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Effect of Electrodes Coated with Different Materials by Electrospark Method on the Resistance Spot Weld Quality

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Abstract— The DP600 dual phase steel is a member of the Advanced High Strength Steel (AHSS) group, which is widely used in the automotive industry. The lightweight for fuel saving and high strength for resistance to vehicle safety are reason for preference of these steels in the body parts of vehicles. DP sheets are generally combined with resistance spot welding methods. The deformation occurs at the electrode tip due to the high temperatures reached at the surface of the electrodes. Furthermore, the application of a certain pressure to the electrode through joining processes is also responsible for deformation on the electrode tip. For this purpose, the coating can apply to extend the lifetime of the Cu-Cr-Zr electrodes. In this study, two different coating materials, TiC-Co and CrNi, were deposited on the surfaces of Cu-Cr-Zr electrodes by electrospark method. Thus, the effect of the coating on the electrodes is investigated and the weld quality of the DP600 steel spot welded couples is also evaluated.

Index Terms—Resistance spot welding, DP600 steel, Electrospark coating, TiC-Co coating, CrNi coating, Weld quality, Microstructure

1 INTRODUCTION

ELECTROSPARK deposition (ESD) process has attracted much attention over the past decade to its efficiency, simplicity and cost-effectiveness [1-3]. This process has also been used for coating electrodes in the resistance spot welding to protect the electrodes from pitting or erosion [4]. The electrode tip can be improved by developing new electrode materials or electrode coating processes. Numerous investigations have been made on the coatings that affect the electrode tip life [5-11]. For example, Howe [5] and Tanaka [6] carried out studies on an increasing electrode tip of life for adjoining Zn-Ni coated steel sheets. They confirm that Ni acted as a diffusion barrier layer preventing the zinc from penetrating into the copper due to Ni present on the electrode surface. Chen et al., [7] explored the coating electrode with TiCP/Ni composite by electrospark deposition (ESD) method to prevent the electrode from alloying with molten zinc.

Zou et al. [11] conducted a study of a multi-layer Ni / (TiCP / Ni) / Ni composite coating onto the copper electrode surface by electrospark deposition method for increasing the life of conventional copper electrodes. As a result, they have confirmed that coated electrodes showed a much longer life than an uncoated electrode. Even though the welding current was lower for the coated electrode set up than that of the uncoated one. On the other hand, Chen and Zhou [8] proposed a multilayer deposition process, which improves the coating quality by using Ni and TiCP/Ni composite as deposition materials alternately. They found that it was possible to reduce or eliminate cracks and delamination of the monolithic TiCP/Ni coating via the multi-layer deposition process using Ni, TiCP/Ni.

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In the present work, two different coating materials, TiC-Co and CrNi were deposited on the tip surfaces of Cu-Cr-Zr electrodes by electrospark coating method to extent the electrode life. The characterization of these coatings has been carried out by scanning electron microscopy (SEM), energy dispersive analysis (EDX), X-ray fluorescence spectroscopy (XRF). The effect of the coating on the electrodes life time and conductivity is investigated. In, addition, the weld quality of DP600 steel spot welded couples is also evaluated by tensile shear test, hardness measurements and microstructure evaluation.

2 MATERIALS AND EXPIREMENTAL METHOD

The commercially obtained Cu-Cr-Zr F16 type spherical head resistance spot welding electrodes are divided in three groups; in which a group electrode was used as-received condition in this study. The rest of two groups electrodes were coated with Cr-Ni and TiC-Co welding consumable at same voltage (80V) under the 13 lt/min. argon gas flow by using electrospark welding machine. The electrospark welding machine and coating assembly is shown in Fig. 1

Fig. 1. Electrospark welding machine and coating assembly.

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TABLE 1
CHEMICAL COMPOSITION OF AS-RECEIVED, TIC-CO AND CR-NI COATED ELECTRODES (%WT)

Element (% weight)	C	Al	Ti	Co	Si	Ni	Fe	Cr	Zr	Cu
Cu-Cr-Zr Electrode	-	-	-	-	-	-	-	0,66	0,05	99,28
TiC-Co Electrode	9,94	0,48	22,4	5,1	0,28	-	-	-	-	Rest
CrNi Electrode	-	-	-	-	5,27	4,74	10,93	12,18	0,08	Rest

The chemical composition of as-received commercial, TiC-Co and Cr-Ni coated electrodes are analyzed by Rigaku ZSX Primus II model WD-XRF equipment. The results are given in Table 1.

