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Analysis of Spot Weld Growth on Mild and Stainless Steel

Nugget growth by varying current and weld time was analyzed in joining mild steel, austenitic stainless steel, and dissimilar steels

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ABSTRACT

Resistance spot welding (RSW) is an important technology in various industries for joining two or more metals. Joining dissimilar base metals has become very common among mechanical assemblies. Hence, this experiment was carried out to analyze the growth of a spot weld in a mixed joint of mild and 302 austenitic stainless steels. Basically, the growth of a spot weld is determined by its parameters such as current, weld time, electrode tip, and force. However, other factors such as electrode deformations, corrosion, different thicknesses, and material properties also affect the weld growth. This investigation was intended to analyze only the effects of nugget growth on mild steel, stainless steel, and mixed steels with respect to the variation of current and weld time. As such, the force and the electrode tips were constant throughout the experiments. The welded samples were all equal size and underwent tensile, hardness, and metallurgical testing to characterize the formation of weld nuggets. The tensile tests showed significant relationship between differing current increments and sufficient weld time to attain a proper weldment. The hardness distributions were measured from the unwelded area on one side of the sample and moved through the regions of the heat-affected and fusion zones and ended at the unwelded area on the other side. The hardness was altered due to heat treatment, and the metallurgical views support this phenomenon.

Introduction

The spot welding process joins two or more metal sheets together through fusion at a certain point (Ref. 1). It is a simple process that uses two copper electrodes to press the work sheets together and force high current to pass through it. The growth of the weld nugget is, therefore, determined by its controlling parameters such as current, weld time, electrode tips, and force (Ref. 2). In this experiment, the current and weld time were varied to see the weld growth, while the electrode tips and force remained constant. The entire work was carried out to observe the weld growth in mild steels joints, stainless steels joints, and both steels in a mixed joint for the same current and weld time (Ref. 3).

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Experimentation

In this experiment, a JPC 75-kVA spot welding machine was used. The machine was capable of joining up to 5-mm-thick base metals for various materials. It uses a pneumatic-based electrode actuation system to produce up to 15 kN of force, and a current range varying from 1 to 25 kA. However, this experiment used only a constant of 3 kN of force for the entire weld schedules at increments of 6, 7, and 8 kA. The weld time was varied from 10 to 20 cycles with 5 as the interval. The electrode tips were 0.5 mm^2 in the round area. The base metals for these experiments were mild steel and 302 austenitic stainless steel (Table 1). Initially, a weld schedule (Table 2) was developed to accomplish these experiments. A standard size (200 × 25 × 1 mm) for the base metals was prepared (Fig. 1) and welded according to the weld schedule as lap joints. The first category was only the mild steel joints, whereas, the second category was only 302 austenitic stainless steel. The third category was mixed base metals of mild and 302 austenitic stainless steels. A total of 200 pairs of welded samples were developed for tensile, hardness, and metallurgical tests (Refs. 4, 5).

KEYWORDS

Dissimilar Steels
Pull Test
Resistance Spot Welding
Spot Weld
Stainless Steel
Weld Nugget
Weld Hardness

Results and Discussion

Hardness Test

The hardness of the welded areas for the mild steel seemed to be higher than the stainless steel and the mixed steels (Ref. 6). Forty-five pairs of samples were analyzed and found that the average of unwelded areas was 54 HRB, and the average of welded areas was 98 HRB. The hardness increment was 44 HRB (81%). These hardness increments were surmized to be the result of heat treatment due to high thermal conductivity and low resistivity of the materials (Ref. 7). Figure 2 shows the hardness of the mild steels.

The hardness of 302 austenitic stainless steels did not change very much as compared to mild steels. This was because of the nature of the material. The heat treatment effect is not supported by the chromium composition of the material (Ref. 8). The effect was reduced by the thermal conducting factors as well as the electrical resistance. The average of unwelded area was 75 HRB and the average of welded area was 85 HRB. The average increment (13%) was only 10 HRB. The results are graphically shown in Fig. 3.

