Investigation of the Quality and Mechanical Properties for Spot Welding of Reworked Galvanneal and High Strength Steel (HSS)

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ABSTRACT

Resistance spot welding is one of the factors that determine the crashworthiness of a vehicle. It is quite normal that in the automotive industry the outer panel is being stoned using whetstone when the worker is trying to find the defect at the panel. The aim of this study is to investigate the welding quality and mechanical properties of 2 layer welding sheet containing a reworked galvanneal metal sheet with HSS. Another set of material consisted of non-reworked galvanneal metal and HSS were welded together as the reference. The welded samples were prepared according to the ISO 14273:2000. Welding parameters for both types of samples were kept the same. The tensile strength, hardness and microstructure of the welded material were checked and the nugget diameters were compared tone another. Based on the results, it was concluded that the rework process of the galvanneal metal sheet did not change much the quality and the mechanical properties of the spot welding.

Keywords: *Mechanical properties; Spot welding; Galvanneal; High Strength Steel*

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Introduction

Resistance spot welding is the most common metal joining technique can be found in a vehicle. The quality of the spot welding is crucial since it determines the safety of occupants. It is reported that the welding quality determines the crashworthiness of a vehicle [1]. The metal sheets used in a vehicle are selected based on the function and necessities. Galvanneal metal sheets are usually used at the outer panel while HSS is used for the vehicle structure. Excellence in corrosion resistance property, the galvanneal metal sheet also has excellent weldability and formability property [2]. HSS in another hand is being widely used in the structure part due to the excellence of its properties to withstand impact during a crash test. It is also widely used as it helps in reducing the body weight of a vehicle.

Many researchers focus the study of dissimilar material in spot weld since the materials used in a vehicle vary. For an instance, Yuan et al. [3] found that the tensile strength of different material experienced increasing and decreasing of tensile strength while there were changes to the nugget size diameter. Marashi et al., in another hand, found that spot welds at high welding currents gave a higher hardness of fusion zone due to martensite formation and larger fusion zone [4]. It is quite normal in the automotive industry that the panel, especially the outer panel is being stoned using whetstone when the worker is trying to find the defect at the panel [2]. The stoning process will remove the thin layer of Zinc coating existing at the surface of the panel. Though there is much research on dissimilar spot weld, the investigation on spot weld of the reworked panel can rarely be found. This paper is to evaluate the welding quality of 2 layer spot welding, containing a reworked galvannealed metal sheet with HSS and a non-reworked galvannealed metal sheet with HSS. The welding characteristic is compared with the available standard by ANSI/AWS/SAE.

Experimental procedure

The samples used for this research were galvanneal metal sheet and HSS, with thickness for each material 0.7mm and 0.75mm respectively. The chemical composition for each sample is shown below. As shown in Table 1 and Table 2, HSS material had shown a higher content of Carbon, which reflects the higher strength compared to galvanneal metal.

As being shown in Figure 1 and 2, it can be clearly seen that the microstructure of galvanneal metal in Figure 1 primarily consists of martensite and HSS in Figure 2 and consists of austenite.

