Improving Electrode Life for RSW of Coated Advanced High Strength Steel

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Abstract

This paper reports an improved electrode life for the resistance spot welding of Dual Phase (DP600) steel. DP600 is an advanced high strength steel and the tested material is GI coated. The electrode life tests were performed to investigate the effects of a TiC coating, varying electrode geometry, as well as different material compositions of the electrode. Tensile shear strength test and peel test were conducted to evaluate electrode life. In addition, welding signal analysis was carried out to numerically correlate with the electrode change during the tip life test. An imprinting test using carbon paper was used to calculate the electrode contact area. The experimental results indicated that the effectiveness of electrode life improvement by TiC coating depended upon the electrode geometry and composition.

Introduction

Resistance Spot Welding (RSW) is widely used in the manufacture of sheet metal products. It remains the primary method of joining sheet metal in the automotive industry. Advanced high strength steel (AHSS) is attractive due to its potential to reduce weight and improve strength. Zinc or aluminum silicon coatings are able to increase the corrosion resistance of AHSS. However, these coatings have a negative effect on the resistance spot weldability and the electrode's life. The zinc coating on steel can easily react with copper electrodes and form alloys due to the resistance heating during the spot welding process [1]. These alloys (Cu_5Zn_8, gamma brass) accumulate on the electrodes surface, resulting in cracks and wearing of the electrodes [2]. Moreover, these cracks introduce pitting on the electrode, which will enlarge during spot welding. The pitted areas can lead to asymmetrical weld nuggets and accelerated electrode degradation, further decreasing the electrode's life [3]. These complex electrode wear mechanisms occur at the same time during RSW. In early research, weld current stepping was suggested as an approach to increase electrode life, although controlling the weld current is not always easy during the welding process [4]. Increasing the weld current constantly and periodically can lead to expulsion, which can cause poor weld quality. In addition, the increased welding current may reach outside the optimal welding parameter range. Therefore, controlling welding parameters is time consuming and sometimes not very practical, since it requires sensitive control in workplace. Another suggested solution is the cleaning of the electrode surface by using a special blade [5]. However, the welding robot must stop working and spend time moving to the designated repairing area. Also, some errors, such as asymmetrical cleaning and the rough cutting of the electrode surface, may occur during the process. Therefore, there are limitations to increase electrode life for spot welding of high strength steel by the above methods.

In this paper, the electrode life of TiC coated electrodes is investigated. The TiC coating is applied by the electro-spark deposition (ESD) process [6]. The ESD process itself can weld certain dissimilar materials with a minimal heat affected zone. In this paper the effects of electrode geometry and material composition on electrode life are discussed. To evaluate the electrode life, mechanical tests and nugget size measurement are carried out every 50 welds. Also, the welding signals and the imprinting images are analyzed for calculating the total heat input as well as the changing of electrode contact area.

Experiment

Resistance spot welding system

Spot welding was conducted by a 250 kVA AC single phase resistance spot welding machine. Constant current control was applied with a frequency of 60 Hz. To analyze the dynamic resistance and total heat input, several parameters were monitored during welding process, as is shown in Figure 1. Welding current, voltage, and force were measured with a rate of 20,000 samples per second from the current coil, secondary voltage, and force sensor, respectively. All signals were measured through a digital acquisition board (DAQ), and were analyzed using a mathematical program. Test material used was 1.0mm thick galvanized (GI) coated dual phase (DP) sheet metal with an ultimate strength of 648MPa. Mechanical properties and chemical compositions of the material are as shown in Table 1.