WELDING RESEARCH

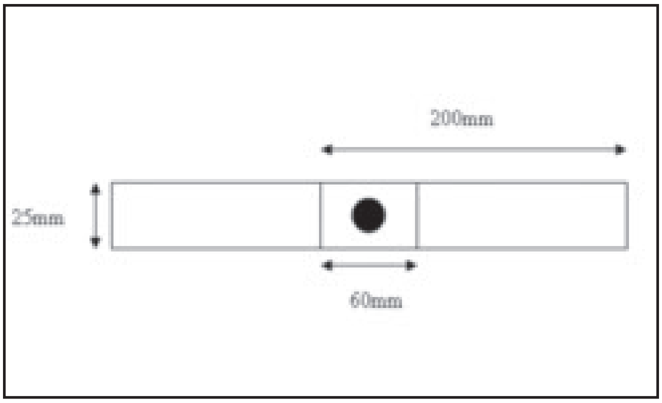

Fig. 1 — Schematic of the test sample.

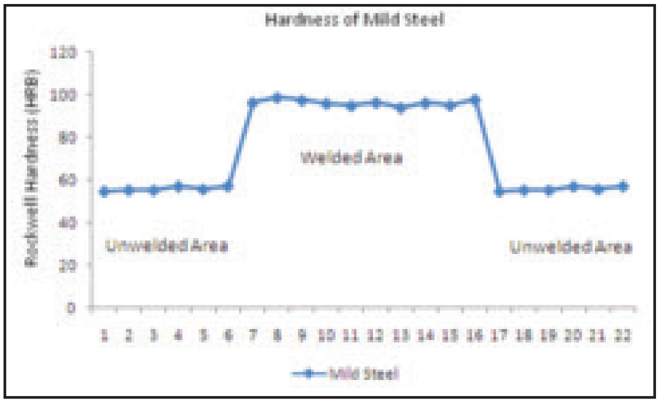

Fig. 2 — Hardness diagram for mild steel.

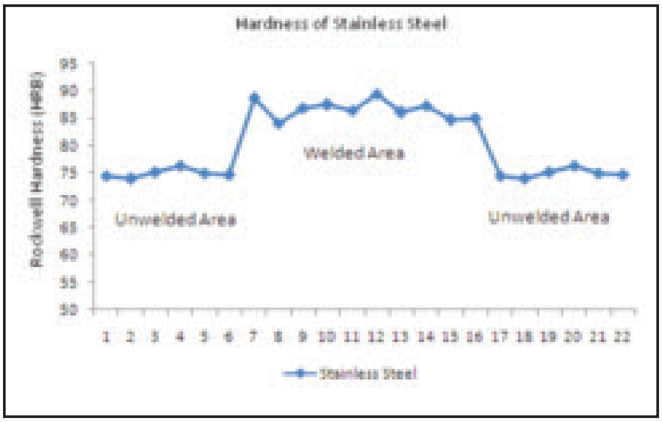

Fig. 3 — Hardness diagram for stainless steel.

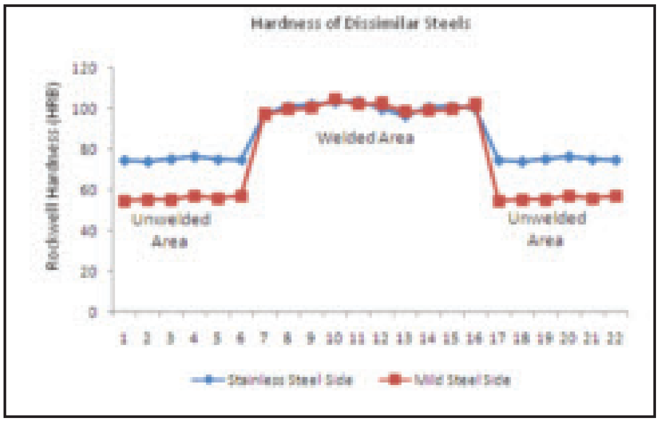

Fig. 4 — Hardness diagram for stainless and mild steels joined.

The final test on hardness was carried out on the dissimilar metal welded sheets. One side of the material was mild steel and the other side was stainless steel, as shown in Fig. 1. The hardness increased slightly on both sides of the weld compared to the mild and stainless steels categories. For instance, the mild steel hardness was found to be 54 HRB at the unwelded areas, whereas, the welded region was 100 HRB. It has increased slightly compared to the mild steel category of 98 HRB. The stainless steel side also increased almost to the mild steel values (101 HRB). It increased from 75 to 101 HRB. Although it fluctuated slightly up and down, the values remained in the region of deviation. The hardness values are plotted against each other in Fig. 4.

