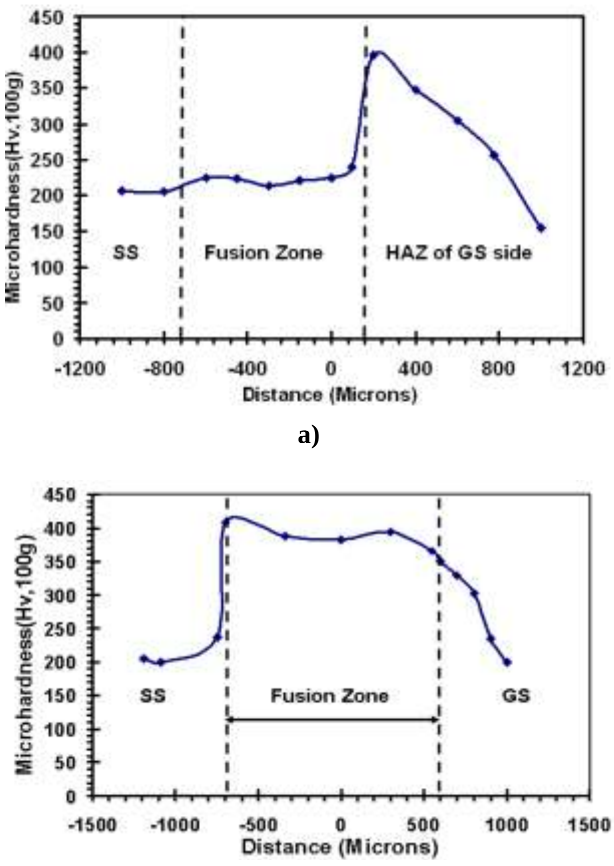

Fig.5 Vertical hardness profile for spot welds made with welding current of a)11kA and b) 8kA

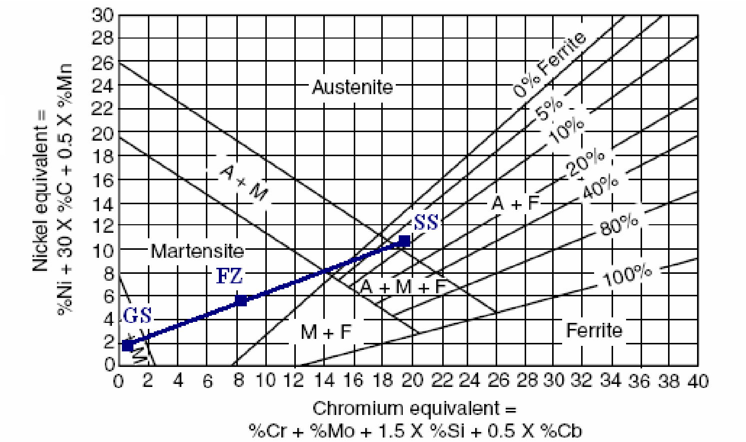

Fig.6 Schaeffler diagram, fusion zone microstructure prediction, when weld nugget consists of 60% galvanized steel

3-2-Failure Behaviour

The experimental results indicate that welding current has a significant effect on the load carrying capacity and energy absorption capability of the spot welds under tensile-shear static test. As can be seen in Fig.7 increasing welding current leads to increasing the peak load and failure energy of dissimilar joint primary due to increasing FZS and fusion penetration depth. Two distinct failure modes were observed during static tensile-shear testing: interfacial fracture and nugget pullout, as shown in Fig.8(a and b). In some cases, sheet tearing was observed after nugget pullout (Fig. 8c). Effect of the welding current on the failure mode is shown in Fig.4. As can be seen in Fig.7, failure mode has a significant influence on the peak load and failure energy of spot welds. Energy absorption capability is an important parameter in vehicle crashworthiness