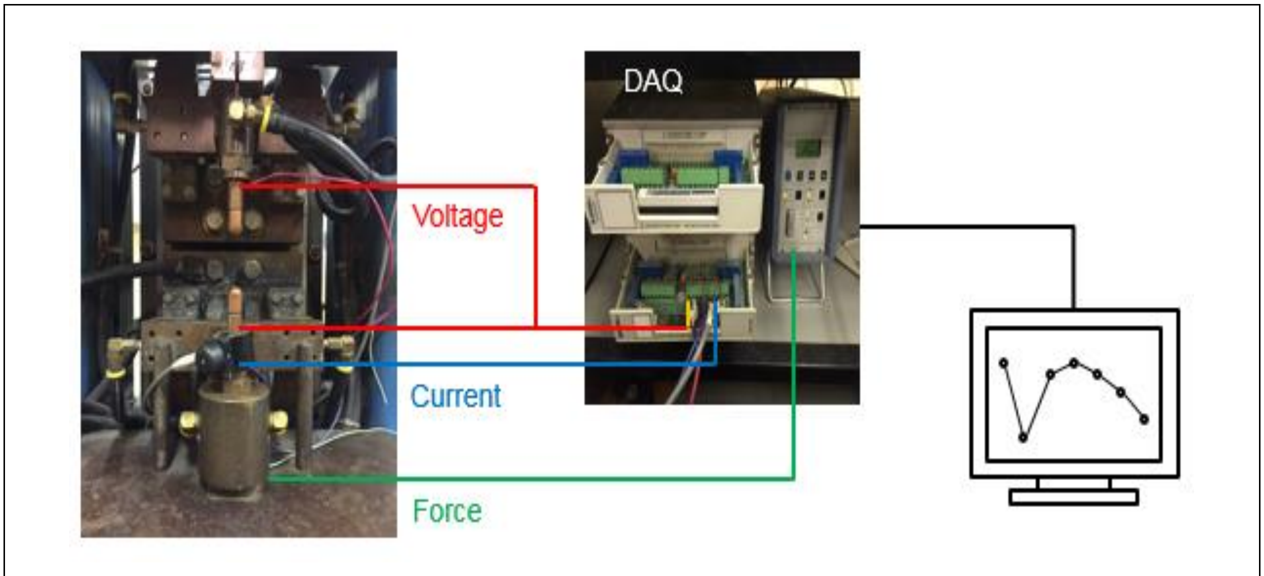


Figure 1. Schematic of resistance spot welding system

Table 1. Chemical compositions and mechanical properties of DP600

Chemical compositions [wt.%]

C	Mn	P	S	Si	Cu	Ni	Cr	Sn
0.1	1.83	0.011	0.003	0.15	0.02	0.01	0.35	0.002
Mo	Alt	Als	Cb	V	Ti	Ca	N	B
0.003	0.036	0.034	0.002	0.003	0.018	0.004	0.006	0.0002

Mechanical properties

Yield Strength	Ultimate Strength	Elongation
356 MPa	648 MPa	25 %

<u>Electrode life test</u>

In this paper, 6 kinds of electrodes with a contact surface diameter of 6mm are discussed. Standard dome shape and parabolic shape electrodes were employed to investigate the effect of electrode shape, as shown in Figure 2. Class 2 and class 3 dome shape copper electrodes were tested to investigate the effect of material composition. The composition of these two materials are shown in Table 2. The class 3 copper has more alloying elements, resulting in a higher hardness but a lower electrical conductivity. Effects of the TiC coating on these different electrodes were evaluated by comparing the life of coated and uncoated electrodes. The AWS D8.9 standard was employed for the electrode life test, specimen size and the procedures were followed [8]. Spot welding conditions, tests, and specimens are shown in Table 3 and Table 4. The operating weld current was determined by using the formula of 200A lower than the maximum weld current. For each kind of electrode, the operating weld current range varies depending upon their different contact resistances. With the appropriate operating weld current, the electrode life was tested on the test panels according to the designated welding direction. One tensile shear strength specimen, one peel test specimen, and two cross section test specimens were made every 50 welds. The detailed dimensions of each weld specimens are shown in Table 3. The tensile shear test specimens were tested with an Instron tensile tester using a cross head speed of 10 mm/min until failure. The peel test was carried out to evaluate the weld quality. If there was no weld button on the specimen after the peel test, the electrode life test was finished after making 50 more welds. The polished samples were etched with a 3% Nital solution for 5 seconds to reveal the microstructure. Optical microscopy was used to measure the nugget size. To identify the relationship between electrode life and electrode surface, the electrode contact area was measured from the imprinting test. Carbon papers were located between the upper and lower electrodes, and the weld force was applied to the carbon paper without weld current. After the release of the electrodes, the contact areas were measured from the imprinted paper.