Table 1 — Chemical Composition of Mild Steel and 302 Austenitic Stainless Steel

Mild Steel

Element	Maximum wt-%
C	0.23
Mn	0.90
P	0.04
S	0.05

302 Austenitic Stainless Steel

Element	Maximum wt-%
C	0.15
Cr	17–19
Ni	8–10
Mn	2.00
Si	1.0
S	0.03
P	0.04

Tensile Test

The strength of the welded samples was tested using tensile peeling methods for the mild steel, stainless steel, and mixed steels. Figure 5 shows the tensile strength with respect to increments of current and weld time.

Tensile test results showed that when welding current and weld time were increased, the strength was also increased as reported in the literature (Refs. 4, 5).

Table 2 — Weld Schedule

Samples Number	Material(a)	Electrode Tips (mm^2)	Force (kN)	Current (kA)	Weld Time (Cycle)
1–5	MS & SS	0.5	3	6	10
6–10	MS & SS	0.5	3	6	10
11–15	MS & SS	0.5	3	6	10
16–20	MS & SS	0.5	3	7	15
21–25	MS & SS	0.5	3	7	15
26–30	MS & SS	0.5	3	7	15
31–35	MS & SS	0.5	3	8	20
36–40	MS & SS	0.5	3	8	20
41–45	MS & SS	0.5	3	8	20

(a) MS – Mild Steel; SS – Stainless steel

However, the experiments were not conducted beyond the expulsion limit to see the extreme cases. It was conducted to see the weld nuggets growth, and therefore, the weld schedule was limited to a few steps from poor welds to sound welds. The weld experiments from numbers 1 to 2 and 2 to 3 have shown strength increments due to current increments from 6 to 7 and 7 to 8 kA, respectively. Similar results were also noticed for weld time increments. Thus, the strength from experiments 1 to 4 and from 4 to 7 have shown increments in strength due to the increments of weld time from 10 to 20 cycles. The experiments that followed also showed the same principles of increase and decrease when the parametric changes occurred — Fig. 5.

This was because an increase in current and weld time caused the weld diameter to

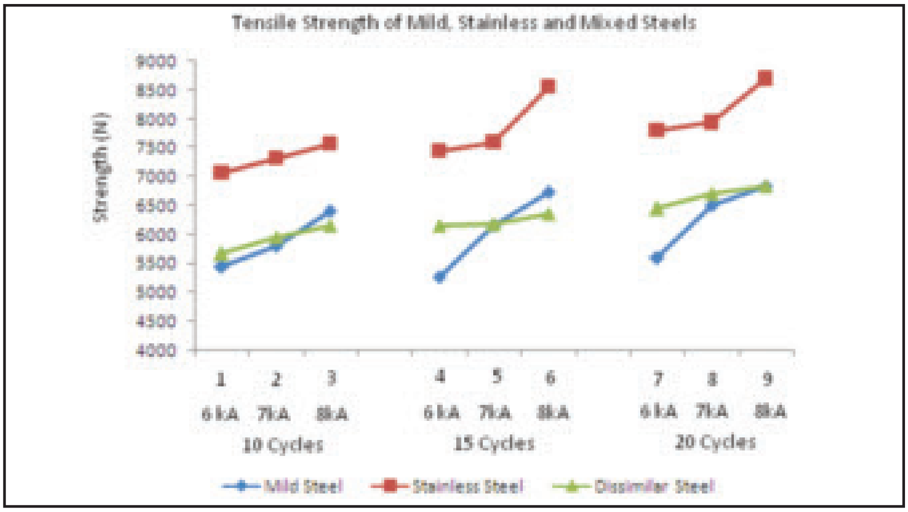

Fig. 5 — Tensile test results.