The electric resistivity of the as-received and coated electrodes was measured by GWINSTEK GOM-802 type ohm-meter having 1 micro-ohm sensitivity. A device has got two pins (11.5 mm distance). It applies constant pressure with spring for measurement. The electrode wear is determined by the weight measurement which is carried out with the balance having 0.001sensitivity.

TABLE 2
THE CHEMICAL COMPOSITION OF DP600 STEEL (WT%).

C	Si	Mn	Cr	Mo	Al	Fe
0.13	0.35	1.426	0.637	0.013	0.053	Rest

The chemical composition of DP600 steel is summarized and given in Table 2. A group of DP600 steel sheet having dimensions of 1.5 x 30 x 100 mm^3 was cut prior to joining of tensile shear test sample Test samples were spot welded in a pneumatic spot-welding machine with 60 kVA capacity in 50Hz electrical circuit. The constant 20 cycle (1 cycle= 0.02 sec) weld time, 7kA welding current, 25 cycle squeeze time, 15 cycle holding time and 5kN electrode force was selected for welding parameter. For evaluation of electrode coating on the properties of spot weldment, a group of DP600 steel couple were joined with as-received spherical tip electrodes (Cu-Cr-Zr) for determined welding parameters. It has got 5.5 mm tip diameter. The other groups of samples were welded with Cr-Ni and TiC-Co coated electrodes, which were coated at 80V by ESD method, for selected welding parameter.

A set of five tensile shear test samples were joined with the determined welding parameters by using as-received, Cr-Ni and TiC-Co coated electrodes. Tests were carried out by SHIMADZU tensile test machine having 50kN capacity at the 5 mm/min constant strain rate. The Vickers microhardness measurement on the weld cross section in which the welded nugget, heat affected zone (HAZ) and base metal was carried out with a load of 500g. The chemical composition of the electrodes was used in this study, which was determined by XRF. The composition of the coating surface and the cross-section of the electrodes were examined by using a Zeiss Ultra-type scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS). Standard metallographic procedure applied on the transverse section of the weldment for preparing metallographic test sample. The sample was etched for 8s with 2% nital for revealing the microstructure. The microstructural examination of welded samples was carried out by using a Nikon Optical DIC microscope.

3 RESULTS AND DISCUSSIONS

3.1 Evaluation of Electrodes

The chemical composition of as-received, TiC-Co and Cr-Ni coated electrodes was determined by XRF. The analysis result is shown in Fig. 2

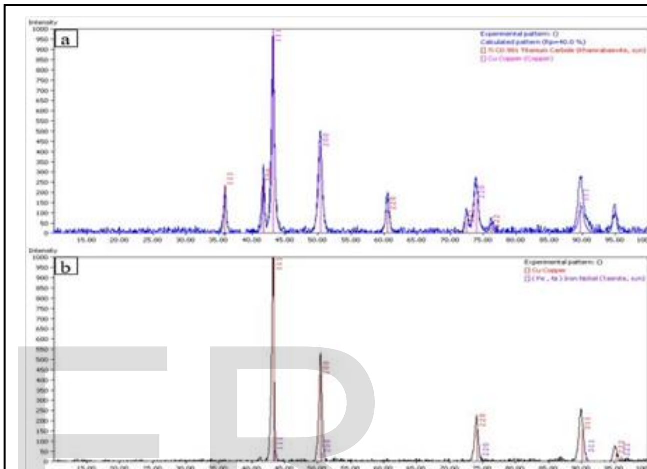
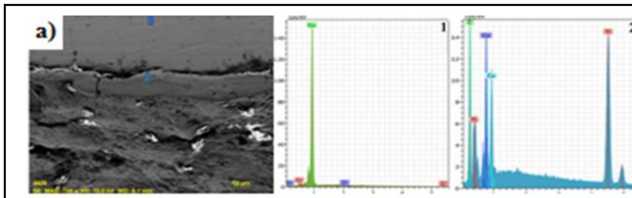
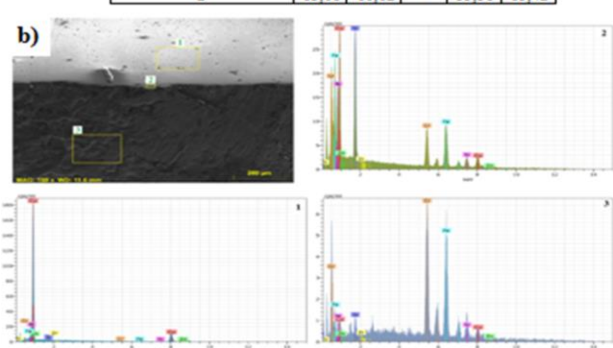


