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Influence of Corrosive Environment on the Surface Quality of Spot Welds

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BIOGRAPHICAL NOTES

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KEY WORDS

Resistance Spot Welding, Tensile Test, Microhardness, Corrosion Resistance

ABSTRACT

CThe paper deals with the evaluation of quality of resistance spot welds. Hot-dip galvanized steel sheets of DX54D+Z quality were used for experi-

ments. Electrochemical properties of used materials were observed. Carrying capacities of spot resistance welds were measured before as well as after exposure in corrosive environment. The tensile test was used for evaluation of carrying capacities. The quality of spot welds was evaluated on the base of microhardness measurements results realized on the scratch patterns too.

1. Introduction

The car body consists of several materials which need to be joined together to form one unit, usually by welding. Due to combining various types of materials having different mechanical properties and chemical composition, specific demands on the weldability of particular types of materials must be taken into consideration to optimize welding parameters with the aim of eliminating defects in welded joints [1,2].

One of the important requirements for materials used for vehicles is their corrosion resistance, which leads to the increasing share of chassis [3,4]. However, this type of surface treatment causes considerable problems for joining metal chassis. Conventional methods such as MIG welding or resistance spot welding, as well as unconventional methods such as laser welding lead to evaporation of protective layers near weld due to the heat and loss of the corrosion resistance of the welded parts [3].

The aim of the contribution is to analyse quality of welds on galvanized sheets and their corrosive properties. Protective efficiency of zinc coatings for automobile sheets was evaluated, based on the determination of their electrochemical characteristics in passivated and non-passivated state, as well as their corrosion resistance in simulated corrosion environments.

2. Materials and methods

Following materials were used for experiments:

1) sample A: DX54D+Z

- *sheet thickness 0.70 mm; zinc coated 140 g.m⁻²*
- *surface treatment: non-passivated*
- *use: for exterior body panels for DACIA LOGAN – roof*

2) sample B: DX54D+Z

- *sheet thickness: 0.70 mm; zinc coated 140 g.m⁻²*
- *surface treatment: passivated Cr3+*
- *use: for exterior body panels for DACIA LOGAN –*

doors

Test samples were cut to size 90 x 40 mm according to STN EN 051 122, length of lapping was 30 mm. Spot welding was carried out on pneumatic spot-welder BPK 20 with welding electrodes CuCr with 5 mm diameter. Selection of the welding parameters was based on the recommendations of British Standard (BS 1140) for spot welding of coated sheets and knowledge of weld growth mechanism [5]. However, the correction of the parameters was necessary, for the specific spot-welder. Welding parameters were: contact force $F_z = 2.6$ kN, welding time $t = 14$ periods, welding current 85 kA [1,2]. Tensile tests according to STN 05 1122 were used for the evaluation of mechanical properties of spot welds before and after the exposure to the corrosive environments. The test of spots and full penetration welded joints were carried out on a test machine TIRA-test 2300, (VEB TIW Rauenstein).

The samples for microhardness evaluation were prepared according to ISO 6507-1 and ISO 6507-2. Microhardness on the cross scratch patterns was measured according to STN EN 1043-2 for hardness evaluation of particular areas of the weld and its transient phases.

The tests were carried out on Shimadzu Bubo microhardness tester with indenter Vickers under a load of 0.01 kN. Indenter load time was 10 s.

The microhardness was measured on cross scratch patterns according to scheme in Fig. 1. Three measurements were carried out: in the base material, heat affected zone and weld metal in DX54D+Z.

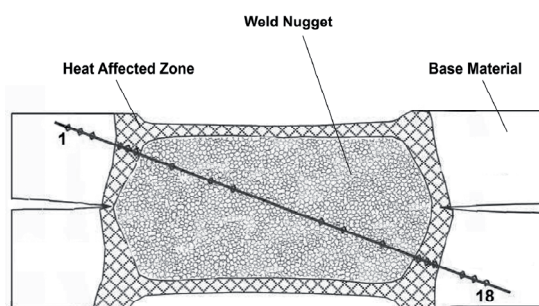


Fig. 1: Places of microhardness measurements.