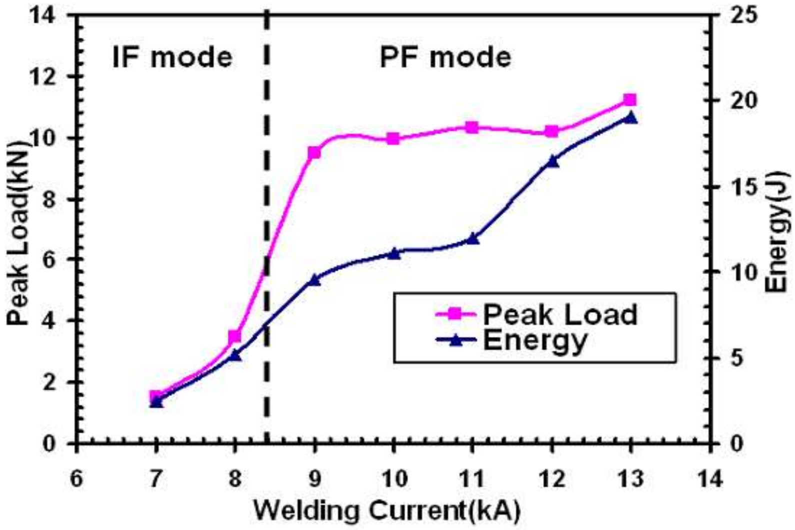

Fig.7 Effect of welding current on the peak load and failure energy

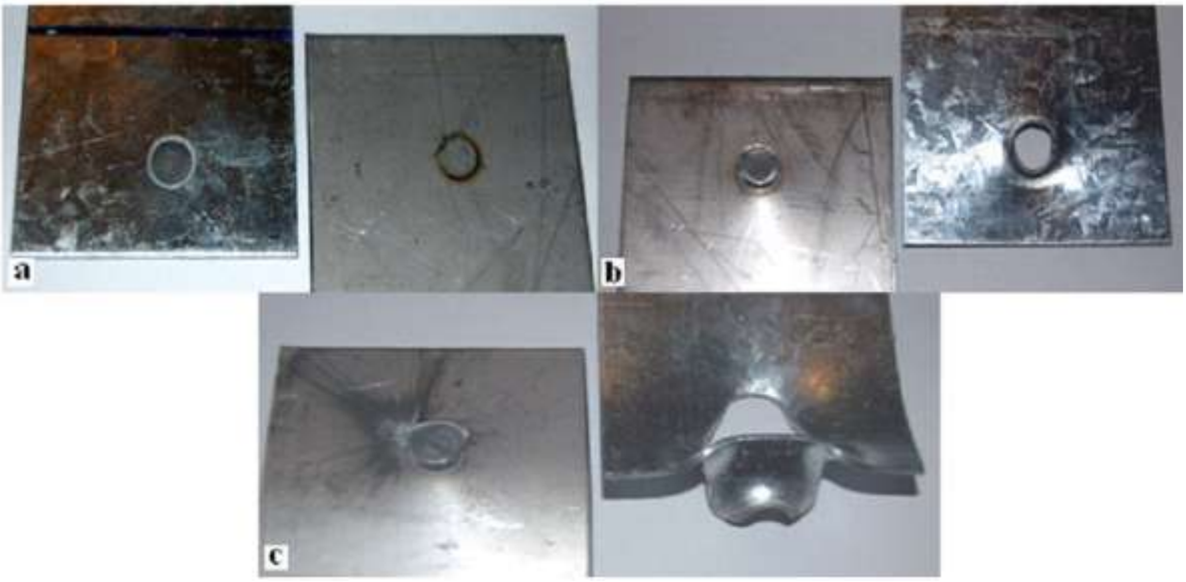

Fig.8 (a) Interfacial failure mode, (b) pullout failure mode and c) nugget pullout followed by Sheet tearing.

Fig.9 shows macrograph of fracture surface of a spot weld which failed at pullout mode indicating the nugget is pulled out from galvanized steel. The failure of the spot weld appears to be initiated near the middle of the nugget circumference in the GS sheet, and then propagated by necking/shear along the nugget circumference in the GS sheet until the upper sheet is torn off. Since tensile strength and hardness of galvanized sheet is lower than stainless steel sheet, the galvanized sheet experienced a severe necking leading to the initiation of the failure in this point. Therefore, it is concluded that the spot weld strength in the pullout failure mode is controlled by the strength and FZS of the galvanized steel side.

Failure mode of spot welds is dictated by FZS, sheet thickness and ratio of weld nugget hardness to failure location hardness. During static tensile-shear test. Pouranvari et al. (POURANVARI et al. 2007) proposed a simple analytical model to predict minimum FZS required to ensure pullout failure mode of spot welds during the tensile-shear test. Critical FZS (d_{Cr}) was attributed to sheet thickness (t) and weld nugget to failure location hardness ratio (HWN/HFL), as follows:

$$d_{Cr} = 8t\frac{H_{FL}}{H_{WN}}$$

Accordingly, interfacial failure mode of the spot welds formed with welding current of 7 and 8 kA, can be related to the lower hardness of the weld nugget which provides lower resistance to crack propagation, and its small FZS which is experiencing much higher shear stress at the nugget interface during the tensile-shear test. However, increase in welding current beyond 8 kA, increases FZS and H_{WN}/H_{FL},which in turn, reduces interfacial failure susceptibility.

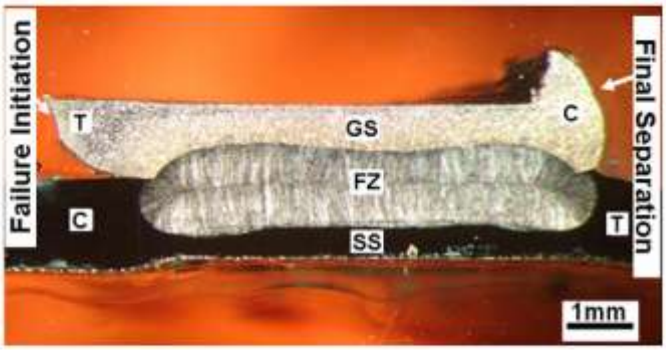

Fig.9 Macrograph of fracture surface cross section, T: Subjected to tensile stress
C: Subjected to compressive stress

IV. CONCLUSIONS

From this research the following conclusions can be drawn:

1- For dissimilar RSW between low carbon galvanized steel and austenitic stainless steel asymmetric fusion zone was obtained due to their different electrical resistivity and thermal conductivity.
2- Fusion zone size and failure mode are the most critical factors in the weld quality in terms of peak load and energy absorption which is governed by the welding parameters such as welding current, welding time and electrode force.
3- Spot weld strength in the pullout failure mode is controlled by the strength and fusion zone size of the galvanized steel side.
4- The hardness of the fusion zone which is governed by the dilution between two base metals, and fusion zone size of galvanized carbon steel side govern failure mode.
5- For spot welds made at low welding currents, low fusion zone hardness and small fusion zone size led to experiencing interfacial mode during shear-tensile test. While for spot welds made at high welding currents, higher hardness of fusion zone due to martensite formation and larger fusion zone led to experiencing pullout failure mode during tensile-shear test.

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