Dome (B-nose) shape

Parabolic shape

Figure 2. Electrode geometry specification

Table 2. Material properties of Class 2 and Class 3 Electrodes [9]

Electrodes	Hardness	electrical conductivity	Chemical compositions						
			Cu	Fe	Ni	Cr	Si	Be	Zr
Class 2	HRB 75	75~80 %IACS Min.	REM.	-	-	0.5~ 1.5	-	-	0.02~ 0.2
Class 3	HRB 90	45 %IACS Min.	REM.	0.1 max.	1.4~ 2.2	-	0.2 max.	0.2~ 0.6	-

Table 3. Welding conditions for electrode life test

Electrodes	Weld current	Weld pressure	Weld time	Hold time	Cooling rate	Welding speed
Uncoated	10.2 kA, 10.3 kA	326 kgf	15 cycles	5 cycles	4 l/min.	20 welds/min.
TiC Coated	9.6 kA					

Table 4. Weld specimens

Experiment	Dimension	Remarks
Tensile shear test	105 [mm] x 45 [mm]	Overlap length: 35mm
Peel test	120 [mm] x 40 [mm]	Weld spacing: 40mm
Cross section test	30 [mm] x 30 [mm]	
Electrode life test	360 [mm] x 126 [mm]	Panel welding

Results and Discussion

<u>The results of electrode life test</u>

Tensile shear strength

Figure 3 shows the tensile shear test results for each electrode life test. The strength criterion for 1mm thick DP600 is 650kgf, and the electrode life was observed when the strength was lower than the strength criterion. The uncoated class 2 dome electrode life was 650 welds, and the class 2 TiC coated dome electrodes exhibit an improved electrode life of 1,900 welds. In terms of parabolic electrodes, the uncoated and TiC coated electrodes finished at the similar number of welds as the uncoated class 2 dome shape electrode. However, class 3 dome electrode life was much shorter than class 2. The uncoated class 3 dome electrode life was 200 welds, while the TiC coated electrode ended at 250 welds. Table 5 shows a changing of electrode surface conditions after finishing the first and final welds. In comparison with the first weld and the final weld, the class 2 electrode surface area and pitting size increased significantly. The surfaces were contaminated from the zinc coating of the steel sheet. However, from the Table 5, it was observed that the class 3 electrodes had not increased the electrode contact area as much as class 2 electrodes had.

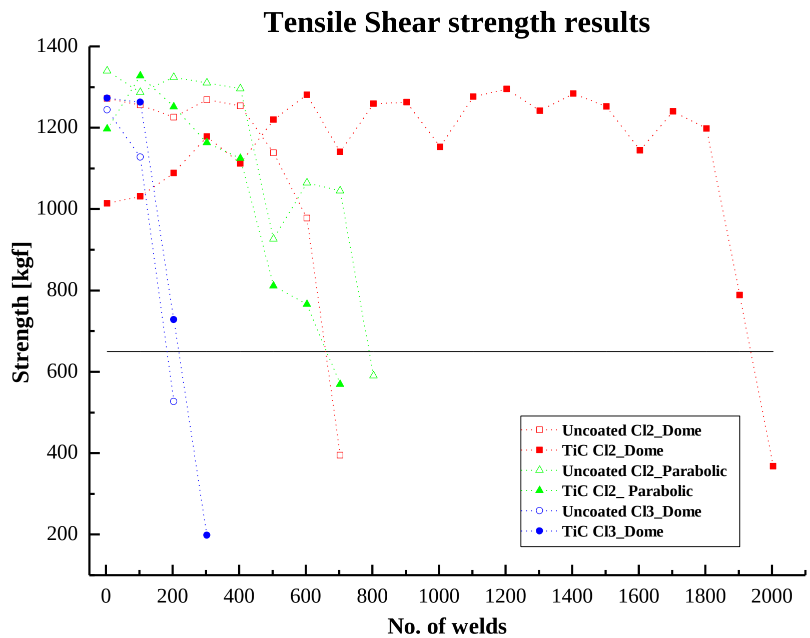
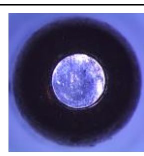
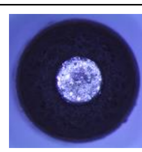
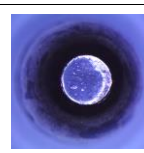
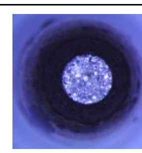
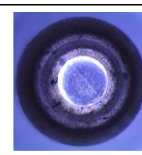
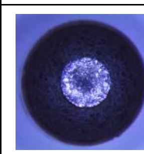
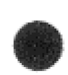
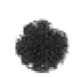
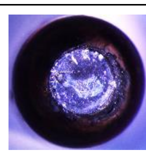
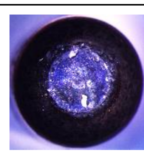
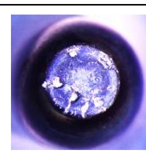
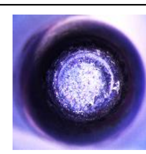
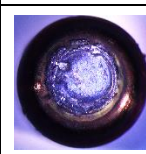
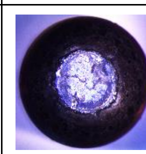
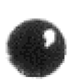
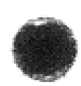
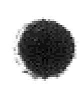