Table 1: Chemical composition in HSS

C	Si	Mn	P	S
0.8%	0.72%	1.74%	0.09%	0.02%

Table 2: Chemical composition in galvanneal metal

C	Si	Mn	P	S	Sol-Al
0.014%	0.2%	0.85%	0.09%	0.02%	0.5%

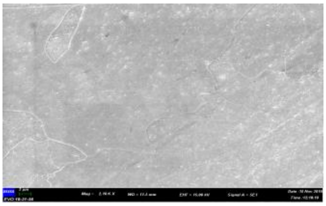

Figure 1: SEM image of microstructure of the HSS material

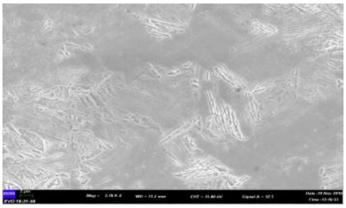

Figure 2: SEM image of microstructure of the galvanneal material

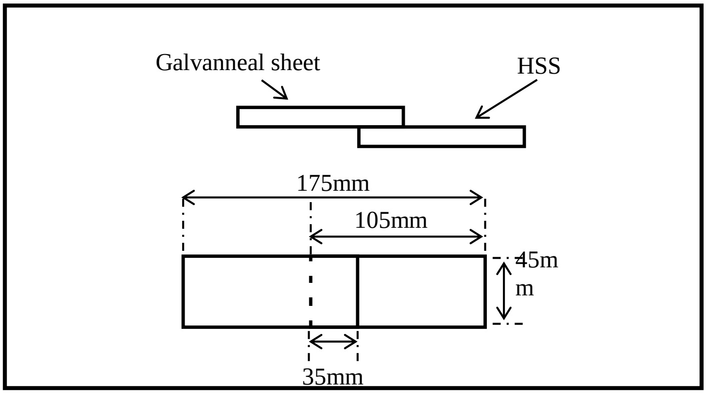

Figure 3: Schematic drawing of sample size and orientation for spot welding

The galvanneal metal sheet was first reworked using abrasive paper to remove the zinc coating. Once the surface finish became shiny they were then welded with HSS material. Another set of welding samples were the combination of non-reworked galvanneal metal sheet and HSS. The size of the material was cut according to the ISO 14273. Figure 3 shows the schematic drawing of the sample size and welding orientation used in this research.

The welding parameters for both specimens were set to the same parameters. Welding parameters for both samples are shown in table 3.

Table 3: Welding parameter

Parameter	**Value**
Current	1.5kA
Pressure	3 bar
Weld time	32 cycle

The nugget size and mechanical properties such as tensile strength, hardness and microstructure for each set of samples were then checked and compared.

Results And Discussion

Nugget Size

Table 4 above displays the nugget size of the sample with a reworked galvanneal metal sheet and HSS, and sample with a non-reworked galvanneal metal sheet and HSS. The sizes of the nugget were checked using a vernier calliper. The nugget size of samples containing non-reworked galvanneal metal sheet was 2.5% larger than samples containing reworked galvanneal metal sheets.

Table 4: Size of the nugget

Sample	Nugget diameter(mm) (sample with galvannealed)	Nugget diameter(mm) (sample with reworked galvannealed)
1	6.1	6.0
2	6.2	6.2
3	6.4	5.6
4	6.3	6.1
5	6.1	6.4

The galvanneal metal sheet is practically the metal sheet containing a zinc layer. During the spot weld process, the zinc coating in non-reworked galvanneal metal sheet decreased the resistance. This is due to the fact that zinc has a lower melt temperature compared to the steel itself. At the first few cycles of spot welding, the zinc becomes molten at the early stage. The molten zinc then will be pushed toward the periphery of the electrode tip and created halo formation in the 1^{st} few cycles. The zinc halo was reported as an excellent conductor and helped lower the total resistance [5]. The formation of zinc halo in samples containing non-reworked galvanneal sheets thus increased the conductivity of the metal sheets during spot welding. It thus increased the nugget size diameter of the samples containing non-reworked galvanneal metal sheet.

The equation (1) below shows the standard recommended by ANSI/AWS/SAE; where *t* is the total thickness of the welded materials.

$$d=4\sqrt{t} \tag{1}$$

ANSI/AWS/SAE recommended a nugget size diameter of 4.82mm for the welding of samples with 1.45mm thickness. Sun et al. [6] had indicated that the undersized weld button would have an average weld nugget diameter larger than $2\sqrt{t}$ and less than $4\sqrt{t}$. The nugget size of samples containing reworked galvanneal metal sheet and non reworked galvanneal metal sheet were 6.06 ± 0.3(mm) and 6.22 ± 0.13(mm) respectively. The value conformed to the requirement of the minimum nugget size recommended by ANSI/AWS/SAE and both exceeded the diameter of $2\sqrt{t}$.

