Canadian Welding Association

INVESTIGATING the copper-chromium electrodes deformation during the welding process of resistance spot welding

Joining the carbon and stainless steels in spot welding process is widely recommended by using class two alloys from Resistance Welder Manufacturers Association (RMWA) [1]. The ground for this sort of recommendations is that it has superior resistance, heat toleration and high corrosive opponent in itself [2].Without the mixture of substances, a pure copper is intrinsically soft and fails prematurely in demanding applications [3]. Mixture of substances is, therefore, a good choice for the manufacturing of electrode caps as to produce superior qualities, specifically for the mechanical and electrical properties. With this consideration in mind, copper-chromium based electrode caps are practically tested to weld approximately nine hundred weld pairs of carbon and stainless steels sheets in this experimental work. *Figure 1* shows the copper and chromium phase diagram for copper based alloys [4]. It shows that the chromium is easily soluble in the Liquids of copper when heated above 1076 ºC and below 1860 ºC. Once the compound is solidified, it requires an equal amount of heat to re-melt it again [5]. This factor creates significance in the welding of the carbon and stainless steels because the carbon steel melting point falls between 1426 to 1540 ºC and the stainless steel melting point falls between 1400 to 1450 ºC. The copper and chromium solubility phases are actually of the eutectic type. The face centered cubic (FCC) will be formed in copper while body centered cubic (BCC) will be formed in chromium when solidification process is concerned in copper-chromium alloy.

Fundamentally the welding process is varied by its process parameters which consist of the welding current, weld time, electrode tips' diameters and electrode force [6]. These parameter variations establish the corresponding heat growth for any materials for which the bonding strengths are mainly anticipated. By doing so, the amount of heat that is produced in an enclosed area of electrode tips will cause the electrode tips' deteriorations. Another factor that obviously affects the electrode tips deteriorations is the electrode pressing forces which is primarily supplied by the pneumatic pressure in this research. Thus, every time the electrodes are pressed to hold the weldable materials together, the hitting effects of electrode tips towards the base metal results in metal hitting effects or simply the hitting effects, subjected to its fatigue. In this experiment the mushroom growth, degradation as well as the deterioration is what is examined for the copper-chromium electrode caps using a 75 kVA spot welder. Part of this research has been previously published for the simulation, tensile shear strength, hardness distribution and the metallurgical analysis and therefore, such information is excluded in this paper but relevant references are given by [7].

2. EXPERIMENTAL

The base metals were prepared in rectangular shape with a size of the length (200 mm), width (25 mm) and thickness (2 mm). The chemical elements found on stainless steel sheets were: C = 0.046, Cr = 18.14, Ni = 8.13, Mn = 1.205, Si = 0.506, S = 0.004, N = 0.051 and P = 0.030. The chemical elements found on carbon steel sheets were: C = 0.23, Mn = 0.095, Si = 0.006, S = 0.050 and P = 0.040. Hardness of austenitic stainless steels was 86.2 HRB whereas as for the carbon steel, it was about 65HRB. A pair of water cooled (4 liters per minutes) truncated-cone electrodes, with 5 mm of round diameter was applied to join these base metals as shown in *figure 2*.

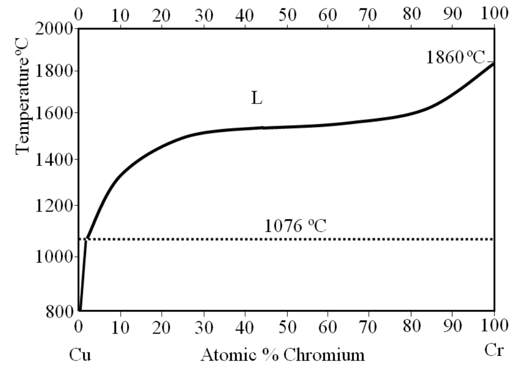


Figure 1: Copper and chromium phase diagram (Chakrabarti DJ, 1984)