Figure 3. Tensile shear strength results

Table 5. Electrode conditions at 1st weld and final weld

		Uncoated Cl2_dome	TiC Cl2_dome	Uncoated Parabolic	TiC Parabolic	Uncoated Cl3_dome	TiC Cl3_dome
1st Weld	Electrode surface						
	Imprint image						
Final Weld	Electrode surface						
	Imprint image						

Nugget size and peel test result

Electrode life was also evaluated from the cross section test and the peel test. The criterion button or nugget size is based upon the formula $4\sqrt{t}$ $(t: thickness\ of\ base\ material)$. As shown in Figure 4 and Figure 5, the results of the nugget size and button size have shown a similar shape as the tensile shear strength results. There may be a little deviation of electrode life due to different standard and test procedures, but the results provide more evidence on the interrelationship between weld quality and electrode life.

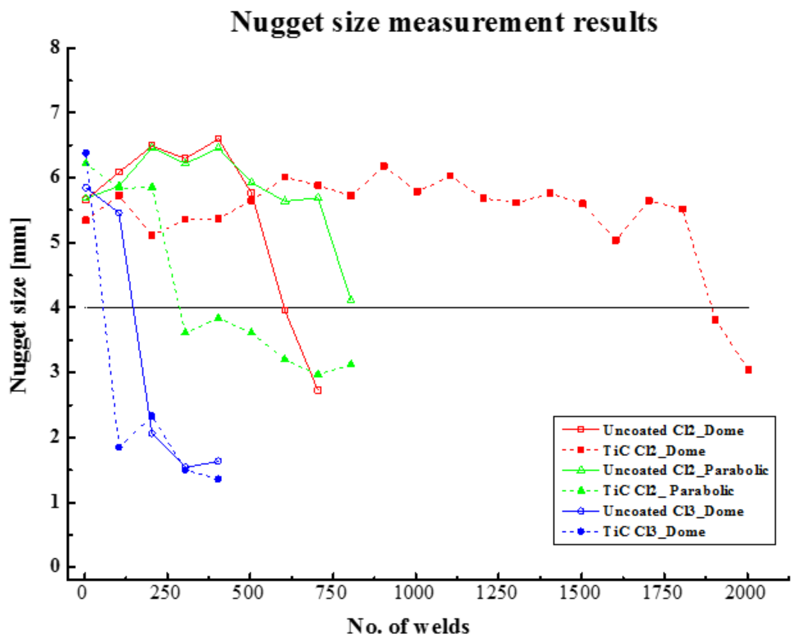


Figure 4. Nugget size result

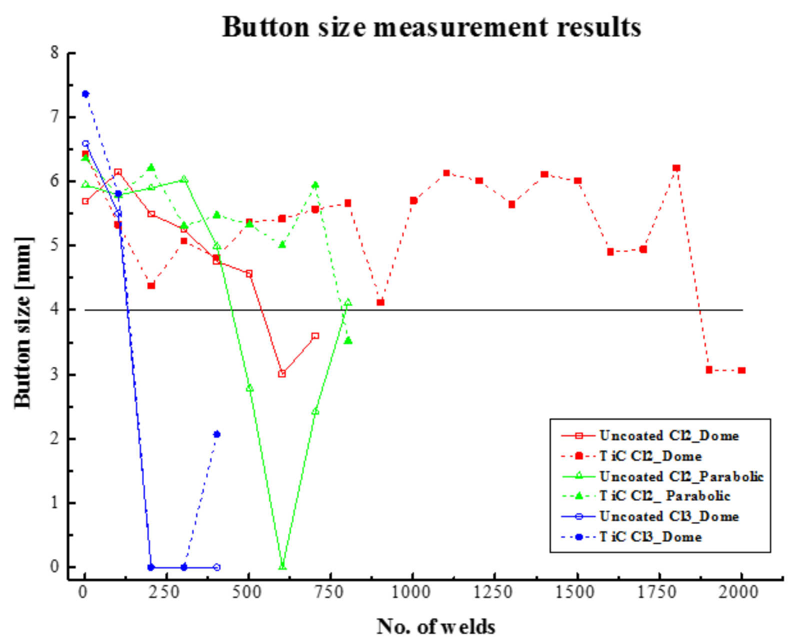
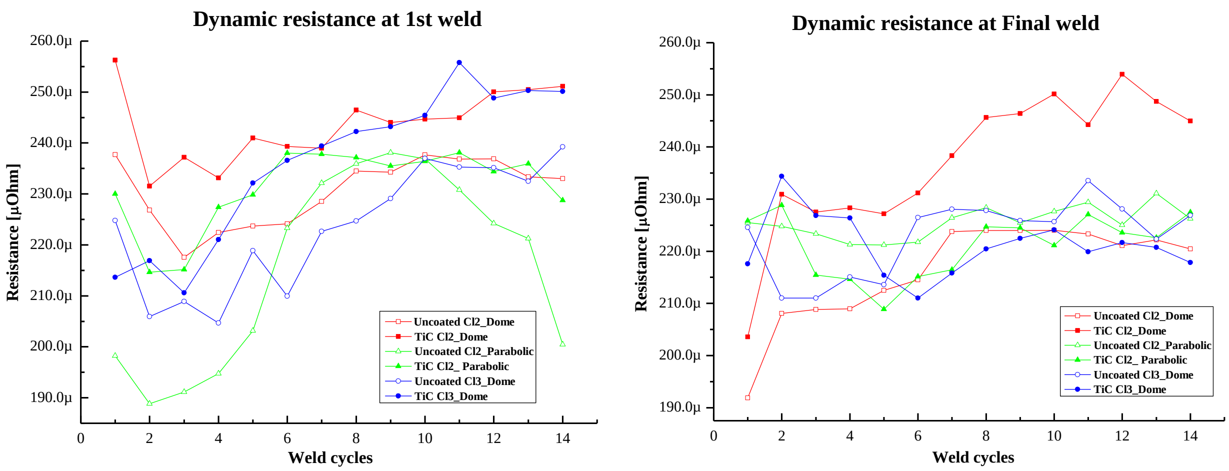


Figure 5. Button size result

Analysis of electrode life

Dynamic resistance

Generally, the dynamic resistance curve gives information and insight into how the weld nugget forms and when the weld nugget starts to form during RSW [1]. Most of all, weld quality can be estimated from the curve shape, such as the α-peak and β-peak. Figure 5 shows the dynamic resistance curves that are measured at the first and final welds of each electrodes. The resistance curves of the first weld for all electrodes formed a good shape with clear α-peak and β-peak, as shown in Figure 6 (a). First, the zinc coating layer from the DP600 reacts with the weld current within 3 to 4 cycles, and then sheet metal starts to melt and form a weld nugget after 4 cycles. Another important point is that the TiC coated electrodes can create higher resistance than uncoated electrodes, which facilities the nugget formation. On the other hand, at the final welds, the dynamic resistance curves were changed to a low and flat shape. This is because the electrodes surface areas were contaminated and widened from the high welding temperature and accumulated alloying on the surface during the repeated spot welding. These phenomena were described in Figure 6 (b). The resistance was increasing at the first few weld cycles due to the formation of alloying. But curves exhibit a low and flat shape after 6 weld cycles. This means that undersized weld nuggets were formed at the final weld. Actually, the fracture mode of all peel test specimens was an interfacial fracture. Even if the TiC electrode formed a high resistance from contaminants, such as alloying and zinc, it was not enough to form a button fracture.