Failure Mode And Tensile Strength

The tensile strength for both of the samples was checked using Shimadzu Universal Testing Machine. The velocity head was set to 10mm/min. Figure 4 and 5 shows the mode of failure of the samples. As being depicted in the pictures, both types of samples depicted the pullout failure. The pullout failure mode was the desired failure mode in a resistance spot welding process, where the weld nugget is pulled out from the sheet. As being shown in Figure 4 and 5, the fracture initiated along the HAZ interface, and a similar trend was also found in the work of Tumuluru et al. [7]. The initiated failure at the HAZ also indicated the softening reaction occurred at the area [8].

Table 5 shows the maximum stress exhibited by both samples during the tensile shear test. The average maximum stress recorded for samples containing non-reworked galvanneal metal sheet was 507.16 ±16.76 MPa, while the samples containing reworked galvanneal metal sheet was recorded as 524.51 ±23.03MPa. The difference of the maximum stress for both samples was merely 3.3%.

Based on the further investigation of the microstructure of the HAZ, it was a clear evidence that the HAZ of the reworked galvanneal metal sheet in figure 7 showing a huge formation of martensite compared to HAZ of the non-reworked galvanneal metal sheet in figure 6. This might be due to the reworked process; removing the zinc layer at the galvanneal metal sheet which increased the resistance during spot welding process. It thus generated more heat compared to the samples containing non-reworked galvanneal metal sheet. The higher heat generated and the rapid cooling during spot welding process might have increased the formation of martensite at the HAZ area.

Figure 4: Pull out failure in sample with galvanneal metal

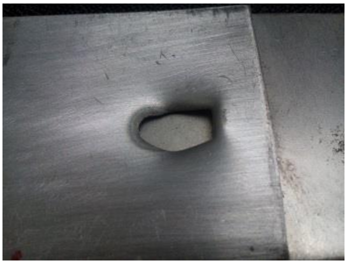

Figure 5: Pull out failure in sample with reworked galvanneal metal

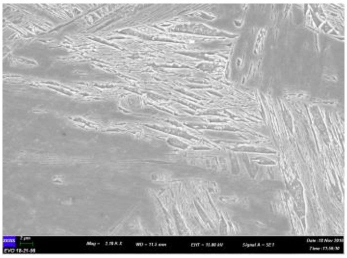

Figure 6: Martensite formation in the HAZ of sample with galvanneal

Figure 7 Higher martensite formation in the HAZ of sample with reworked

Hardness

The hardness of the nugget for both samples was measured, and the result is shown in Table 6 above. The hardness of the specimens was investigated using Brinell Hardness Tester.

Table 5: Maximum stress for each sample

Sample	Max stress, MPa (sample with galvannealed)	Max stress, MPa (sample with reworked galvannealed)
1	491.78	515.504
2	535.686	507.241
3	502.868	516.812
4	499.914	517.97
5	505.529	565.013

The average reading for the hardness of the fusion zone for samples containing reworked galvanneal metal and non-reworked galvanneal metal were recorded as 71.72 ± 4.93 HRB and 72.92 ± 4.93 HRB respectively. The similar chemical composition in both samples contributed to the similar result in the hardness value [9]. The heat transferred to the welded material and rapid cooling during spot welding process transformed the microstructure of the material into complete martensite, as being shown in Figure 8 and 9.

