JOINING MATERIALS BY SELF-PIERCING RIVETING METHOD

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Abstract

The paper describes a relatively new fastening technique, which is known as self-piercing riveting (SPR) method. Self-pierce riveting is becoming increasingly used in the automotive industry as a way to join materials of different grades. The following materials were used in the joining process: microalloyed steel H220PD with the thickness of 0.8 mm, extra deep-drawing grade steel DC06 with the thickness of 0.7 mm and drawing grade steel DX51D+Z with the thickness of 0.9 mm. The properties of SPR joints were evaluated by tensile test – to determine the carrying capacities of the joints and by a metallographical analysis – for observing the joints’ structures.

Key words: self-piercing riveting, joining, evaluation of properties.

INTRODUCTION

Automotive manufactures are under increasing pressure from government agencies and consumer advocate groups to produce safer and more durable vehicles while improving fuel economy and emission standards. The automotive industry envisions that the optimized vehicle, in terms of performance and cost, can only be achieved by using different materials at different vehicle locations to utilize the materials’ functionalities to the fullest extent [1,2]. Resistance spot welding, which is the most widely used technique to join steel body panel, is not satisfactory to join all types of sheets, especially when combination of various sheet metals is required, for example high-strength steel with deep drawing steel or deep drawing steel with aluminium steel [3]. Consequently, an increasing interest to develop new joining technologies as a replacement for spot welding – especially for lightweight metals such as aluminium alloys – is appearing in the automotive industry [4,5].

The self piercing riveting (SPR) is a relatively new fastening technique which has encountered the favour of many producers for its wide applicability and its better performance in joining steel sheets and aluminium sheets than resistance spot welding [6]. It is a cold forming process which creates a strong mechanical interlock between two or more sheets by means of a semi-tubular rivet, which, pressed by a punch, pierces the upper sheet and flares into the bottom one. If the rivet length is correctly chosen, the lower plate goes under heavy deformation but remains unbroken; that ensures a corrosion, gas and waterproof stable joint [7].

The paper evaluates joints made by self-piercing riveting the materials utilized in automotive industry in car body production.

PRINCIPLE OF SELF-PIERCING RIVETING

The self-piercing riveting is a cold process for joining two or more sheets by directly piercing the sheets with a rivet. Since the self-piercing riveting does not require a pre-drilled hole unlike the conventional riveting, the joining speed is the same level with that of the spot resistance welding, and the equipment is similar. In the self-piercing riveting, the difference between melting points of dissimilar sheet metals is not a problem because of plastic joining [8,9]. The die on the underside of the materials causes the rivet to flare under the force, creating a mechanical interlock [10].

Fig.1 Principle of self-piercing riveting [11]
The punch, under the pressure conveyed by a hydraulic power device, pushes the rivet to penetrate into the top plate, and the die shape causes the rivet to flare within the lower sheet in order to form a mechanical interlock. This process therefore requires access to both sides of the joint. The entire process of piercing and forming the joint is carried out in a single operation - Fig. 1.

Possibilities of utilization of SPR method in the automotive industry are shown in Fig. 2.

![Gas Tank Straps](image1)
![Brake Pedal Bracket](image2)
![Automotive Hood](image3)
![Roof Bow](image4)

**Fig.2 SPR in automotive industry**

**MATERIALS AND EXPERIMENTS**

The following steel sheets were used for experiments: microalloyed steel HSLA H220PD with the thickness of 0.8 mm, extra deep-drawing grade steel DC06 with the thickness of 0.7 mm and DX51D+Z with the thickness of 0.9 mm.

Their basic mechanical properties and chemical composition are shown in Tab. 1 and Tab. 2. Mechanical properties of DX51D and DC06 steels were specified by producer.

**Tab.1 Basic mechanical properties of used materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Rp (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>DC06</td>
<td>170</td>
<td>270-330</td>
<td>41</td>
</tr>
<tr>
<td>DX51D+Z</td>
<td>≥ 140</td>
<td>270-500</td>
<td>23</td>
</tr>
</tbody>
</table>

The following samples of the same material combinations for the joining were used:

- Samples A: H220PD (a0 = 0.8 mm)
- Samples B: DC06 (a0 = 0.7 mm)
- Samples C: DX51D (a0 = 0.9 mm)

On order to evaluate the properties of the joints, the following tests were performed: tension test and a metallographical analysis.

The samples with dimensions of 40 x 90 mm and 30 mm lapping according to STN 05 1122 standard were used for the experiments (Fig. 3). Six samples were prepared for every combination of sheets. It was not necessary to clean the surfaces of samples before clinching. The self-piercing riveting method was realized with the aluminium rivets (Fig. 4).

The carrying capacities of the SPR joints were evaluated according to standard STN 05 1122 – Tension test of spot welded joints. This test was used for measuring the maximum carrying capacities Fmax of the joints. The test was carried out on the metal strength testing machine TIRAtest 2300 produced by VEB TIW Rauenstein, with the loading speed of 8 mm/min. Further tests for quality evaluation of SPR joints included the metallographical analysis.