(a) 1st weld (b) Final weld

Figure 6. Dynamic resistance curves at (a) 1st weld and (b) Final welds

Electrode surface area

Table 5 shows the results of the imprinting test. Electrode surface areas were measured to investigate the electrode's degradation. The enlarged electrode surface area can decrease the weld current density and resistance, which is critical in forming a good nugget. In terms of TiC coated dome electrodes, the increasing rate of surface area was lower than uncoated dome electrodes because the hard coating layer can decrease the deformation of electrode surface. The surface area of parabolic electrodes increased dramatically after 200 welds. Parabolic electrodes also exhibited a pitting area, but the real contact surface area was not diminished. The increasing speed of contact area of the parabolic electrode was slower than the other electrodes until 200 welds. However, after 200 welds, the increasing speed of uncoated and TiC coated parabolic electrodes was faster than the other electrodes, and electrode life was finished at around 700 welds. The imprinting results in Table 5 indicates that the parabolic electrodes were easier to deform. On the other hand, even though surface areas of class 3 dome electrodes were not increased as the other electrodes, electrode life tests were finished within 250 welds. Figure 7 shows that the surface area of class 2 electrodes reaches 40mm^2 after the final weld of tip life test.

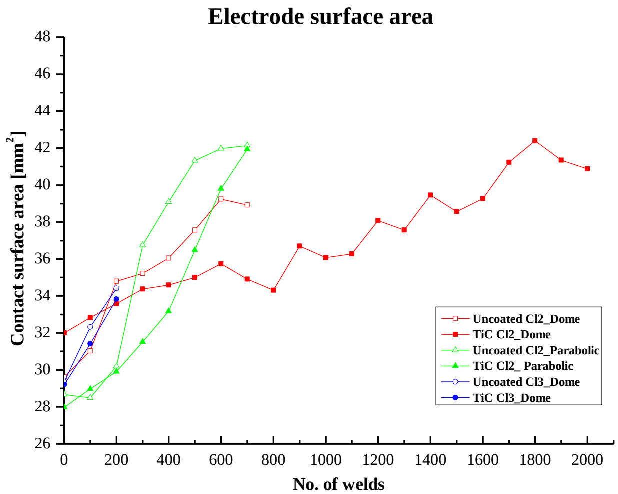
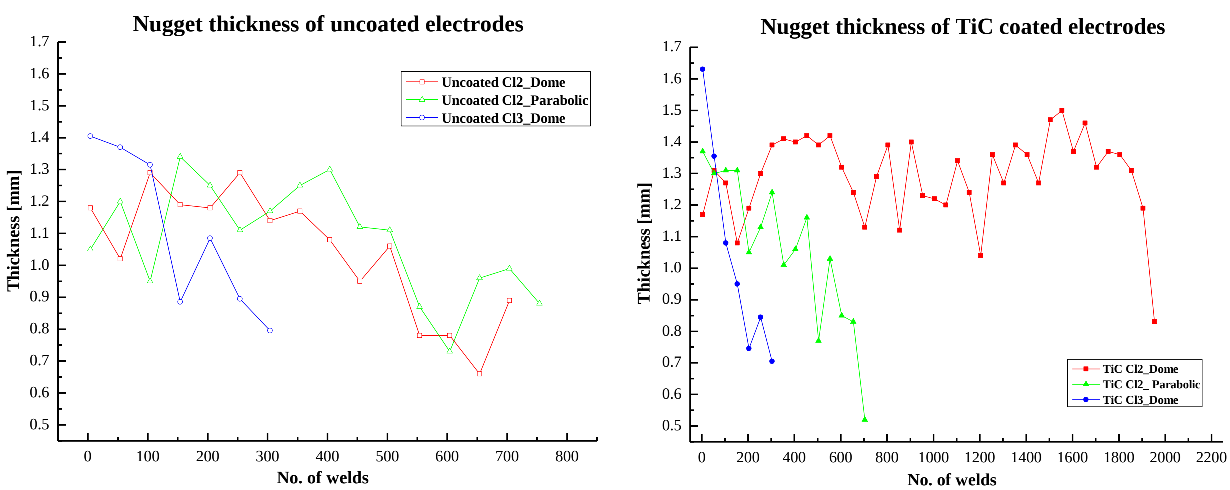