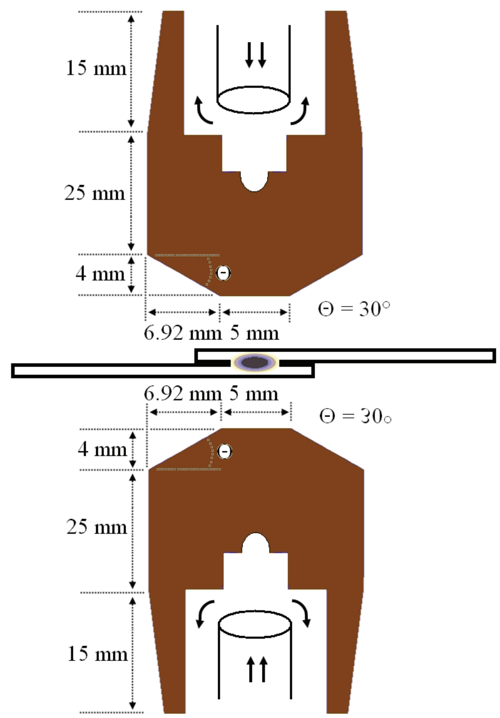


Figure 2: The dimension of electrodes on welding materials

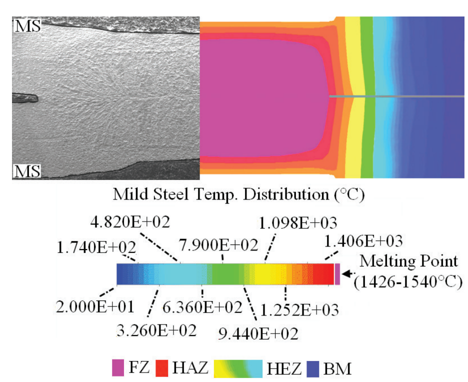


Figure 3: Carbon steel weld (real vs simulation)

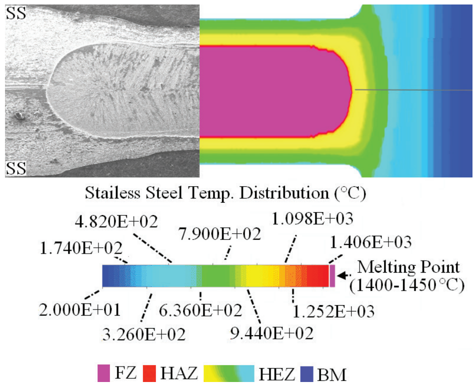


Figure 4 Stainless steel weld (real vs simulation)

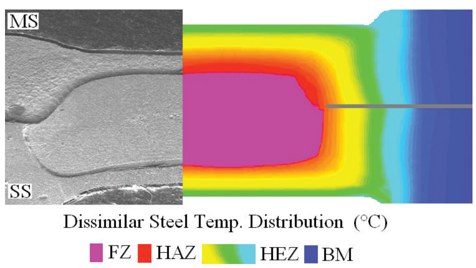


Figure 5 Carbon and stainless steel weld (real vs simulation)

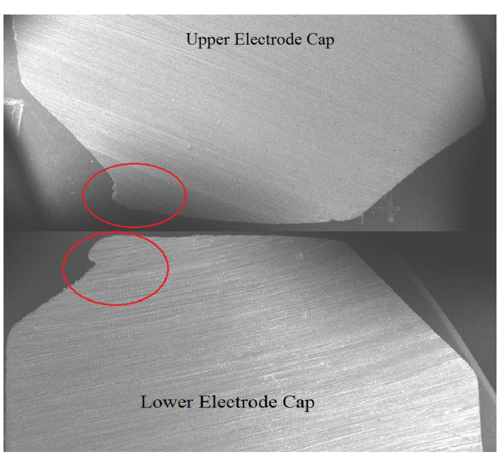


Figure 6 A macrograph view of the electrode caps after undergoing one sided detoriaration

Table 1 Properties of copper-chromium electrodes

CMW Alloy (Class 2)	C18200
Chemical Elements	Copper - 99.1% Iron 0.10%, Chromium - 0.60%, Silicon - 0.10%, Lead - 0.05%
Rockwell Hardness (HRB)	70
Electrical Conductivity % IACS@68F	80
Tensile Strength (KSI)	70
Yield Strength (KSI)	55
Elongation % in 2 inch	21
Thermal Conductivity (W/m.K (min))	187
Thermal Expansion (/K)	9.8×10^{-6}

