Microstructural investigation of SPA-C steel sheets used in railway vehicles in resistance spot welding

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Abstract This paper presents an experimental study on resistance spot welding of SPA-C steel sheets used in side wall and roof in rail vehicles. SPA-C steel sheets having 2.3 mm thicknesses were joined by using resistance spot welding as lap joint. A timer and current controlled resistance spot welding machine having 120 kVA capacity and a pneumatic application mechanism with a single lever was used to prepare the specimens. Welding periods were chosen as 5, 10, 15, 20, 25 and 30 cycles and also welding currents were increased from 6 kA up to 14 kA by rise of 0,5 kA. The electrode force was kept constant at 6 kN. The micro and macro-structures of prepared welding specimens were investigated by means of an optical microscope and scanning electron microscope (SEM) in order to see the joinability of SPA-C steel sheets by resistance spot welding.

Key words: Resistance spot welding-Rail vehicles-Atmospheric corrosion resistant steels-SEM

1. INTRODUCTION

Resistance spot welding (RSW) is one of the oldest of the electric welding processes in use by industry today. The weld is made by a combination of heat, pressure and time. As the name implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part [1].

The RSW is a complex process which involves electrical, thermal, mechanical and metallurgical phenomenon. These complicated phenomenon have a major influence on the formation of a welded joint, including the nugget and the heat-affected zone (HAZ) [2]. In order to appropriate weld nuggets, understanding these complicated factors and evaluating the role of the major metallurgical factors and processing parameters are necessary.

The weld microstructure is the most complete measure of weld quality and is therefore the best way to define process requirements [3]. However, RSW produces more complex microstructures than other welding processes, because it involves rapid heating and cooling. Microstructural changes during RSW dramatically affect mechanical properties by transforming the base metal microstructure [4]. The result of this usually weld nugget with significantly different microstructure than the base metal. A coarse granular structure is susceptible to hot cracking. A finer structure, distorted columnar structure, or equiaxed structure is more resistant. The structure and crystallographic orientation of grains in the heat affected zone generally continue to the fusion zone [5]. This complex microstructure development can impact the failure behavior of RSW and should be taken into account.

To date, the microstructures and failure mechanisms of RSW SPA-C steel sheets have not been examined in sufficient detail. So, the objective of the present study is to characterize the microstructure of SPA-C steel sheets after RSW, as a basis for understanding the relationship between the microstructure and the failure behavior.

2. EXPERIMENTAL WORK

2.1. Materials

The materials studied are SPA-C steel sheets having 2,3 mm thicknesses, which are used in rail vehicle bodies. The chemical composition and the mechanical properties of the sheet are, respectively, shown in Table 1 and 2.

2.2. Welding Process

A timer and current controlled RSW machine having 120 kVA capacity and pneumatic application mechanism with a single lever was used in the experiments.

Table 1 Chemical composition of steel sheets used in experiments

Chemical composition	C	Si	Mn	P	S	Cr	Ni	Cu
wt. %	0.097	0.397	0.433	0.0913	0.0016	0.605	0.257	0.331

Table 2 Mechanical properties of the sheet steel

Yield strength (MPa)	430
Tensile strength (MPa)	550
Total elongation (%)	45

The electrode force was continuously measured and controlled during the experiments. Weld time, hold time and clamping time were adjusted automatically by electronic devices of machine. Welding was carried out by using water cooled conical Cu–Cr electrodes having a contact surface of same diameter (7 mm) in accordance with EN ISO 5182 [6].

The prepared specimens were overlapped with 30 mm. spacing and welded. For joining, 5, 10, 15, 20, 25 and 30 cycles weld time were applied while other welding parameters such as applied electrode pressure (6 kN) and clamping and hold times of electrode (25 cycles) were kept constant. The welding current was increased from 6 to 14 kA by 0,5 kA increments.

The cross-sections of the weld joints were polished mechanically and etched with Nital. The specimens were then examined with an optical microscope (Nikon SMZ800) and a scanning electron microscope (SEM; JEOL JSM-6060LV).

3. RESULTS AND DISCUSSION

The spot weld joint of SPA-C steel sheets contains three microstructural zones of primary interest that will be described based on the proximity to the weld. Figure 1 displays the three zones of interest:

i) Fusion Zone (FZ) or weld nugget contains the sections of the material that becomes molten and resolidifies during the welding and subsequent cooling.

ii) Heat Affected Zone (HAZ) which is experienced solid state microstructural alterations during thermal cycle of welding. This section of the weld has not been melted; however, significant thermal affects are evident. Several microstructural changes can occur in the HAZ. The HAZ of a spot weld can be subdivided in to three main regions which include the coarse grain (CG), fine grain (FG) and intercritical (IC) HAZ [4].

iii) The final zone is the base material (BM). This zone is adjacent to the HAZ and represents the portion of the spot weld joint that has not been affected by the

welding process and is comprised of the parent material used to produce the weld [7].

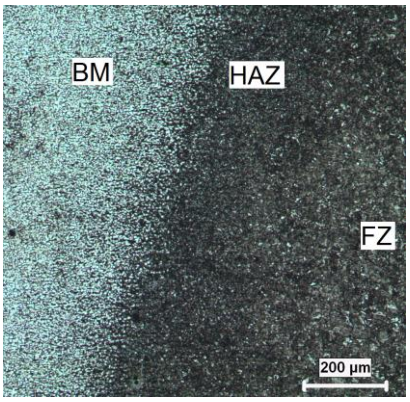

Figure 1: Metallurgical zones of the spot weld joint of SPA-C steel

Figure 2 shows the weld microstructure for SPA-C steel. The BM microstructure consists of ferrite grains (grey) with carbides (dark colored) situated at grain boundaries (Figure 2 a).