Figure 7. Changing of electrode surface area

Nugget thickness of class2 and 3 electrode

To help determine the latent characteristics of the class 3 electrode life, nugget thickness was measured. Generally, the weld nugget was thick and well formed in the initial welds. However, the nugget thickness decreases as the weld numbers increase. This is largely because of the decreased weld current density, which is caused by the accumulated alloying and enlarged electrode surface area. Eventually, electrode life and weld qualities will be detrimentally affected for these reasons. The nugget thickness of the first weld and the final weld were the same, as shown in Figure 8. Even though the class 3 electrode surface area was not increased significantly in Figure 7, nugget thickness was decreased significantly in both uncoated and TiC coated electrodes after 100 welds. From the result of heat input in Figure 9, class 3 electrode was proved that there was some resistance heat loss during welding process. Additionally, uncoated and TiC coated electrodes used the same welding conditions for class 2 electrodes, but the heat input of initial welds indicated that class 3 electrode generated less heat than class 2 electrode. As a result, the weld current of class 3 was not enough to form a good nugget. When the heat input was lower than 820J and 740J, uncoated and TiC coated electrodes life test finished respectively.



(a) Uncoated electrodes (b) TiC coated electrodes

Figure 9. Nugget thickness, (a) Uncoated electrodes and (b) TiC coated electrodes

The difference between class 2 and class 3 copper is mainly the alloying elements. Initially, class 3 copper has more alloying elements, which results in a higher hardness and electrical resistivity. Higher resistivity of the electrodes makes them consumes more weld current in themselves that cause the decreased heat input available to form a nugget. This explains the heat input drop during RSW process, since the electrode having a higher electrode resistance may cause more energy loss from the electrode. From Fig. 9, class 3 electrodes life is short because of the insufficient heat input to form the required nugget.

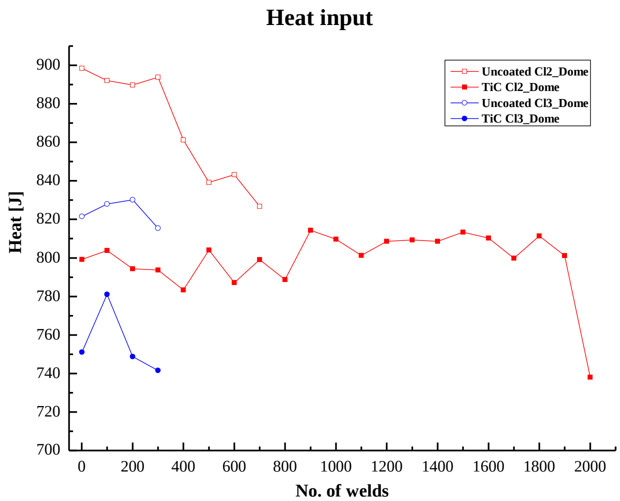


Figure 10. Heat input of Class 2 and Class 3 dome electrodes

Conclusion

The study reported here evaluated electrode life by using mechanical tests and weld signal analysis. The results indicated that the class 2 TiC coated dome electrode had the most improved electrode life among the electrodes tested. The TiC coating improved the class 2 dome electrode life from 650 welds to 1900 welds. It maybe because the TiC coated layer introduced a high resistance between the electrodes and the sheet metals, which is beneficial in forming good welding nuggets. Even when the electrode surface area increased, the dynamic resistance remained higher than the other electrodes. The TiC coated parabolic electrode failed after 250 welds. The short electrode life is because the electrode surface increased faster than dome shape electrodes. Class 3 TiC coated electrodes showed a shorter electrode life than class 2 TiC coated electrodes, which may be attributed to its lower electrical conductivity. The heat input results indicated class 2 TiC coated electrode is better than class 3 TiC coated electrode for transporting weld current, which leads to good welding nugget and increased electrode life.

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