Fig. 2. The XRF analysis of a) as-received and TiC-Co coated electrodes, b) as-received and Cr-Ni coated electrodes



Mass Percent Spectrum	Cr	Cu	Zr	Ti	Co
1	0,31	99,55	0,14	-	-
2	15,08	16,12	-	53,38	15,42



Mass Percent Spectrum	Si	Cr	Fe	Ni	Cu	Zn	Zr
1	1,25	0,23	0,00	0,00	97,65	0,58	0,29
2	14,51	16,36	33,38	12,70	22,59	0,43	0,03
3	0,64	31,46	43,64	12,86	11,21	0,18	0,00

Fig. 3. EDS analysis carried out on a) TiC-Co coated electrode, b) CrNi coated electrode

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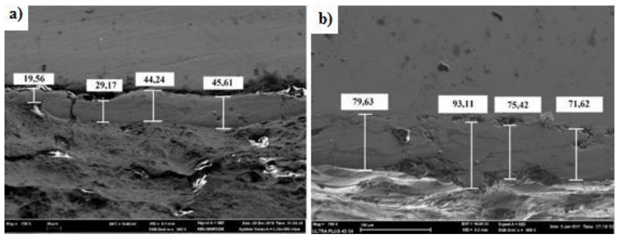

Fig. 4. The coating thickness on the electrode end tip a) TiC-Co coated, b) CrNi coated

The XRF result confirms that the commercial spot-welding Cu-Cr-Zr electrode was successfully coated with TiC-Co and Cr-Ni. Furthermore, the variation in the composition on the surface of the electrode was determined by EDS analysis indicating successfully coating process. The coating thickness was also measured by SEM. The point EDS analysis of TiC-Co and Cr-Ni coated electrodes are shown in Fig. 3 a and b respectively.

The EDS analysis revealed that the as-received electrode consisted of Cu-Cr-Zr alloying elements. The Ti, Co and Co alloying elements were detected on the surface of TiC-Co coated electrodes and the Cr, Ni and Fe alloying elements were detected on the CrNi coated electrodes. As mentioned earlier, the coatings were successfully succeeded (Fig. 3 a and b). The thickness measurement was carried out on the cross section of the electrodes, the thickness of TiC-Co coated electrode varies between 15-42 µm and the thickness of CrNi coated electrode varies between 70-93 µm (Fig. 4 a and b). It is believed that the coating thickness is affected from the filler metal composition and the welder skill. The presence of a coating layer on the electrode surface may affect the welding assembly and hence the welding behavior. For example; the electrical resistivity of the as-received electrode is very low, so it is presumed as a 0. The resistivity of TiC-Co and CrNi coated electrodes was 2.378 mΩ and 2.922 mΩ respectively. It means that the coating layer thickness on the electrode surface increases to the resistance to the electrical circuit.

The heat generation ($Q = I^2Rt$) during resistance spot welding (RSW) can be expressed, where Q is the heat energy in joules, I is the current in amperes, R is the resistance in ohms, and t is the time in seconds [9]. According to this equation, the heat input is mainly controlled by the current, time, and electrical resistance. The electrical resistance was affected from the used work pieces and the electrodes. The coated electrodes have higher contact resistance, which can cause high heat input ($Q = I^2Rt$) during RSW. It is believed that a higher heat input results in a larger melting area and thus an extension in nugget diameter. Chen and Zhou [8] claim that the lower contact resistance for uncoated electrode is owing to smooth surface and softness compared to the coated electrode, resulting in a lower heat input. It is believed that deformation or mushrooming of the electrode face is associated with electrode force. It increases contact area and decreases both current density and welding pressure. Weld quality will deteriorate as electrode tip deformation proceeds.

