MECHANICAL JOINING AS A GREEN ALTERNATIVE TO RESISTANCE SPOT WELDING

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Abstract
Steel is the most important material for car body production in the automotive industry. Hot-dip galvanizing is a common procedure utilized to protect steels from corrosive environments. But low melting and boiling points of zinc create undesirable effects due to its evaporation during welding and formation of pores or cracks. The satisfactory weld nuggets production of galvanized steel sheets is realized by using longer weld times, higher electrode forces and higher welding currents; resulting in an increase in energy costs. Therefore, mechanical joining has attracted more and more attentions. The properties of the resistance spot welded joints and the mechanical joints such as the clinched joints and the clinch-riveted joints of hot-dip galvanized steel sheets were evaluated. The tensile test for determination of the load-bearing capacity of the joints as well as the metallographic observation to evaluate the joints’ structures were performed.

Key words: clinching, clinch-riveting, resistance spot welding, tensile test, metallography

INTRODUCTION
Increasing demands for body in white assembly lead to new solutions for materials and manufacturing. A dissimilar combination of materials and their thickness are specified for a special local requirements of the car body. The use of a wide range of materials is related to decreasing the car weight to reduce gas emissions and fuel consumption. Resistance spot welding (RSW) is one of the most widely and important joining methods in the automotive industry. RSW is economical, fast and a well-known joining technique for car body assembly that produce robust features [1-3].

The spot weld is created by absorbing heat energy. Then melting and solidification process in localized materials occurs. The heat energy is obtained from resistance of joined samples when welding current passes and by application of welding force [4].

The joined materials are clamped during resistance spot welding by the electrode tips. The electrodes also conduct welding current into the joined materials and perform the cooling process of the weld [5,6].

When hot-dip galvanized steel sheets are welded, the zinc layer on the sheet surfaces is responsible for defects in the spot weld. The contact resistances at the faying surface and electrode-workpiece interfaces influence the quality of the spot weld, its homogeneity, structure, and especially the life of the electrodes. The pure zinc surface reduces the amount of heat generated during welding process between the welded sheets, therefore a higher welding current is required. During the spot welding between galvanized steel sheets, the zinc melts and is extruded from the weld area. This creates an annulus surrounding the spot weld. A part of the welding current is escaping through the annulus and therefore a larger welding current is needed [4,7].

Zinc begins to melt and diffuse into copper welding electrodes tips, where a brass layer is formed before the weld begins to form. The brass has a higher electrical resistance than copper so the heat is produced in the brass layer. The electrode tips are further heated and the welding lens size decreases [8].

For these reasons, there is an effort to replace resistance spot welding by some other joining methods. Mechanical joining methods such as clinching, clinch-riveting and self-piercing riveting represents viable methods to meet these requirements [9,10].

The clinching (CL) is a cold joining process. The upper and lower sheets are formed by local hemming with a clinching tool consists of a punch and die [12]. The materials between punch and die is forced into a radial flow to form the undercut. The joined materials are deformed locally by creating a mechanical interlock [13]. The material flow during the clinching process and then formation of the undercut is controlled by the die shape. In this technique, no additional elements such as bolts, screws, rivets are needed [14,15].

The methods of clinch-riveting (CR) and self-piercing riveting (SPR) are similar. The interlock of joined materials is achieved by the plastic deformation of a solid rivet. The difference between these two joining techniques is in the used rivets: a tubular rivet for self-piercing riveting method and a solid one for clinch-riveting method. The upper sheet is perforated during SPR process using the tubular rivet. The joined materials are locked by anchoring the tubular rivet in the lower sheet. When using the CR process, the solid rivet anchors in the upper sheet [16,17].
The research focused on the evaluation of properties of the clinched joints and the clinch-riveted joints of hot-dip galvanized steel sheets H220PD and DX51D as the green alternatives to resistance spot welded joints.

MATERIALS AND EXPERIMENTS

The following hot-dip galvanized steel sheets were used for joining: a high-strength microalloyed steel sheet H220PD and an alloy quality low carbon steel sheet DX51D+Z; both sheets with the thickness of 0.8 mm. The chemical composition and the basic mechanical properties of the materials (Rp0.2 – yield strength, Rm – ultimate tensile strength, A80 – elongation) for experiments are presented in Tab. 1 and Tab. 2.