Approximately nine hundred welding attempts were made and the electrode caps were sharpened once to remove the mushrooms after which about four hundred welding attempts were completed. The electrode caps are then removed from the holder and cut at the line of its diameter (middle) using an abrasive cutter to form flat surfaces. Once it has been cut across the diameter, it was mounted using resin powder on a hot press mount-machine, such that it shows the cross sectional view of the electrode caps. The mounted samples were thereafter polished well using silicon papers, graded as 1200/800p and 600/200p and also continuously polished using Metadi polishing cloth. This polishing process has been conducted about thirty minutes to an hour on each sample until the shining (mirror-like) surfaces are seen. The V2A etchant that consists of 100 ml water, 100 ml hydrochloric acid and 10 ml nitric acid is used to etch the polished samples. It was immersed into a box for approximately 45-60 minutes. After that the samples were well-rinsed off using plain water; dried using air blower, anti-corrosion liquid was applied and kept in vacuum chamber for SEM scanning. These preparatory steps and the above listed polishing materials are good enough to get reasonable micro and macro graphs for analytical purpose.

3. RESULTS AND DISCUSSION

3.1 Weld nuggets for the carbon, stainless and mixed steels

Classical concerns about the spot welding of carbon and stainless steels rely on the dissimilarity of melting points in individual weld joints and also the heat imbalances in the dissimilar weld joints[7]. In this experiment, both issues have been observed for several combinations of process parameters, i.e. the variations of welding current levels against the variations of welding time cycles have been monitored[7]. *Figure 3, 4* and *5* show the carbon, stainless and both steels mixed welds using the copper-chromium electrode caps, respectively. The right sides of *figure 3, 4* and *5* represent the corresponding SORPAS simulations in which the maximized temperatures are clearly shown before the solidification processes started; whereas the left sides shows the real welds after the solidification processes are done. Color representations are used to interpret the molten zones and also its vicinities, as to distinguish the heat affected and also the heat extended zones vividly. General point is that the copper-chromium electrode caps have significantly contributed for the formation of sound welds in carbon, stainless and mixed materials but in the long run, it deteriorates itself.

3.2 Electrode mushrooming effect and chemical changes

The class two spot welding electrode caps are primarily made of copper and chromium materials as major components according to RMWA's clasiffication[8]. It has dual phase mixture of chromium and alpha copper as major chemical elements although it has other minor ones. See *table 1* for the detailed-list of chemical elements as well as other properties of the electrode caps. The changes in properties happen at the rise of temperature ($Q=I2Rt$) due to the precipitation of chromium out of the solid solution. Literally, when the electrode is heated together with metals, it has a high tendency of forming new kinds of alloys [9][10]. This is where the precipitation of chromium out of the solid solution is easily noticed [11][12]. This has also been confirmed in the micro structural view of the electrode caps as shown in *figure 7*.

As the welding processes are repeatedly being carried out on carbon and stainless steels, the mushrooming effect is growing due to heat exposure at the electrode tips' surfaces. It is nothing but simply enlarging the areas (A) of the caps' tips, on the other end, causing the drop of contact resistance ($R=\rho\ell/A$) adverse to efficient welding processes[13][14]. In this research, the electrode tip of both sides was originally 5 mm diameter and it was partially-mushroomed. Literally the upper electrode tip diameter was enlarged up to 7.458 mm whereas the lower electrode tip diameter was enlarged up to 7.238 mm. Figure 6 shows the deterioration of electrode tips which were engaged to weld about nine hundred times.