Table 6 Hardness of the fusion zone

Sample	Hardness HRB (sample with galvanneal)	Hardness HRB (sample with reworked galvannealed)
1	72.7	73.8
2	79.6	68.4
3	65.7	76.3
4	73.5	75.3
5	73.1	64.8

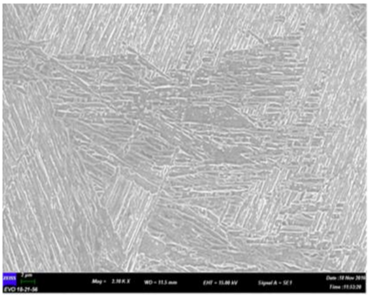

Figure 8: Martensite formation in fusion zone of samples with reworked galvanneal metal

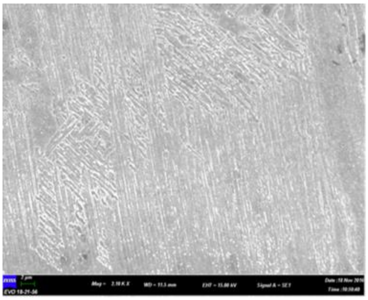

Figure 9: Martensite formation in fusion zone of samples with galvanneal metal

Conclusion

Based on the mechanical testing results of both types of samples, it can be concluded that:

i. The nugget size of the welded samples containing reworked galvanneal steel was smaller compared to the samples containing non-reworked galvanneal metal sheet. The existence of the Zn coating at the surface of non-reworked galvanneal metal sheet decreased the resistance of the material during spot welding process resultant in a bigger nugget size. However, both samples conformed to the requirement of recommended nugget size by ANSI/AWS/SAE.

ii. Both samples exhibited a pullout failure mode which is the desired result test in tensile-shear testing for the resistance spot welding process. The pullout failure initiated at the HAZ area suggesting that it underwent softening effect during spot welding process.

iii. The tensile strength of the material with slightly different due the reworked process of the galvanneal metal sheet. The samples containing reworked galvanneal material had shown a higher tensile strength compared to the other samples. Further SEM checking on the microstructure of the HAZ area indicated of higher martensite formation at the area.

iv. The hardness of the fusion zone for both types of samples was slightly similar. This is due to the fact that the microstructure of the fusion zone completely changed into martensite.

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References

[1] J. Lim, J. Ha, and C. Oh, "Practical Failure Criterion of Spot Weld for Crash Simulation." (2015)

[2] S. Hazra, R. Roy, D. Williams, R. Aylmore, and D. Hollingdale, "Journal of Materials Processing Technology A Novel Inspection Method for Determining the Cosmetic Quality of Automotive Skin Panels." Journal of Materials Processing Tech. 213 (11). Elsevier, 2049–63 (2013

[3] X. Yuan, C. Li, J. Chen, X. Li, X. Liang, and X. Pan, "Resistance Spot Welding of Dissimilar DP600 and DC54D Steels." Journal of Materials Processing Technology 239, 31–41 (2017)

[4] P. Marashi, M. Pouranvari, S. Amirabdollahian, A. Abedi, and M. Goodarzi, "Microstructure and Failure Behavior of Dissimilar Resistance Spot Welds between Low Carbon Galvanized and Austenitic Stainless Steels" 480: 175–80, (2008).

[5] S.A. Gedeon, and T. W. Eagar, "Resistance Spot Welding of Galvanized Steel: Part II. Mechanisms of Spot Weld Nugget Formation." Metallurgical Transactions *B* 17 (4), 887–901(1986).

[6] X.Sun, E. V. Stephens, and M. A. Khaleel, "Effects of Fusion Zone Size and Failure Mode on Peak Load and Energy Absorption of Advanced High-Strength Steel." Welding Research, 18–25 (2007)

[7] M.Tumuluru, "The Effect of Coatings on the Resistance Spot Welding Behavior of 780 MPa Dual-Phase Steel." Welding Journal 86 (6), 161–69 (2007).

[8] M. Pouranvari, H. R. Asgari, S. M. Mosavizadch, P. H. Marashi, and M. Goodarzi, "Effect of Weld Nugget Size on Overload Failure Mode of Resistance Spot Welds." Science and Technology of Welding and Joining 12 (3), 217–25 (2007).

[9] S. S. Nayak, V. H. Baltazar Hernandez, Y. Okita, and Y. Zhou. "Microstructure-Hardness Relationship in the Fusion Zone of TRIP Steel Welds." Materials Science and Engineering A 551, 73–81. (2012).