Welds were exposed to salty environment of 5% NaCl solution and ecological solution Solmag used during winter season on roads. The above environments simulated conditions of vehicle operation

[6,7]. Gravimetric method was used for the evaluation of the corrosion processes. Potentiodynamic polarization curves were measured for determination of the electrochemical characteristics of these materials. The values of E_k – corrosion potential by Tafel, i_k – corrosion current density and R_p – polarization resistance were measured. Electrochemical characteristics of the tested samples were evaluated before exposure to the corrosive environment and after 240, 480 and 720 hrs of exposure according to Tafel and Stern method. A computer-controlled potentiostat/galvanostat VOLTALAB 21 PGP201 (producer Radiometer Analytical, Denmark) with software VOLTAMASTER 4 was used for potentiodynamic measurement; a schematic diagram of apparatus in three-electrode configuration is in Fig. 2. Scanning electron microscope JEOL JSM - 7000F was used for microscopic observations.

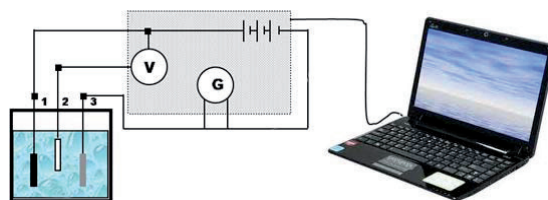


Fig. 2: Scheme of measurement of base corrosion characteristic with linear voltammetry method V – voltmeter, G – ammeter, 1 – sample, 2 – SCE – saturated calomel electrode, 3 – Pt – auxiliary electrode.

3. Results

Fig. 3 shows that the force determining the strength of spot welds before their exposure to the corrosive environments was ~ 11% higher in material B in passivated state than in the case A in non-passivated state. Both materials were exposed to the corrosive environment of 5% NaCl solution, after which increased carrying capacity of welds was observed in material B (passivated state). When the values of F_{max} before and after the exposure to the corrosive environment are compared, strength increase was found in for both types of spot-welds (for samples A by $\pm 0.45\%$, and samples B by $\pm 5.1\%$). Both materials were exposed to the corrosive environment of ecological solution Solmag, after which increased carrying capacity of welds was observed in material B (passivated state).

Fig. 4 shows the macrostructure of the cross-

section of the weld. No signs of defects and, heat affected areas and local flashing of the Zn layer in the contact place of welding electrodes can be seen.

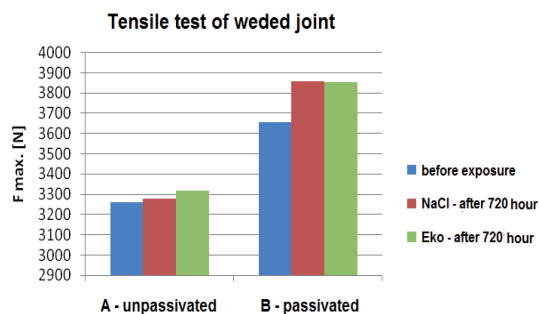


Fig. 3: Average values of maximum strength of A and B samples.

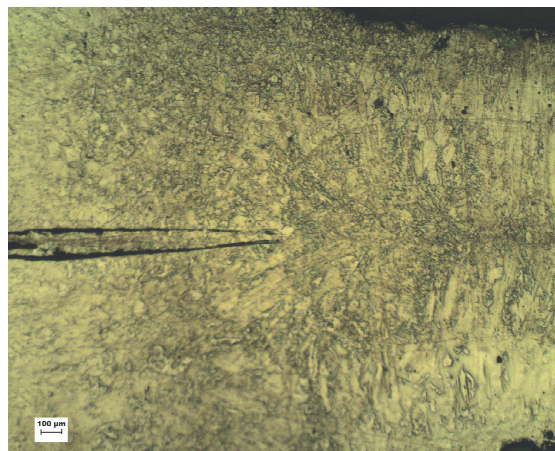


Fig. 4: Macrostructure of the cross section of the weld.

Fig. 5 illustrates the formation of the zinc corrosion products on the surface of the test samples after the corrosion tests in NaCl environments. It is possible to observe white zinc hydroxide, products of corrosion, which was confirmed by EDX analysis.

The measured values of microhardness are represented in Fig. 6. The measurements show that changes in parameters of resistance spot welding do not cause significant microhardness changes in the weld metal or heat affected zone of DX54D+Z steel.

Agresive environment does not influence microhardness of welds.

Galvanized sheet behaves like a galvanic cell when the moisture is present, where zinc layer with lower electric potential is the anode and steel rep-

resents the cathode. Oxygen is very important factor in the atmospheric corrosion because the thin layers of moisture act as diffusion barriers into the condensed moisture [8, 9]. Therefore, reaching the dew point is not necessary for the electrochemical reaction. As a result, very thin layer of electrolyte solution (0.005 to 0.15 mm) forms on a metal surface already at a low humidity (corrosion humidity ~60%).

