Exploring the electrodes alignment and mushrooming effects on weld geometry of dissimilar steels during the spot welding process

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Abstract. The class two of RWMA electrode caps has very common application-purpose for the welding of steels and withstand for high thermal application on wrought cast. It has been experimentally used to weld carbon and stainless steels up to 900 weld attempts using AC waveform, C-type JPC 75 kVA, Japanese made spot welder. So the electrode alignments and resulting mushrooming effects are finally analysed in this research as well as the weld geometry of dissimilar (carbon and stainless) steels. When considering such weld joints, the heat imbalances are very interesting factors on spot welding research and therefore I have simulated the dissimilar weld joints using Ansys 14. Initially, it was simulated and later those results are compared with real welded samples. The common welded regions such as: fusion zones, heat affected zones, heat extended zones and base metals are all well-noticed for carbon steel sides but not for stainless steel sides. Besides, the electrode mushrooming effect on both sides of electrodes are not parallel deterioration and it has some demerits on internal structure indeed. Some of the dissimilar welded samples and electrode caps are eventually underwent metallurgical test to identify the improper alignment.

Keywords. Spot welding; dissimilar joints; electrode deformation; electrode mushrooming.

1. Introduction

The geometry of dissimilar weld joints is basically made of asymmetrical weld nuggets. In such welding joints, the heat imbalances will be the main factor and it has to be properly aligned in the middle of base metal to produce a proper weld nugget (Aravinthan & Nachimani 2011a). So the electrode alignment during welding process plays a significant role on the formation of weld

geometry. In this research, the carbon and stainless steels are analysed for the weld nuggets alignment as well as the mushrooming growth of electrodes after 900 welds were done. The growth of the weld nugget is therefore determined by the welding current, sufficient time for current delivery, reasonable electrode pressing force and sufficient area for current delivery (electrode tip) (Aravinthan & Nachimani 2011b). Basically, the welding current and weld time lead to the root generation of heat in the welding process while the electrode pressing force and electrode tips' accomplish it successfully (Mehdi *et al* 2008). Although the welding current and weld time cause the heat generation at the concerned areas (electrode tips' area); the electrode tips diameter and electrode pressing forces are also directly influencing the welding process (Nachimani 2012). So the class two electrode types are engaged in the welding process and consequently monitored the deformation and mushrooming effects after approximately 900 welds were done.

2. Experimentation

The carbon and stainless steels were prepared in rectangular shape (Chang *et al* 2006) with a size of the length (200 mm); width (25 mm) and thickness (1 mm). A pair of water cooled (2 liters per minutes) 30 degree truncated type of electrodes (5 mm of diameter) was used to join (JPC 75 kVA) of these base metals as shown in figure 1. The pair of test sample was initially loaded on the top of lower electrode (tip) of the welder as overlaying 60 mm on each other (lap joint) and then the initiating pedal was pressed. The upper electrode lever has moved towards the lower electrode and squeezed the based metals that placed in between (Rao *et al* 2009). The welding current was released immediately after the squeezing cycles of pneumatic based electrode actuation is achieved. Thereafter the electrode pressing mechanism has consumed some time for cold work and eventually returned to the home position of upper electrode (Yeung & Thornton 1999). These process controlling parameters (welding current, weld time and electrode pressing force)

Figure 1. Lap joint welding process.

Table 1. The chemical properties of base metals.

304L (2B) Austenitic stainless steel							
Element	C	Cr	Ni	Mn	Si	S	P
	0.048	18.12	8.11	1.166	0.501	0.006	0.030
Carbon steel							
Element	C	Cr	Ni	Mn	Si	S	P
	0.23			0.90	0.006	0.050	0.040

Table 2. General properties of CMW copper based alloys.

CMW Alloy (Class 2)	CMW 3 (ME 14 Z)
Condition	Cast wrought
Principle elements	Copper, chromium
RWMA alloy number	2.18200
Rockwell hardness (HRB)	70–83 B
Electrical conductivity % IACS	80–85
Ultimate tensile strength (PSI)	55–75 k
Elongation % in 2"	15–20
Permanent softening begin at	500°C

Figure 2. Hot press mounted samples for SEM scanning.

were set before the welding process starts; based on the manufacturers of welding lobe for 1 mm thicknesses. Table 1 lists the chemical properties of base metals and table 2 lists the general description of copper based alloy-electrodes that used in this analysis.