The electrode end tip images after 0-5-10-20-100 were taken for determining the tip geometry and life of electrodes. Images are shown in Fig. 5 a-d.

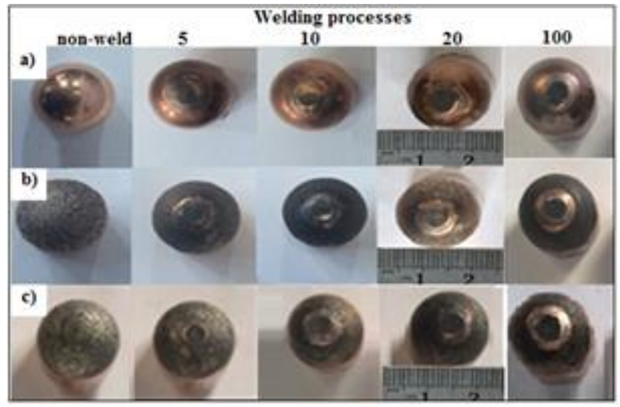

Fig. 5. The electrode end tip image after 0-5-10-20-100 welding processes a) As-received electrode, b) TiC-Co coated electrode, c) CrNi coated electrode.

As seen in Fig. 5, the deformation and mushrooming of the as-received electrode surface type associate with the electrode during welding processes have become larger than coated electrodes. It is believed that larger deformation and mushrooming is definitely due to the lower softening temperature of Cu-Cr-Zr electrode material [12-15]. The resistance to deformation and mushrooming on the electrode tip depends upon the proportional limit and the hardness of the electrode alloy. The proportional limit is largely established by heat treatment. The resulting temperature of the electrode is the governing factor because this is where the softening takes place [16]. The softening of the electrode base material due to heating has been shown to accelerate the deformation process [17]. Therefore, the maximum mushrooming determined on the as-received electrode tip.

3.2 Tensile Shear Test Results

The mean tensile shear strength-elongation curves of welded samples, which were joined with as-received, TiC-Co and CrNi coated electrodes, are shown in Fig. 6.

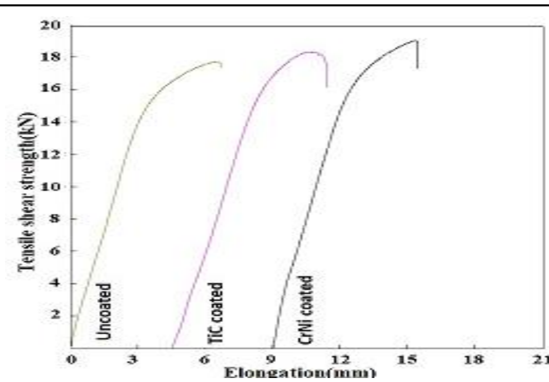

Fig. 6. The tensile shear curves of DP600 weldment joined with as-received. TiC-Co and CrNi coated electrodes

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The Fig. 6 clearly shows that the tensile shear strength of the weldments joined with coated electrodes is higher than weldment that was joined with as-received one. It is believed that the TiC-Co and Cr-Ni coating resulted in increased electrical resistivity and contact area. The coating creates more heat on the electrode end tip. The more heat input for the resistance spot weld expands the weld nugget diameter that causes the recovering on the strength. The tensile shear strengths of the weldments are 17,80 kN, 18,35 kN and 18,98 kN, respectively, which were joined with as-received TiC-Co and CrNi coated electrodes. Meanwhile, the elongations are 5,98 mm, 5,65 mm and 5,25 mm, respectively, which were joined with as-received, TiC-Co and CrNi coated electrodes. The maximum strength obtained from the sample, which was welded with CrNi coated electrode. It could be related with low thermal conductivity of CrNi coating.

3.3 Hardness Measurement

The hardness measurement was carried out on the cross-section of weldment, which consists of base metal, HAZ and weld nugget and the results are shown graphically in Fig. 7.