Having considered the deterioration that happens on the electrode caps after undergoing nine hundred welding attempts, it was scanned for the profound structural changes. Point A of figure 7 represents the cap's tip at which the base metals' molten heat (max. ≈1600° C) was directly exposed. Points B and C of *figure 7* are the following points leading to the way to the electrode holder which are also exposed to the thermal flow but cooled by internal water flowing. Thus, the chromium to copper ratio is gradually diminished from point A to C. The micro structural views reveal that the chromium precipitation is higher at the cap's tip (point A) due to the direct exposure of heat,

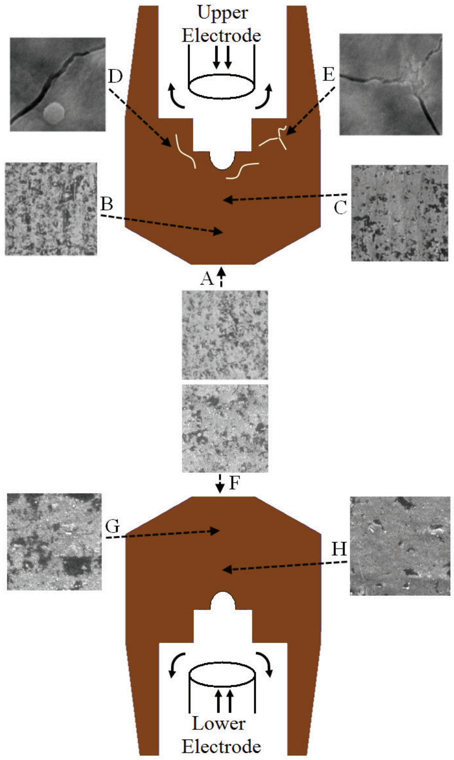
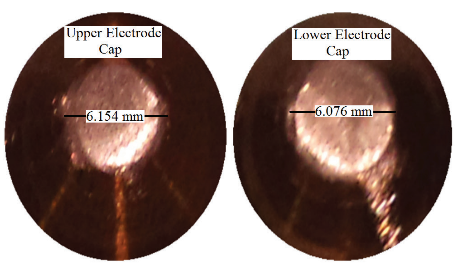
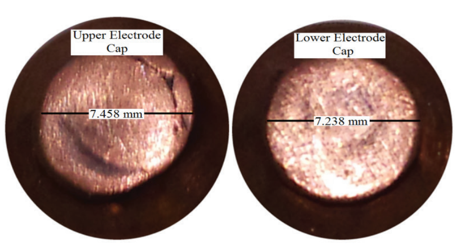


Figure 7 The electrode microstructural view (welding and cutting)



a) 400 welded attempt



b) 900 welded attempt

Figure 8 The electrode caps physical changes due to mushroom cleaning process

which is above the threshold of melting points of copper-chromium alloys (*figure 1*). The point B was, somehow, balanced with the chromium to copper ratio which is located between point A and C. However the difference of cooling rates at point C due to water coolant (4 liters per minutes) that flow inside the electrode holders prevents chromium precipitation but resulted in internal cracks on the upper electrode cap. Lower electrode cap has similar effects (point F, G and H of *figure 7*) to that of the upper electrode cap had in terms of changes in chemical properties but no internal crack is found because of its position as static during the welding process. Theoretically, the heated and cooled tips' surfaces encounter the similar experiences of the annealing and quenching process caused in metal processing [15]. Annealing in copper-chromium alloy can induce ductility over time [16]. Chemical distribution of the copper-chromium alloy has been graphically compared for both electrode caps and similar patent of the gradual precipitation of chromium out of the solid solution was found.

The electrode tips' diameter was measured for every hundred weld attempts and it is shown in figure 8 to visualize the tips' enlargement. The upper electrode cap's mushrooming effect is slightly higher than the lower one because it has to bear the pressing forces (impact) while the squeezing process takes place every time. The severe deformation of electrode tips was noticed after undergoing the first mushroom cleaning process. The diameter of the tip was increased beyond 7 mm after undergoing nine hundred welding attemps for which it requires the increments of the combination of process controlling parameters (i.e. welding current, welding time and electrode force) [17].