The welded sample was cut at the line of its diameter and mounted using resin powder on hot press mount (Marashi *et al* 2008). The mounted samples (figure 2) were roughly polished using silicon papers 1200/800 p and 600/200 p; and also continuously polished using Metadi polishing cloth with suspension liquid of 0.05 micron. This polishing process has been conducted about thirty minutes to one hour on each sample until the shining surface was seen. At last, the ferric chloride (500 ml) was used to immerse these well-prepared (shining surface) samples in a pot about 30–45 minutes. After that the samples were rinsed off using plain water; dried using air blower; anti-corrosion liquid was applied and kept in vacuum chamber for SEM scanning. Similar procedures were carried out to analyse the macro and micro structural changes of electrodes after about 900 welds were made in one year.

3. Results and discussion

3.1 A comparative study of simulation and real type of dissimilar weld joint

A simulation of dissimilar (carbon and stainless steel) weld joint was carried out prior to the real experiment using Ansys 14 (figure 3). The simulation results have revealed asymmetrical fusion zones due to dissimilar thermal characteristics for dissimilar weld joint. So in overall, I have categorized those regions as (i) fusion zone, (ii) heat affected zone, (iii) heat extended zone and (iv) base metal. So it is obvious that the heat imbalances were noticed due to different electrical properties of base metals.

Table 3 lists the general properties of carbon and stainless steels. From table 1, it is clearly seen that the melting point of both metals vary from each other so the melting process starts

Figure 3. Simulating a dissimilar weld joint (before solidification starts).

Table 3. General properties of base metals.

Properties	Stainless steel	Carbon steel
Density	8.00 g/cm ³	7.85 g/cm ³
Melting point	1400 – 1450°C	1426 – 1538°C
Electrical resistivity	$6.89 \times 10^{-7} \Omega.m$	$1.611 \times 10^{-7} \Omega.m$
Thermal conductivity	16.2 W/m.K (min)	54 W/m.K (min)
Thermal expansion	$17.2 \times 10^{-6} /K$	$12 \times 10^{-6} /K$

Figure 4. A real macro view of dissimilar weld joint (after solidification).

Figure 5. A real macro view of dissimilar weld joint (best).

at different circumstances (Jamasri *et al* 2011). Thus, the thermal conductivity coefficients are higher in carbon steels as compared to stainless steels; therefore wider ranges of heat affected and heat extended zones (HAZ and HEZ) are visible at the carbon steel side. However, the thermal expansion coefficient is lower as compare to stainless steel; so that the melting rate differs and resulting smaller width and also shorter height of fusion zone. On the other side, the stainless steels seemed to have higher thermal expansion coefficient but lower thermal conductivity coefficient. So the heat affected zones (HAZ) was smaller in region but the fusion zone was wider and higher as compared to carbon steel (Dursun & Zyurek 2008). Technically, this phenomenon is called as heat imbalance. A real dissimilar weld joint of carbon and stainless steel is shown in figure 4. Some of the regions that revealed by the simulated results were exactly seen at the stainless steels (Shamsul & Hisyam 2007). Moreover, the heat extended regions of stainless steels are not certainly seen with the macrograph image clearly, but it did exist (Fukumoto *et al* 2008). This is because of the nature of stainless steel as it does not easily create different grain sizes to differentiate the heat affected and heat extended regions. Unlike carbon steel, as it shows all the regions with different grain sizes and therefore easily identifiable.

3.2 Electrode alignment during welding process

The welded zones were analysed for the electrodes alignment and found to be very few good weld using pneumatic based electrode actuation system. One of them is presented in figure 5. The upper and lower electrodes' surfaces were properly placed during welding process so that a balanced weld nugget was obtained. The welded zone has asymmetrical fusion zone (FZ), asymmetrical heat affected zone (HAZ), asymmetrical heat extended zone (HAZ) and symmetrical supporting base metals (BM) (Cha & Na 2003). There was no side effect on the weld surfaces because the electrodes were very new at the time of welding except small pores (Martín *et al* 2009). The pores were noticed due to unstable forging force during welding process and it could not be fully eliminated in pneumatic based electrode actuation system of JPC 75 kVA spot welder.