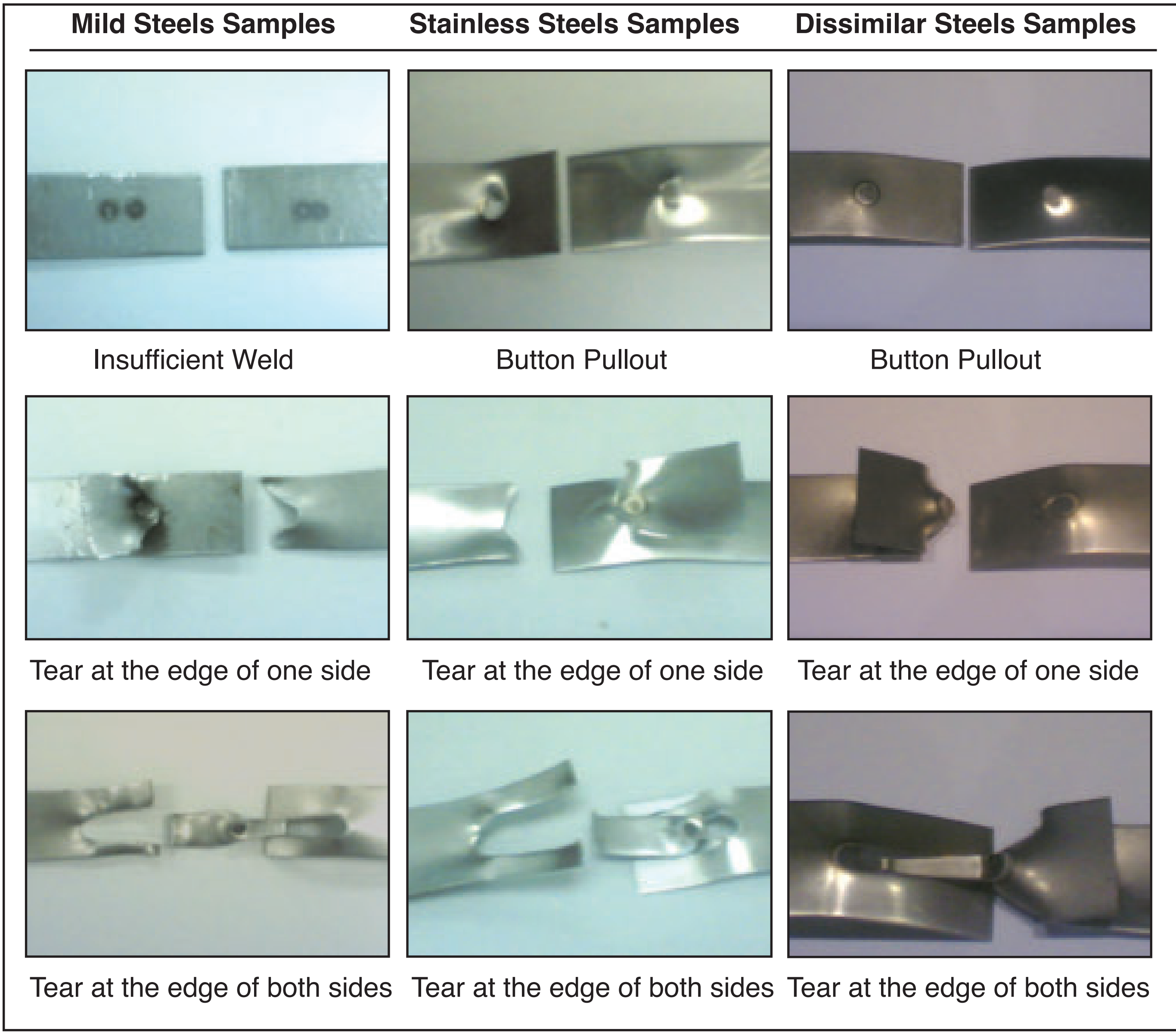

Fig. 6 — Tensile tested samples of mild, stainless, and dissimilat steels.