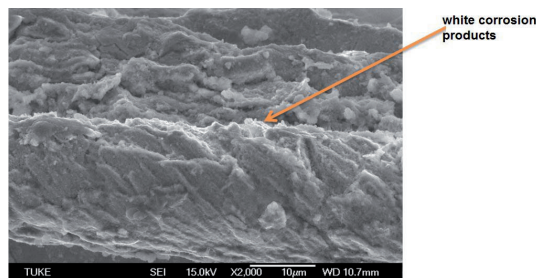


Fig. 5: Zinc layer on the sample surface after corrosion test.

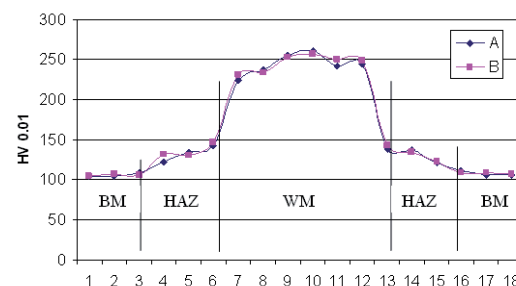


Fig. 6: Microhardness profile in materials A and B. BM – base material, HAZ – heat affected zone, WM – weld metal.

When the samples were exposed to the environment of 5% NaCl solution for up to 240 hours, their weight increased due to formation of corrosion products, mainly zinc. However, when the exposure of samples to chloride environment exceeded 240 hours, there was a significant weight loss of zinc coating, caused by release of corrosion products into the electrolyte. The protective efficiency of zinc coating is significantly reduced in the aggressive environment. The comparison of weight losses of A and B samples in 5% NaCl solution showed a difference of 53.66%, Fig. 7. It indicates that the passivated samples are more resistant to mass loss than non-passivated in 5% NaCl solution. When the samples were exposed to the environ-

ment of the ecological solution Solmag, their weight did not significantly change during the time of exposure. The potentiodynamic polarization curves of the samples measured in both states (non-passivated and passivated surface) evaluated by Tafel method are shown in Fig. 8. Non-passivated zinc-coated sheet (A) and passivated zinc-coated sheet (B) in 5% NaCl solution after 720 hours exposure show the same corrosion current densities J_k , i.e. passivation is effective only in the early phase of exposure.

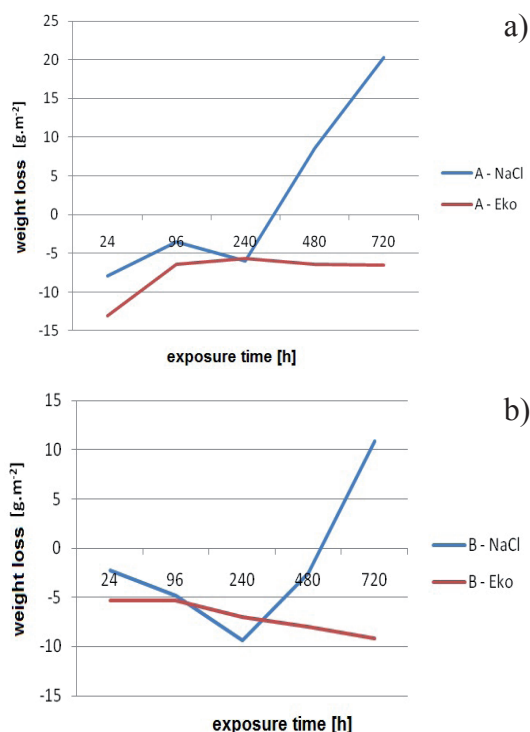


Fig. 7: Weight loss in corrosion environments, a) material A; b) material B.

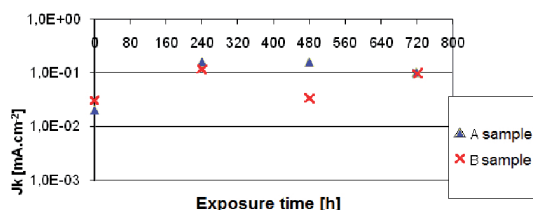


Fig. 8: Tafel method for determination of J_k .

The influence of chloride corrosive environment on galvanized sheets is so intense, that after sever-

al tens of hours' exposure there is no significant difference between passivated and non-passivated surface in zinc-coated steel sheet.