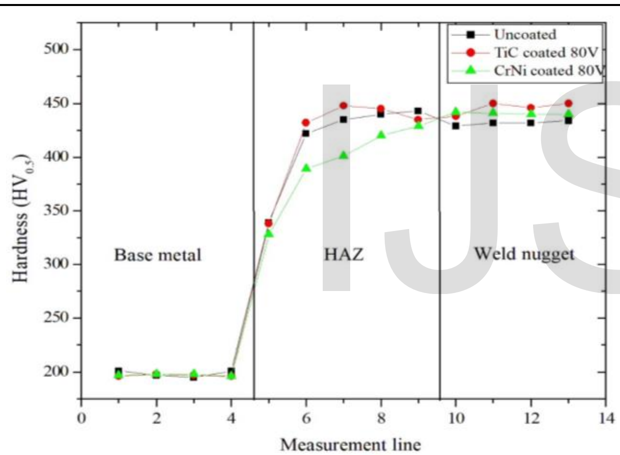

Fig. 7. Hardness result of weldments joined with as-received, TiC-Co and CrNi coated electrodes.

The base metal hardness average value is measured as 198 $HV_{0.5}$. The hardness values increase from base metal through HAZ and weld nugget. The hardness values in the weld nugget were 416-430 $HV_{0.5}$, 425-450 $HV_{0.5}$ and 426-440 $HV_{0.5}$ for samples which were joined with as-received, TiC-Co and CrNi coated electrodes respectively. As seen in Fig. 7, the hardness of the weld nugget was obtained by coated electrodes slightly higher. The maximum hardness value for HAZ and weld nugget is determined in the sample adjoined with TiC-Co coated electrodes.

3.4 Microstructure Investigation

The microstructures of weldments are shown in Fig. 8-10 respectively, which were adjoined with as-received, TiC-Co and CrNi coated electrodes.

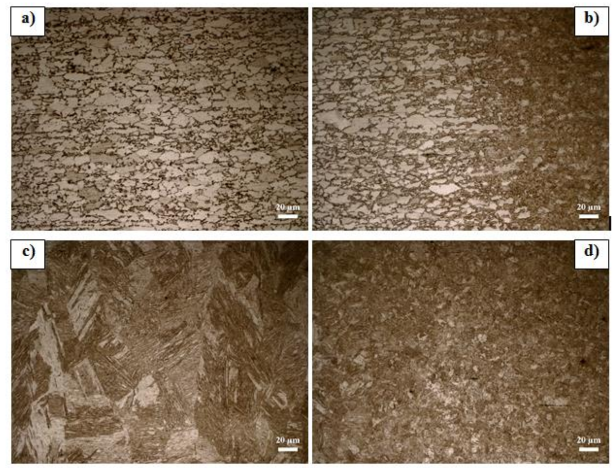

Fig. 8. The microstructure of weldment joined with as-received electrode, a) base metal, b) transition zone, c) weld nugget, d) HAZ

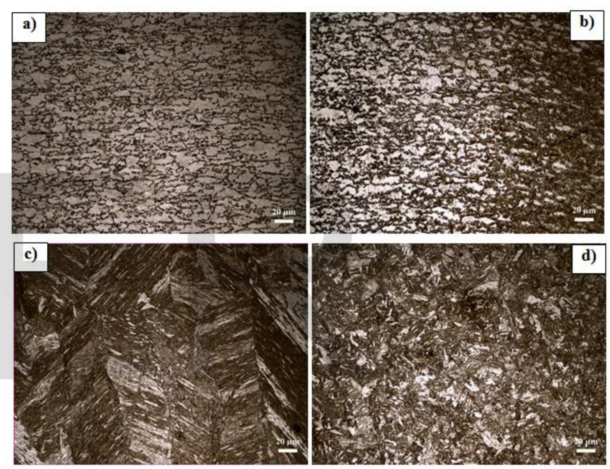

Fig. 9. The microstructure of weldment joined with TiC-Co electrode, a) base metal, b) transition zone, c) weld nugget, d) HAZ