Tab. 1 Chemical composition of joined steel sheets (wt%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>H220PD</td>
<td>0.012</td>
<td>0.119</td>
<td>0.435</td>
<td>0.057</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>0.041</td>
<td>0.046</td>
<td>0.009</td>
<td>0.013</td>
<td>0.033</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>DX51D</td>
<td>0.064</td>
<td>0.178</td>
<td>0.106</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.120</td>
<td>0.023</td>
<td>0.004</td>
<td>0.002</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Tab. 2 Basic mechanical properties of joined steel sheets

<table>
<thead>
<tr>
<th>Material</th>
<th>Rp0.2 [MPa]</th>
<th>Rm [MPa]</th>
<th>A80 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H220PD</td>
<td>238</td>
<td>382</td>
<td>36</td>
</tr>
<tr>
<td>DX51D</td>
<td>160</td>
<td>390</td>
<td>23</td>
</tr>
</tbody>
</table>

The surfaces of both joined materials were degreased in concentrated CH3COCH3 only before the spot welding process. Clinching and clinch-riveting methods do not require the cleaning of the surfaces of joined materials.

The load-bearing capacity of the spot welded joints, clinched joints as well as clinch-riveted joints were measured according to standard STN 05 1122 - Welding: Tensile test on spot - and complete penetration welds. The static tensile test was performed on the testing machine TIRAtest 2300, the loading speed of 8 mm/min.

RESULTS AND DISCUSSION

The static tensile tests were performed under displacement control conditions on all samples configurations – clinched joints, clinch-riveted joints and resistance spot welded joints in order to characterise the behaviour of the observed joints and to estimate the maximum shear force. The maximum shear force Fmax was the most significant value obtained from the “load-displacement” curves as shown in Fig. 2 and 3.

Fig. 2 Load-displacement curves of the samples with H220PD sheets - clinched joints (CL), clinch-riveted joints (CR) and resistance spot welded joints (RSW)

The samples with resistance spot welded joints (RSW) showed the highest values of load-
bearing capacities in comparison to clinched joints (CL) and clinch-riveted joints (CR). The lower values of load-bearing capacity were measured on the samples with CR joints and the lowest values on the samples with CL joints. The values of load-bearing capacity of CL joints as well as CR joints were similar in both joined steel sheets. However, in case of RSW samples, the load-bearing capacity of the joints with DX51D steel sheets was approximately 2000 N higher than the load-bearing capacity of welded joints with H220PD steel sheets.

The typical indentations formed by resistance spot welding electrode tips are shown in Fig. 4. The zinc layer on the surfaces of the both joined materials was destroyed under welding electrode as well. The zinc melts and is extruded from the weld area. This creates an annulus surrounding the spot weld.

Unlike the resistance spot welding, the clinching and the clinch-riveting process does not destroy the zinc layer on the surfaces of joined materials – Fig. 5.

The metallographic observation of resistance spot welded joints confirmed formation of typical fusion welded joints, characteristic by the areas of weld metal, heat affected zone and base material – Fig. 6. Some pores and cavities occurred in the area of weld nugget in the samples with H220PD steel sheets, as shown in Fig. 6a. These internal discontinuities were caused by the higher value of welding current in comparison to the spot welds made with DX51D steel sheets.

The metallographic observation of the mechanically joined samples confirmed suitability of the clinching and clinch-riveting method for joining the observed hot-dip galvanized steel sheets. No cracks or failures occurred during the clinching process, as documented in Fig. 7a and Fig. 7b. The rivets in clinch-riveting technique are shown in Fig. 7c and Fig. 7d. Nevertheless, the crack in the bulge area of the CR joint was observed on the upper sheet of H220PD steel sheets – Fig. 7c. However, the rivet bears a major part of the load, therefore the crack created during the joining process does not have a significant influence on the load-bearing capacity of the joint.
CONCLUSION

The observed joining methods clinching and clinch-riveting are suitable for joining the tested hot-dip galvanized steel sheets H220PD and DX51D, although the clinched joints reached the lowest values of load-bearing capacity. The clinch-riveted joints reached the higher values of load-bearing capacity in comparison with clinched joints, and were similar to carrying capacities of resistance spot welded joints, when joining the H220PD steel sheets.

The metallographic analysis confirmed no cracks or failures occurrence in the area of the clinched and clinch-riveted joints during joining processes. The crack in the bulge area of the clinch-riveted joint occurred when H220PD steel sheets were joined. Hence, the crack does not have a considerable effect on the load-bearing capacity of the CR joint.

Using the clinch-riveting method led to significant hardening of the joint in the interlocking area in comparison to the clinching method.

References

Acknowledgment
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