Figure 6 shows the vertical mismatch during welding process. The upper and lower electrodes are vertically misaligned so that a portion of weld nugget was uncontrollably developed at the right hand side (point A). This portion can easily cause heavy expulsion if the heating process goes little longer. Moreover, the upper side base metal (carbon steel) had little corrosion and

Figure 6. A real macro view of dissimilar weld joint (vertically mis-aligned).

Figure 7. A real macro view of dissimilar weld joint (horizontally mis-aligned).

it was not even fully eliminated during welding process. So the upper indentation is partially damaged and cause odd-surface outlook on the carbon steel side.

Meanwhile, the horizontal mismatch of electrode had caused odd type of weld diameter as shown in figure 7. However, the upper and lower indentation is not very much affected except inclusions (Yuhang *et al* 2011). Some inclusions were seen at the carbon steel side. This kind of misalignment leads to electrode mushrooming growth and increases the diameter of electrode tips predominantly.

3.3 Electrode mushrooming effect

The class two spot welding electrodes are made up of copper and chromium elements, according to the RWMA classification (Bower *et al* 1990). It has two phase mixture of chromium and

Figure 8. A macrograph view of electrodes after 900 welding process Source: (Welding and Cutting).

Figure 9. The electrode microstructural view Source: (Welding and Cutting).

alpha copper. Basically, the changes in properties can happen at the rise of temperature due to the precipitation of chromium out of the solid solution. This is what has been widely noticed in the micro structural view of electrodes. As the numbers of welds are repeatedly welded on carbon and stainless steels, the mushrooming effect are growing due to heat exposure at the electrode tips' areas. In this research, the original electrode tip of both sides was 5 mm of diameter and it was mushroomed to 7.458 mm on upper electrode tip side and 7.238 mm on lower electrode tip side. Figure 8 shows the macrograph of electrode tips which was used to weld about 900 times.

Having considered the mechanical and chemical changes that took place on the electrodes after 900 numbers of welds; it was SEM-scanned for structural changes (figure 9). Point A of figure 9 was the electrode tip at which the base metals' molten heat ($\approx 1600^{\circ}\text{C}$) was directly exposed. The point B and C are the places lead to the electrode holder which are also exposed to the thermal expansions. Thus, the chromium to copper ratio is affected due to heat exposure as shown in figure 9. The micro structural views shows that the chromium precipitation is higher at the tip (point A) due to the direct exposure of heat beyond melting points of steels (Chen *et al* 2005). The point B has balanced chromium to copper ratio between point A and C. However, the different cooling rate at point C due to water coolant (2 liters per minutes) inside the electrodes prevents chromium precipitation but resulted cracks on upper electrode side after 900 welds (figure 9).

Eventually, the electrode tip diameter was measured for every hundred weld attempts and it was shown in figure 10. The upper electrode's mushrooming effect was slightly higher than the lower electrode because it enacts for the pressing forces (impact) everytime during the welding process.

Figure 10. The electrode microstructural changes Source: (Welding and Cutting).

4. Conclusion

This paper dealt with the weld zone geometry using carbon and stainless steels for the electrode alignment and its mushrooming effects. The following conclusions were drawn.

- (i) A simulation of spot welding process showed that the heat imbalances occurred during the welding of carbon and stainless steels.
- (ii) A proper weld zone had asymmetrical weld nugget consisted of fusion, heat affected, heat extended and base metal zones.
- (iii) The proper electrodes' alignment played an important role on quality of the proper weld geometry regardless of thicknesses.
- (iv) Misalignment of electrodes caused expulsion and also lead to poor weld zones.
- (v) Electrodes class two (chromium and copper) showed cracks on its internal structure after 900 weld attempts using carbon and stainless steel.
- (vi) The precipitation of chromium out of the solid solution was noticed at the tip of electrodes which caused mushrooming effects after significant number of weld trials.
- (vii) The initial weld processes up to 400 times increased the electrode tip (mushroom) diameter to about 23% on upper electrode and 19% on lower electrode.
- (viii) The further weld processes up to 900 times have increased the electrode tip diameter to about 49% on upper electrode and 45% of lower electrode.

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