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Welding Time Effect on Tensile–Shear Loading in Resistance Spot Welding of SPA-H Weathering Steel Sheets Used in Railway Vehicles

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This paper presents an experimental study on the resistance spot welding of SPA-H weathering steel sheets used in side wall and roof application of rail vehicle bodies. A timer and current controlled resistance spot welding machine having 120 kVA capacity and a pneumatic application mechanism with a single lever were used to prepare the specimens. Welding periods were chosen as 10, 15, 20, 25, and 30 periods (1 period = 0.02 s) and also welding currents were increased from 6 kA up to 11 kA by rises of 0.5 kA. The electrode force was kept constant at 4 kN. The prepared welding specimens were exposed to tensile–shear test and the obtained results were supported by diagrams and, finally, appropriate welding parameters were advised to the users.

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1. Introduction

The most common types of damage that occur to structural steels during their lifetime are fatigue and rusting. Except for stainless steels, which are more costly, almost no uncoated ferrous products can resist the influences of various corrosion factors coming from the atmosphere, e.g. sulfide, chloride, dust, and moisture. However, weathering steel is a kind of steel that can be maintained for dozens of years at low cost and without coating [1].

Weathering steels, also known as low-alloy steels, are mild steels with a carbon content of less than 0.2 wt%, to which mainly Cu, Cr, Ni, P, Si, and Mn are added as alloying elements totalling a few percent maximum [2].

In the 1920s US Steel produced a new family of HSLA steels intended primarily for the railway industry. In 1933 US Steel launched the first commercial weathering steel under the brand name USS Cor-Ten steel. This product was claimed to provide a 30% improvement on the mechanical properties of conventional carbon steel, thus reducing the necessary thickness and accordingly the weight of steel to be used for a given set of mechanical requirements [3].

SPA-H superior atmospheric corrosion resistant steels are applied to rolling stock body, architecture, steel tower, and other structures.

Resistance spot welding (RSW) is a joining process in which coalescence of the metal sheets is produced at the contact surface by the heat generated at the joint by the resistance of the work to the flow of electric current [4, 5]. The first usage of this welding technique had been seen at the end of the 19th century, and it was started to use in combination of sheets after 1920s [6]. Because of the processes requiring relatively simple equipment, it is easily and normally automated and once the welding parameters established it should be possible to produce repeatable welds; the resistance spot welding is the most widely used joining process for sheet materials [7].

Resistance spot welding is the most widely common method used for joining structures and plates of different materials in automobile, railroad, airplane structures, and in certain nonstructural components in aerospace industry [8, 9].

Like any other welding processes, the quality of the joint in RSW is directly influenced by welding input parameters. In most cases, good spot-welding practice requires three parameters that have to be controlled, namely, current, time, and electrode force [8]. A common problem faced by manufacturer is the control of the process input parameters to obtain a well welded joint with required strength. Thus, finding the relationships between the strength of spot weld and process parameters is of great interest in related industrial applications. Therefore the tensile–shear loading of the joint in RSW is an important index to welding quality [10].

Welding time is directly proportional to the amount of heat being generated. Increased welding time results in increased heat generation. It facilitates nugget growth which enhances the mechanical performance of weldments. However, excessive welding time results in expulsion due to nugget overgrowth. This can introduce weld defects into the weldment, such as voids and excessive indentation, which adversely affects weld performance [6, 11].

The purpose of this work was to investigate the effect of welding time on tensile–shear strength in RSW of SPA-H steel sheets. The samples were exposed to tensile–shear tests in order to determine the joint strengths. The effect of welding time on tensile–shear strength was determined by using weld lobe diagrams and the optimum welding currents and times were advised.

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2. Experimental studies

The sheets were welded by RSW by fixing electrode form, materials type, cooling water flow rate and electrode force and changing welding current and time. All series were exposed to tensile–shear tests in order to determine the joint strengths.