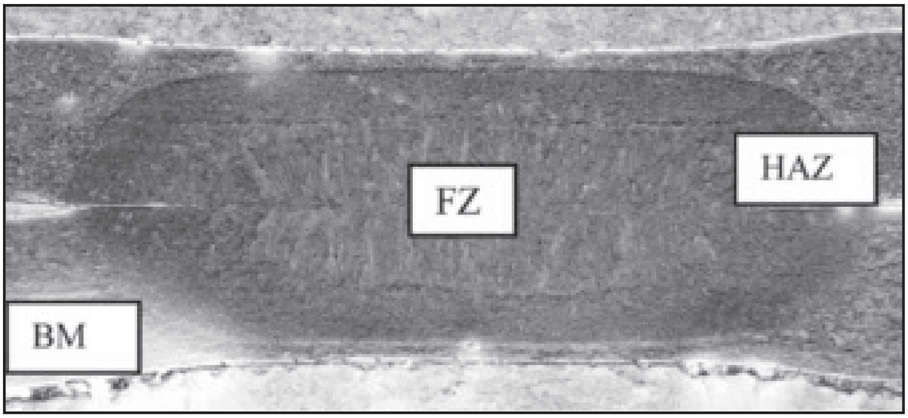

Fig. 7 — Different areas of test sample. FZ — fusion zone; HAZ — heat-affected zone; BM — base metal.

increase, and therefore the weld strength increased. The amount of heat generated at the weld interface increased as the weld current and weld time increased. The weld zone expanded radially and once cooled then formed a weld nugget. The stainless steel welds seemed to have higher tensile strength compared to the other two types of joints, since the breaks happened at the border of the spot weld (tear from edge of the nuggets), which was expected by the materials properties. However, some cases showed button pullout when the weld was moderately weak (Refs. 6, 7). In the mixed steel joint, the mild steel side was broken first. Besides, the improper joint was noticed in the weakest weld only. Figure 6 shows three types of common breaks that happened during tensile testing. If a com-