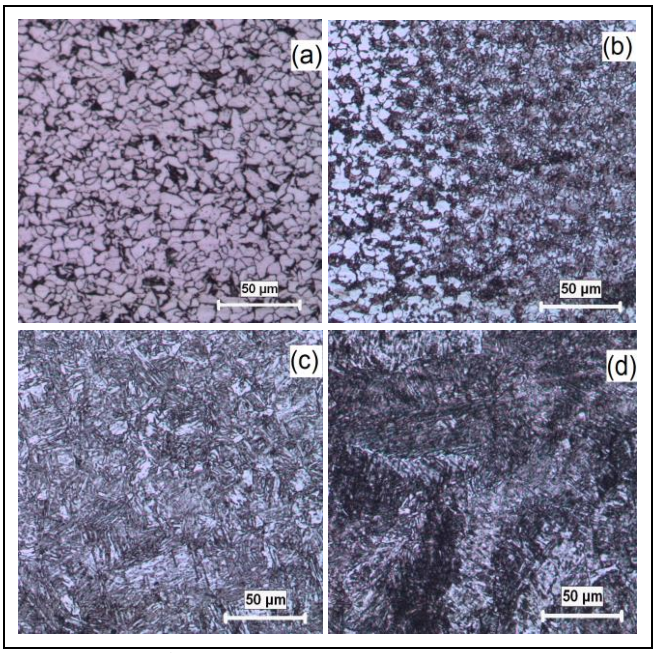

Figure 2: Microstructures of spot welded SPA-C samples (a) base metal, (b) IC-FG HAZ, (c) CG HAZ, and (d) fusion zone or weld nugget

The IC HAZ consists mainly of ferrite and some pearlite (Figure 2 b). The FG HAZ consists mainly of pearlite and some ferrite (Figure 2 b). The CG HAZ shown in Figure 2c has a needle like structure. The needle like structure consists of island and side plate ferrite with stripes of grain boundary ferrite. The FZ consists of a columnar structure composed mainly of martensite, which is shown in Figure 2d. In this region which experience grain coarsening during thermal cycle of the welding process, both high cooling rate and large grain size promote the formation of martensite.

Several researchers have noted the presence of martensite in the RSW nugget and HAZ. Martensite will create altered mechanical properties (i.e., increased strength, reduced ductility) in comparison to the original material properties [8].

Figure 3 shows the SEM micrograph of (a) BM, (b) IC HAZ, (c) CG HAZ and (d) FZ. As shown in Figure 3(a), the microstructure of base metal used in this investigation is ferritic with a small amount of Fe_3C. EDS analysis of point (1) were given in Table 3. SEM images of FZ (Figure 3d) reveal that there exist needle-like microstructures within the martensite laths.

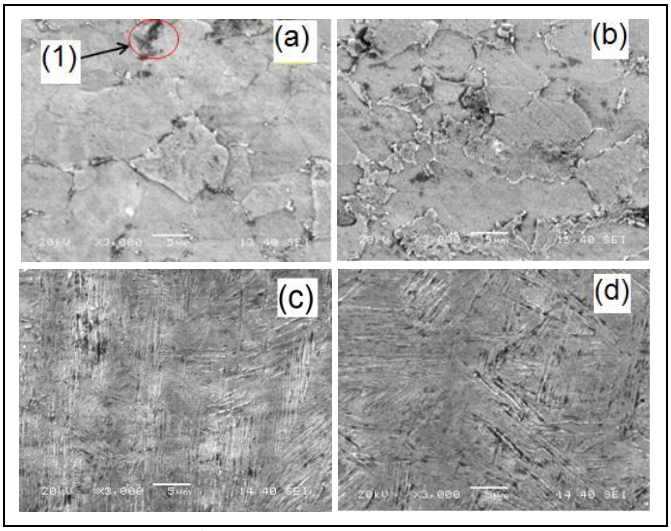

Figure 3: SEM micrograph of spot welded SPA-C samples (a) base metal, (b) IC HAZ, (c) CG HAZ, and (d) fusion zone or weld nugget

Table 3 EDS analysis of point (1)

Elt.	Line	Intensity (c/s)	Error 2-sig	Conc	Units	
C	Ka	3.85	1.240	3.744	wt. %	
O	Ka	14.04	2.370	5.043	wt. %	
Fe	Ka	338.99	11.644	91.213	wt. %	
				100.000	wt. %	Total

4. CONCLUSION

The microstructures in the fusion zone of SPA-C steel sheets after RSW were characterized by means of optical microscopy and SEM. The main conclusions are summarized as follows.

- The microstructure of base metal used in this investigation is ferritic with a small amount of Fe_3C.

- The microstructure of weld nugget, which mainly consists of martensite. Despite the low carbon content of the base metal, martensite phase was formed due to high cooling rate involved in RSW process.

- Several microstructural changes can occur in the HAZ. The HAZ can be subdivided in to three main regions which include the coarse grain (CG), fine grain (FG) and intercritical (IC) HAZ. The IC HAZ consists mainly of ferrite and some pearlite. The FG HAZ consists mainly of pearlite and some ferrite. The CG HAZ has a needle like structure. In HAZ, the grain coarsening occurred owing to thermal cycle of the welding process.

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