An interesting phenomenon occurred between 240 to 480 hours of passivated zinc-coated steel's exposure in non-aggressive environment, when the corrosion products show a high polarization resistance R_p to corrosion current flow (1.2 – 1.6 MΩ; see Fig. 9). However, after 720 hours of exposure, this passive layer is damaged even in low-aggressive environment and the "run-off" effect of zinc (emissions of Zn into the environment) predominates.

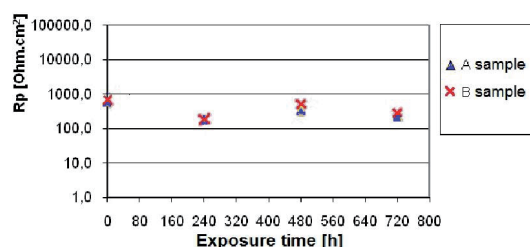


Fig. 9: Stern method for determination of R_p .

4. Conclusion

Welds on passivated sheets have higher carrying capacity in their initial state than the welds on non-passivated sheets. After exposure of samples to both corrosive environments the welds on passivated samples have higher carrying capacity. This increase is caused by zinc corrosion products, which, despite their low adhesion to the substrate, increase the strength of welds.

The measured values of microhardness shown in Fig. 6 are in accordance with the observed microstructures and their components. The maximum values were measured in the sample in WM (261 HV 0,01). This value corresponds to microhardness of a dominant beintic compound in the weld metal. The change of microhardness in the weld metal was continuous and it corresponded to mixing the weld metal of particular types of steel.

Microscopic analysis proved high-quality of welds, which also showed that optimum technological parameters of welding were used. Local flashing of zinc layer was observed in the contact place of welding electrodes. After exposure of samples to corrosive environments, zinc corrosion products, so-called "white corrosion", formed, as a result of condensa-

tion of air moisture or effect of the electrolyte.

The weight of samples exposed to ecological solution Solmag during corrosion tests increases in consequence of accrued zinc corrosion products, and the corrosion process is slower than when exposed to NaCl solution. In the relatively aggressive corrosive environment of NaCl there occurs significant weight loss. The potentiodynamic electrochemical measurements show that both types of sheets have the same corrosion current densities after 720 hours of exposure. That indicates that passivation is useful only in the early phase of exposure of materials to corrosive environment. Corrosion products with a high polarization resistance R_p form on the surface of the passivated samples, keeping their favorable properties up to approximately 500 hours of exposure to corrosive environment.

Optimization of spot resistance welding parameters is essential for improvement of the quality of the resulting joints as well as for minimization of technical risks, energy consumption and environmental impact.

5. Acknowledge

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6. References

- [1] Kaščák Ľ., Spišák E., Joints of thin sheets made by forming and resistance spot welding: evaluations of properties, ID-DRG 2007 – Forming the future, Győr, Maďarsko, p. 545-550.
- [2] Spišák E., Kaščák Ľ., Joining car body steel sheets using the clinching method, In: Acta Mechanica Slovaca, Vol. 15, No. 1, 2011, p. 28-34.
- [3] Zhang H., Senkara J.: Resistance Welding: Fundamentals and Applications, Taylor&Francis Group, New York, 2006.
- [4] Tumulu D. M.: The Effect of Coating on the Resistance Spot Welding Behavior of 780 MPa Dual-Phase Steel, Welding Journal, Vol. 86, 2007, No.9.
- [5] Harlin N., Jones T.B., Parker J.D.: Weld Growth Mechanism of Resistance Spot Welds in Zinc Coated Steel, Journal of Materials Processing Technology, Vol. 143-144, 2003, p. 448-453.
- [6] Aslanlar S.: The effect of nucleus size on mechanical properties in electrical resistance spot welding of sheets used in

automotive industry, Materials & Design, Vol. 27, 2006, p. 125-131.

- [7] Mabbutt S., Mills D., Woodcock Ch.: Developments of the electrochemical noise method (ENM) for more practical assessment of anti-corrosion coatings, Progress in Organic Coatings, Vol. 5, 2007, No. 3, p. 192-196.
- [8] Chang B.H., Shi Y.W., Dong J.: A Study on the Role of Adhesives in Weld-Bonded Joints, Welding Research Supplement, 1999, p. 275-279.
- [9] Stachowicz, F.: Instantaneous Plastic Flow Properties of Thin Brass Sheets Under Uniaxial and Biaxial Testing. In: Acta Mechanica Slovaca, Vol. 15, No. 1, 2011, p. 22-26.