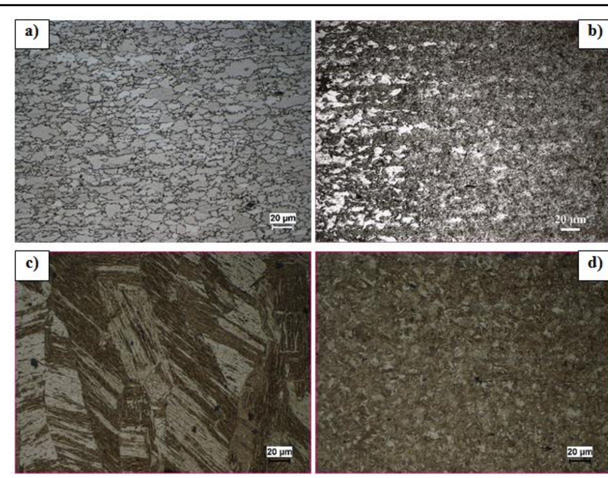

Fig. 10. The microstructure of weldment joined with CrNi electrode, a) base metal, b) transition zone, c) weld nugget, d) HAZ

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As seen in Fig. 8-10a, the microstructure of DP600 base metal consists of certain amount of martensite phases in ferrite matrix. As seen in Fig.8-10c, the nugget of welds is decorated by fully martensite phase where the temperature exceeds Ac_3 so it is completely austenitized during the welding and then rapid cooling rate encourages the martensite transformation [18-20]. The HAZ region of weldment exhibits martensitic and ferritic microstructure for all weldments (Fig.8-10 d). As compared to the DP600 base metal, the martensite volume fraction of the HAZ region was increased due to the temperature reached between Ac_1 and Ac_3 range during welding so that it was partially austenitized and then transformed into martensite associate with cooling regime [18-20]. It is reported that the subsequent rapid cooling, the carbon rich austenite transforms to the martensite phase and the ferrite remains the same in the structure [17,21]. However, the microstructure was predominantly martensite side-by-side welded nugget (Fig. 8-10b), where it is believed that the formation of crack proceeds and propagates during tensile shear and cross tensile test. Since the DP600 steel has been joined with similar welding parameters, it has not been observed different microstructural formation in the HAZ and weld nugget for all weldment that obtained varies electrodes.

3 General Results

Conclusion is derived from this study as summarized as follow;

- The XRF and EDS analysis confirms that the F16 type commercial spot weld electrode can be coated with TiC-Co and Cr-Ni substrate successfully. The EDS analysis confirms that the as-received alloys consist of Cu-Cr-Zr alloying elements. The Ti, C and Co alloying elements were detected on the end tip of TiC-Co coated electrodes, while the Cr, Ni and Fe alloying elements were found on the surface tip of the CrNi coated electrode.
- The thickness of TiC-Co coated electrode varies between 15-42 µm and the thickness of CrNi coated electrode varies between 70-93 µm due to manual coating operation on the spherical head of electrode.
- The electrical resistivity of the as-received electrode is very low so it is presumed as a 0. The resistivity of TiC-Co and CrNi coated electrodes was 2.378 mΩ and 2.922 mΩ respectively. The coating layer thickness and coating substrate on the surface of the electrode has a high electrical resistivity, increasing the resistance to the electrical circuit.
- The lower strength of the as-received Cu-Cr-Zr electrode materials compared to the TiC-Co and CrNi material also contributed to the large mushrooming of the as-received electrode.

- The tensile shear strengths of the weldments joined with TiC-Co and CrNi coated electrodes were determined higher than as-received one. It is believed that the coating increases the contact resistivity. It creates more heat on the electrode tip. The more heat input expands the weld nugget diameter so that the joint strength is recovered. The maximum tensile shear strength of the weld was obtained with joint Ti-Co coated electrode, as 18,98 kN.
- The base metal average hardness value is measured as 198 $HV_{0.5}$. The hardness of the weld nugget that was obtained by coated electrodes found slightly higher. The maximum hardness value for HAZ and weld nugget determined in the sample adjoined with TiC-Co coated electrodes.

- The DP600 steel consists of martensite phases in ferrite matrix. Meanwhile, the HAZ region in DP600 steel side of weldment exhibits martensitic and ferritic microstructure. The martensite volume fraction increases towards to the weld nugget. The weld nugget is decorated by fully martensite phases. Since the DP600 steel has been joined with similar welding parameters, it has not been observed any different microstructural formation in the HAZ and weld nugget for all weldment.

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