2.1. Material

The materials studied are SPA-H weathering steel sheets having a 2.3 mm thickness, and which are used in side wall and roof application of rail vehicle bodies. The chemical composition and the mechanical properties of the sheet are, respectively, shown in Table I and Table II. Before welding, the materials were cut into pieces in dimensions of 200×30 mm^2, and the surfaces of all samples were cleaned mechanically.

TABLE I

Chemical composition of steel sheets used in experiments [wt%].

C	Si	Mn	P	S	Al	Cu	Cr	Ni
0.081	0.419	0.426	0.084	0.006	0.031	0.315	0.664	0.328

TABLE II

Mechanical properties of the sheet steel.

Yield strength [MPa]	Tensile strength [MPa]	Total elongation [%]
457	572.7	40

2.2. Welding equipment

A timer and current controlled RSW machine having 120 kVA capacity and pneumatic application mechanism with a single lever were used in the experiments. The electrode force was continuously measured and controlled during the experiments. Also welding current values were continuously calculated and controlled by means of a current transformer which is set up on the lever of welding machine and an ampere-meter. Welding time, holding time and clamping time were adjusted automatically by electronic devices of the machine. Welding was carried out by using water cooled conical Cu–Cr electrodes having a contact surface of the same diameter (8 mm) in accordance with EN ISO 5182 [12].

2.3. Welding process and tensile–shear test

The specimens were overlapped with 30 mm spacing and welded in accordance with EN ISO 14373 [13] as shown in Fig. 1a. The electrode force was fixed at 4 kN and controlled during experiments. The welding time was applied as 10, 15, 20, 25, and 30 periods (per). Clamping and hold times were remained constant as 25 per in all series. The welding current was increased from 6 kA to 11 kA by 0.5 kA increments. Therefore, different welds joint properties were obtained. The welded parts were exposed to tensile–shear tests in a testing machine in laboratory conditions. The tensile speed was remained constant during test. The values given as tensile–shear strength are the maximum values read from the scale of the machine. Samples of them are shown in Fig. 1b.

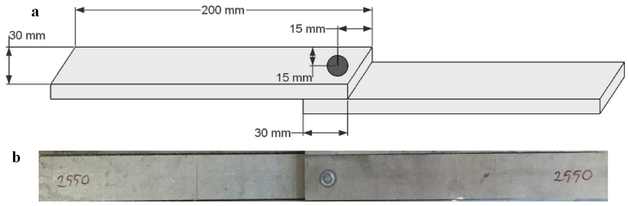

Fig. 1. (a) The dimensions of the tensile–shear specimens, (b) specimen welded by resistance spot welding.

3. Results and discussion

In the light of results obtained from diagrams in Fig. 2, increasing welding time causes high heat input to weld zone and extending weld nugget, so the tensile–shear strength of joints increases [8, 14, 15]. It increases from 7.5 kA to 9.5 kA in 10 period welding times. In 15 and 20 periods, tensile–shear strengths of specimens increase sharply up to 9.5 kA and then this increment continues with a lower rate. In 25 period welding times, tensile–shear strengths of specimens increase fast up to 9 kA where the maximum point is for this period. In 30 period welding times, tensile–shear strengths of specimens increase up to 8.5 kA where the maximum point is for all periods and it decreases after 8.5 kA.

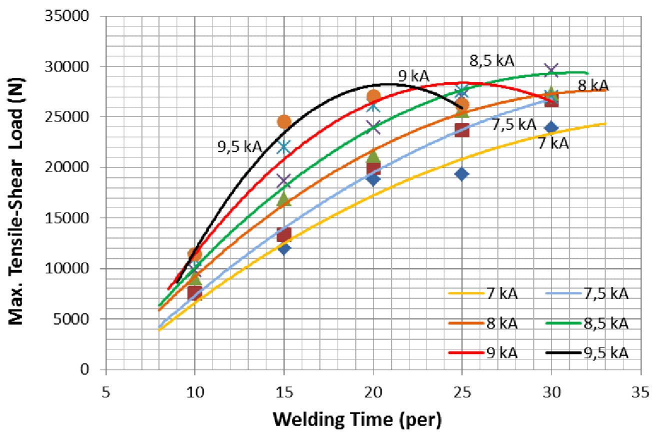

Fig. 2. Effect of welding current on tensile–shear load of weld joints.