**Fig.3 Dimensions of tension test sample**

**Fig.4 Aluminium rivets for self-piercing riveting method**

**Tab.2 Chemical composition (in [%] of wt) of used materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>Cu</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>H220PD</td>
<td>0.012</td>
<td>0.435</td>
<td>0.119</td>
<td>0.057</td>
<td>0.002</td>
<td>0.041</td>
<td>0.040</td>
<td>0.013</td>
</tr>
<tr>
<td>DC06</td>
<td>0.020</td>
<td>0.071</td>
<td>0.010</td>
<td>0.017</td>
<td>0.002</td>
<td>0.055</td>
<td>0.038</td>
<td>0.011</td>
</tr>
<tr>
<td>DX51D</td>
<td>0.064</td>
<td>0.178</td>
<td>0.007</td>
<td>0.016</td>
<td>0.002</td>
<td>0.120</td>
<td>0.041</td>
<td>0.002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Cr</th>
<th>Ti</th>
<th>V</th>
<th>Nb</th>
<th>Mo</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>H220PD</td>
<td>0.046</td>
<td>0.033</td>
<td>0.012</td>
<td>0.052</td>
<td>0.009</td>
<td>0.047</td>
</tr>
<tr>
<td>DC06</td>
<td>0.022</td>
<td>0.062</td>
<td>0.008</td>
<td>0.023</td>
<td>0.009</td>
<td>0.035</td>
</tr>
<tr>
<td>DX51D</td>
<td>0.023</td>
<td>0.002</td>
<td>0.005</td>
<td>0.015</td>
<td>0.004</td>
<td>0.019</td>
</tr>
</tbody>
</table>
RESULTS

The measured values of carrying capacities of self-piercing riveting joints are shown in Tab.3.

Tab.3 Measured values of carrying capacities Fmax

<table>
<thead>
<tr>
<th></th>
<th>Fmax [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples A</td>
<td>Samples B</td>
</tr>
<tr>
<td>4952</td>
<td>3673</td>
</tr>
<tr>
<td>4820</td>
<td>3929</td>
</tr>
<tr>
<td>4703</td>
<td>3901</td>
</tr>
<tr>
<td>4763</td>
<td>3893</td>
</tr>
<tr>
<td>4725</td>
<td>3889</td>
</tr>
</tbody>
</table>

Tensile tests were executed under displacement control conditions on the specimen configurations in order to characterise the static behaviour of the joints and to estimate the ultimate tensile strength. The maximum shearing load was the most significant value obtained from the “load-displacement” curves as shown in Fig.5. The form of the curves indicates the behaviour of the joints under loading.

![Fig.5. Load-displacement curves of SPR joints](image)

The average maximum shearing load was:
for sample A around 4800 N with the displacement about 0.4 mm, for sample B around 3800 N with the displacement about 0.5 mm and for sample C around 4800 N with the displacement about 0.4 mm. During the riveting process the rivet and the riveted sheets undergo massive deformation to form the mechanical interlock. This energy is stored within the interlock leading to higher energy absorption.

Joints made by self-piercing riveting method failed in the manner of a press-stud in combination with the mode of one edge of the joint fails. This method results in a loosening of the joint after quite small displacements. The upper sheet was then pull out form the joint with the significant crack in the critical area - failed at the neck. There is insufficient material in the neck of the joint, and loading will result in failure in the neck; excessive elongation in the region of the joint neck causing cracks formation – Fig. 6.

![Fig.6 Samples of SPR joints after tension test](image)

Fig.6 Samples of SPR joints after tension test
DS – die side, PS – punch side

Metallographical analysis confirmed suitability of the self-piercing riveting method for joining the observed material combinations. Using the self-piercing riveting method led to significant hardening of the joint in the critical area (Fig. 7) in comparison to the classical clinching method as was described in [4]. The critical area of joints is the place of the most significant thinning of the joined materials in the area of neck joints.

![Fig.7 Interlocking of joined materials with the critical area of the joint (CA)](image)

Fig.7 Interlocking of joined materials with the critical area of the joint (CA)
CONCLUSION

The development of the self-piercing riveting technology in recent years has broadened the application of the technology in the automobile industry. Although the self-piercing riveting process is a young joining technology, it has become more and more popular during the last decades.

Most authors focus on the self-piercing riveting process using steel rivets. The self-piercing riveting using aluminium rivets is indeed a challenging task, since the strength of aluminium alloys are much weaker than that of steels. The aluminium rivet can be easily deformed when compressed into the plates, and hence no interlock is formed.

The self-piercing riveting method is suitable for joining the tested materials. The maximum load values of self-piercing riveting joints were 4790 N of the samples with H220PD materials, 3857 N of the samples with DC06 materials and 4798 N of the samples with DX51D materials.

The carrying capacities of these samples were sufficient and the metallographical analysis confirmed no occurrence of cracks or failures in the area of joints during joining processes.

References


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