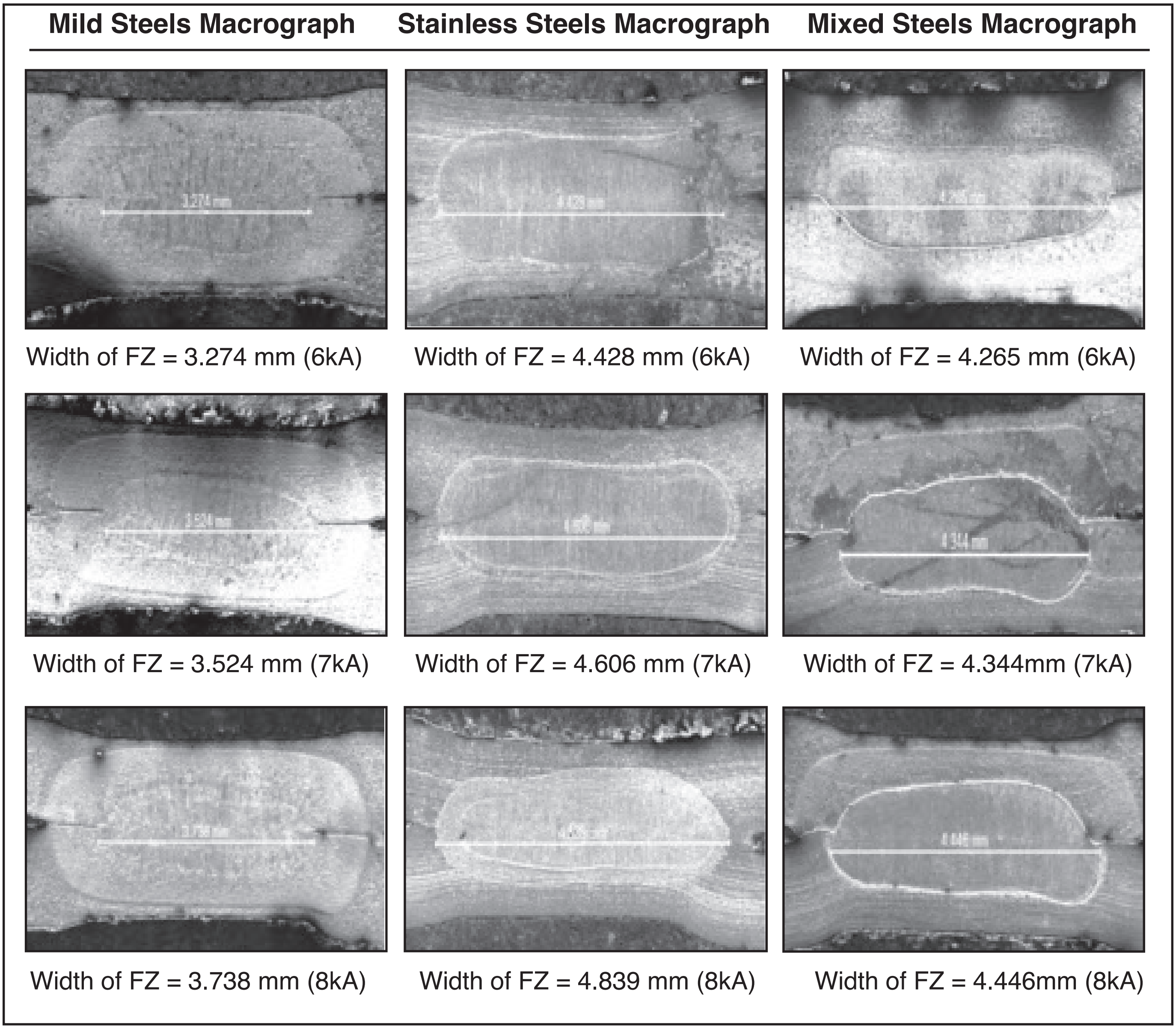

Fig. 8 — Nugget cross section of mild, stainless, and dissimilar steels.

parison study of strength between categories is considered, then the mild and stainless steels have created upper and lower strength bands and the dissimilar joints almost fall between these two.

Macrograph Views

Metallographic samples were produced using standard procedure with an optical microscope. It was taken to measure the exact weld nugget diameters rather than seeing the mixture of chemical properties. A typical macrostructure for mild steel, stainless steel, and mixed steels shows three distinct structural zones — Fig. 7.

The different areas are described below.

1) Fusion zone (FZ). Zone that undergoes complete melting and resolidification during weld cycle with a coarser grain. The width of the zone is equivalent to the weld nugget diameter.

2) Heat-affected zone (HAZ). Zone that undergoes microstructural alteration during the weld cycle. The grains were finer than in the FZ.

3) Base metal (BM). Area that is not affected during the weld cycle, and the grains remain the same.

The macrograph was developed to see the exact diameter of nuggets, and it showed three distinct structural zones as mentioned previously (Refs. 4, 7). As for mild steel, the fusion zone was made of coarser grains and the HAZ was finer grains. However, the HAZ was higher due to better thermal conductivity and higher electrical resistivity as compared to stainless steel. In contrast, the stainless steel had a lower HAZ and therefore the fusion zone seemed to be higher as compared to mild steel for the same weld schedule (Refs. 9, 10). The dissimilar welds showed asymmetrical views when both materials were concerned. The mild steel side was shorter in length as compared to stainless steel with different HAZs. Figure 8 shows the comparison of weld zones for mild, stainless, and dissimilar welds.

The average diameter of five samples was considered to characterize the weld diameter growth for three different currents and three different weld times. In mild steel, the result showed that the incremental from lowest weld schedule to highest was 2.240 mm, in stainless steel it was 1.072 mm, and in the dissimilar steels it was 0.494 mm. As such, the mild steel seemed to have the highest nugget growth compared to the other two types of joints — Fig. 9.