In low welding time application, small weld nugget diameters were obtained; similarly, lower tensile–shear strength value than that of base-metal was measured due to low heat application to welding zone. As a result, break type was observed as separation. However, the tensile–shear strength increases with increase of welding time. Therefore, break type was observed as knotting and tearing. During the tensile–shear tests, three types of breaking failure were observed: separation, knotting, tearing [16–19]. Samples of them are shown in Fig. 3.

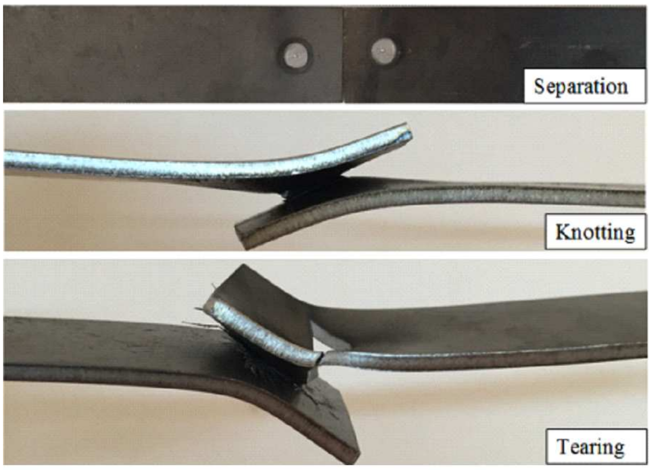

Fig. 3. Breaking failure samples observed in tensile–shear tests.

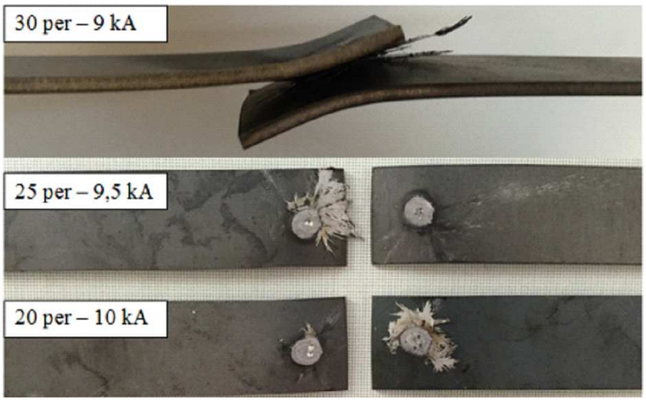

Fig. 4. Spurt out failure observed in weld nuggets.

In long welding time and high welding current application, cross-section area decreases; as a result, tensile–shear strength of joint decreases. Electrodes react to work piece due to excessive heating of them which cannot be compensated by cooling water. In addition, weld nugget spurts out between two sheets resulting in the decrease in diameter. This may be a reason for decreasing trend of tensile–shear strength shown in Fig. 4. At the same time, an over-coloured, retained structure with deep electrode marks and deformations was determined in weld zone [16–19].

4. Conclusion

As a result of this, the work performed at 4 kN electrode force, the obtained results and some suggestions are given below.

In the joining of SPA-H steel sheets, maximum tensile shear strength is obtained at 8.5 kA welding current in 30 period.

When the high surface quality is more important than strength, 9 kA welding current for 20 period welding time or 8.5 kA welding current for 25 period welding time are enough. The depth of electrode indentation into the material has not exceeded the 30% of sheet thickness limit which is accepted for a good surface quality [20].

The increase in welding time to critical limits would rapidly increase in weld nugget strength, due to the increase of the weld nugget area.

In low welding time, small weld nugget diameters were obtained and similarly lower tensile–shear strength value than that of base-metal was measured due to low heat application to welding zone. However, in high welding time, cross-section area decreases. Weld nugget spurts out between two sheets resulting in the decrease in nugget width.

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