3.3 Hardness distribution

Spot welding process reduces the hardness of the copper-chromium electrode caps over time, particularly at the tip areas. This is possible because both the electrode tips are always working on the encapsulation of heat generation as for the weld formation [18]. Once the faying surfaces of metals are fused together and formed new composite of phases, the electrode caps ensure that the holding force is enough to avoid any escape of molten metals or to avoid over pressure at the molten areas [19]. This behaviour is clearly subjected to the closed contact with weldable metals without producing asperity [20]. Here, the hardness is what matters and hence, both, the upper and lower electrode caps are measured for hardness distributive patterns. Hardness distribution is shown in figure 9 as ten measuring points are considered for each of the electrode caps separately. The thirty degree-truncated electrode caps are then measured along the cone areas approximately for the first four millimeters of distance, which is marked with small letters a and b in this case, as shown in figure 9. Meanwhile the capital letter A and B represent the vanished portions and thereby no results were found for these portions. It should be noted once again here that the average hardness of a brand new, class two copper-chromium alloy is around 70 HRB. This value is significantly reduced at the tip areas and ascending gradually with increase of distance from tips towards its rear portions (see figure 9) which is marked with red points for upper electrode cap and blue points for lower electrode cap. This pattern

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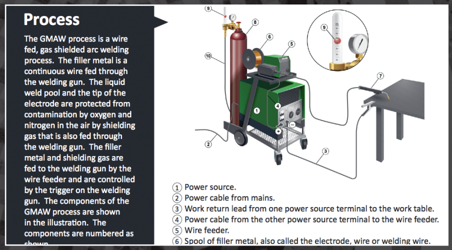

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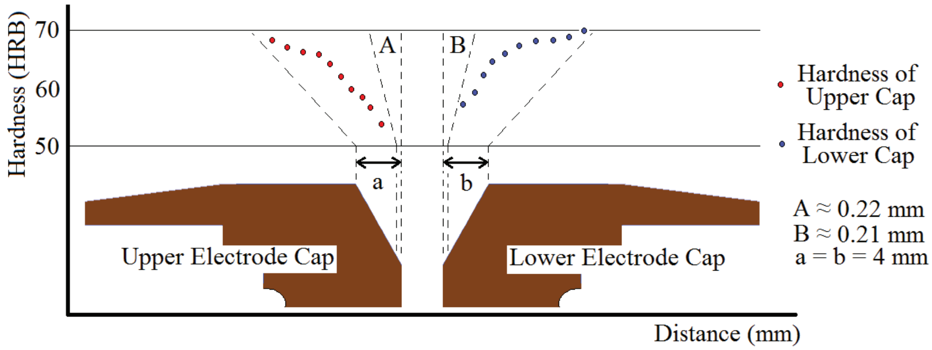

Figure 9 The electrode caps' hardness distribution after nine hundred weld attempts.

supports the previous findings that the chromium precipitation is higher at the tips, as long as the rear portions are compared regardless of upper or lower position of electrode-placements. However, the hardness reduction is still slightly higher in upper electrode caps as compared to lower one. So, with this magnitude of analysis, a conclusion is drawn that the hardness of electrode caps' tips (copper-chromium alloy) reduce and deform themselves over a number of repetitive welding processes in welding carbon, stainless and mixed steels [21].

4. CONCLUSIONS

This paper looks into the spot welding electrode caps' deteriorations and their related issues using carbon and stainless steels. Eventually the research outcome concludes that:

1. The precipitation of chromium out of the solid solution is higher at the electrode caps' tips as compared to its rear portions. This happens due to the frequent encapsulation of heat generation for the spot weld formations.
2. The precipitation of chromium out of the solid solution leads to deterioration of tips' surfaces as well as degrading themselves.
3. The initial welding processes of up to 400 times increases the electrode tips diameters about 23% of its original value due to mushrooming effects.
4. Further welding processes of up to 500 times more (after the initial 400 times) increase the electrode tip diameter to another 26% of altered value, even after the accomplishement of sharpening of electrodes are done.
5. Overall, 49% of its original value (5 mm) of upper electrode tip diameter increment is noticed, whereas the lower electrode tip diameter increment is about 44%.
6. The hardness of the upper electrode cap's tip is reduced to approximately 54 HRB as compared to its original value of 70 HRB.
7. The hardness of the lower electrode cap's tip is reduced to approximately 57 HRB as compared to its original value of 70 HRB.

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