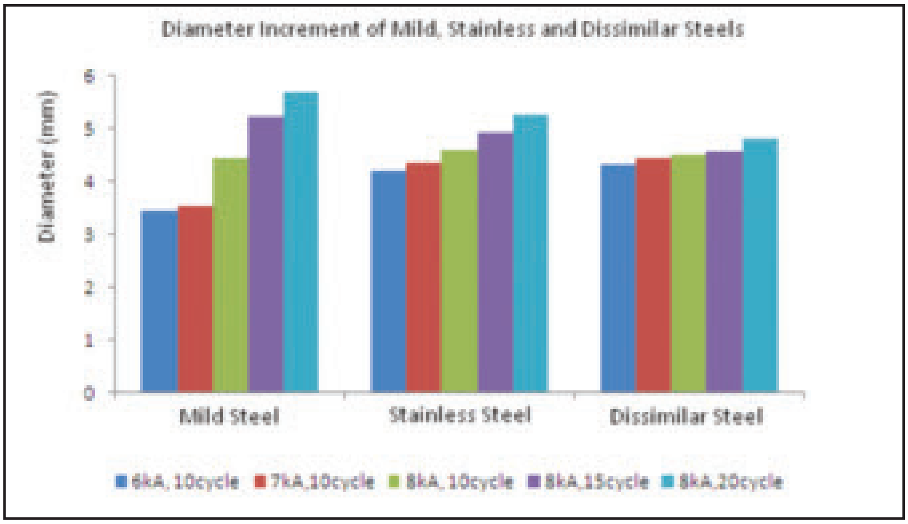

Fig. 9 — Diameter increment in mild, stainless, and dissimilar steels.

Conclusions

This project investigated spot weld nuggets' growth in mild steel, stainless steel, and dissimilar steels, all with a 1 mm thickness. The investigation concludes the following:

1) Hardness of the welded zone is greater than the hardness of the unwelded zone for all three joints.

2) The increase in hardness between the unwelded zone and welded zone was greater in mild steel compared to stainless steel because of the better thermal conductivity and lower electrical resistance.

3) The increase in current or weld time does not influence the increase in hardness distribution in the welded region. It fluctuated without relationship.

4) Stainless steel seems to have higher weld strength compared to mild steel and the mixed welds due to the nature of the material's hardness. The pull out breaks occurred at the border of the weld (tear from edge) in most cases. Button pull out was noticed for poor welds.

5) Strength of the mixed weld (mild steel and stainless steel) is almost similar to the strength of pure mild steel welds.

6) The diameter of the nugget in stainless steel is bigger than the diameter of nugget in mild steel for the same current and weld time because stainless still has lower thermal conductivity and higher electrical resistance as compared to mild steel.

7) The heat imbalance in the dissimilar joints caused the asymmetrical shape of weld nuggets.

8) Mild steel seemed to have the highest nugget growth rate as compared to the other two types of joints.

References

1. Shamsul, J. B., and Hisyam, M. M. 2007. Study of spot welding of austenitic stainless steel Type 304. *Journal of Applied Sciences Research* 3(11): 1494–1499.

2. O¨zyu¨rek, D. 2008. An effect of weld current and weld atmosphere on the resistance spot weld ability of 304L austenitic stainless steel. *Materials and Design* 29: 597–603.

3. Qiu, R., Satonaka, S., and Iwamoto, C. 2009. Effect of interfacial reaction layer continuity on the tensile strength of spot welded joints between aluminum alloy and steels. *Materials and Design* 30: 3686–3689.

4. Sun, D. Q., Lang, B., Sun, D. X., and Li, J. B. 2007. Microstructures and mechanical properties of resistance spot welded magnesium alloy joints. *Materials Science and Engineering A* pp. 460–461, 494–498.

5. von Maubeuge, K. P., and Naue, H. E. 2000. Comparison of peel bond and shear tensile test methods for needle punched geosynthetic clay liners. *Geotextiles and Geomembranes* 18: 203–214.

6. Bayraktar, E., Moiron, J., and Kaplan, D. 2006. Effect of welding conditions on the formability characteristics of thin sheet steels: mechanical and metallurgical effects. *Journal of Materials Processing Technology* 175: 20–26.

7. Kong, X., Yang, Q., Li, B., Rothwell, G., English, R., and Ren, X. J. 2008. Numerical study of strengths of spot-welded joints of steel. *Materials and Design* 29: 1554–1561.

8. Marashi, P., Pouranvari, M., Amirabdollahian, S., Abedi, A., and Goodarzi, M. 2008. Microstructure and failure behavior of dissimilar resistance spot welds between low carbon galvanized and austenitic stainless steels. *Materials Science and Engineering A* 480: 175–180.

9. Maa, C., Chena, D. L., Bhole, S. D., Boudreau, G., Lee, A., and Biro, E. 2008. Microstructure and fracture characteristics of spot-welded DP600 steel. *Materials Science and Engineering A* 485: 334–346.

10. Oikawa, H., Murayama, G., Sakiyama, T., Takahashi, Y., and Ishikawa, T. 2007. Resistance spot weldability of high strength steel (HSS) sheets for automobiles. Nippon Steel Technical Report No. 95.