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THE STRUCTURE OF THE STRENGTH OF RIVETED JOINTS DETERMINED IN THE LAP JOINT TENSILE SHEAR TEST

Jacek MUCHA*, Waldemar WITKOWSKI*

*Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology,
al. Powstancow Warszawy 8, 35-959 Rzeszów, Poland

j_mucha@prz.edu.pl, wwitkowski@prz.edu.pl

Abstract: The article presents the analysis of the structure of the load capacity of riveted joints. For the four joining systems the lap joint specimens were made and tested in the shearing test. The joints were prepared for the three combinations of the DC01 steel and EN AW-5754 aluminium alloy sheets with the thickness of 2mm. On the basis of the obtained load-elongation diagram tensile shear test curves, the basic parameters defined in the ISO/DIS 12996 standard were determined. In the case of the conventional riveted joints the maximum load capacity of the joint is determined by the strength of the fastener. For the joints with aluminium-steel blind rivet , the load capacity of the joint was on the strength limit of the rivet tubular part and on the strength limit of the sheet material. The strength of the SSPR joint is determined by the mechanical properties of the material of the joined sheets. From all sheets and rivet specimens arrangements the highest load capacity of the joint was obtained for the DC01 sheet material joints, and the lowest load capacity of the joint was obtained for the EN AW-5754 sheet material joints.

Key words: Riveted Joints, Mechanical Joining, Sheets Joining, Shearing Test, Joint Strength

1. INTRODUCTION

The branches of industry which generate new product solutions very fast are construction, aerospace and automotive industry. Steel elements are increasingly substituted by fiber-reinforced plastic parts or by light metal alloys parts such as aluminium or magnesium alloys. New material generates the need of developing the new joining technologies or modifying standard technologies. The use of new material in the production processes resulted in the use of the alternative joining technologies at the expense of the traditional technologies. That is why the experimental studies related to the formation and strength of new joining systems are required. The new joining solutions not always can ensure an adequate strength of a joint. In some cases the joint formation for the new materials is very difficult. Thus, the riveted joint technologies with blind rivets or with blind rivets for closing up are still used and will certainly continue to be used in the future. A very large group of the riveted joints includes self-piercing rivet joints "SPR" (Gao and Budde, 1994; Voelkner et. al., 2002; Nong et. al., 2003; Neugebauer et. al., 2008; He et. al., 2008; Todtermuschke, 2009). The self-piercing riveting technology has several varieties of formation with high values of forming force. One of them is solid self-piercing riveting (SSPR), the technology offered by the Kerb-Konus-Vertriebs GmbH company (2013). The SSPR technology ensures the joint flat surface from the rivet side (Neugebauer et al., 2010; Mucha, 2013; Mucha, 2014). This joining technology also allows to effectively join materials with significant difference in mechanical properties, eg. soft with tough materials (Meschut, 2014). During the joint formation by sheet pressing, e.g. clinching (CL), self-piercing riveting with tubular rivet (SPR) or clinch riveting (CR,) the material can crack (Kaščák et al., 2013). Moreover, these type of joints are characterized by the flash, which is the result of the joint formation technology. In Poland, these types of joints are not under any adequate standard.

The classification of joints formed by pressing is presented in DIN standard (DIN 8593-0:2003, 2003a; DIN 8593-5:2003, 2003b). Other international standards define the specimens dimension, testing conditions and the failure of the lap joints of various types (DIN EN ISO 14272, 2002; EN1993-1-8, 2005; ISO/DIS 12996, 2013). The main types of separation of the lap joint were included in the previously mentioned standards and their descriptions can be found in many scientific works. There are not many works about the structure analysis of the strength of joints, especially based on the criteria included in the ISO standard (2013), related to the comparison of the strength of joints formed by various joining technologies (Fig. 1). In their recent work Mucha and Witkowski (2014) presented the comprehensive analysis of the strength of clinching joints.

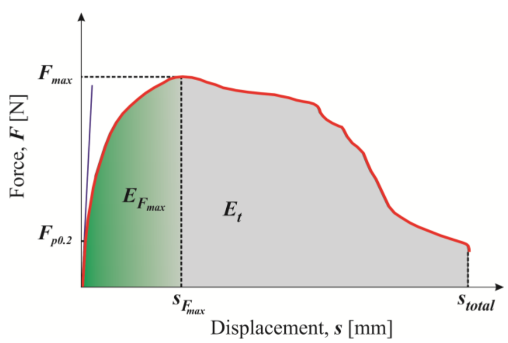

Fig. 1. Characteristic values of a load-elongation diagram for the tensile shear testing (ISO, 2013)

The performance of joints is characterized by the following properties which are of decisive importance for the mechanical

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behaviour of components:

- stiffness c,
- technical yield or elastic load limit $F_{p_{0.2}}$,
- slippage load F_s,
- dissipated energy W and to a lesser extent by the maximum tensile shear load F_{max}.

The stiffness of a joint corresponds to Youngs modulus of metals or the shear modulus of an adhesive, and is a measure for the rigidity of a design or component. The slippage load F_s or the technical elastic load limit $F_{p_{0.2}}$ indicate the load a component (or joint) can withstand without suffering permanent setting or plastic deformation.

This paper presents the analysis of the structure of the joint load capacity, for riveted joints formed by various joining technologies. For the four joining systems, the specimens were prepared and tested in the tensile shear test. The influence of the sheet material on the strength of the joint during the tensile shear testing, was experimentally studied for the classic riveted lap joints and for joint with solid self-piercing rivet (SSPR).

2. EXPERIMENTAL PROCEDURE

Experimental studies were conducted to present the influence of the arrangement of the joined sheets on the load-elongation diagram for the tensile shear testing, and on the structure of the joint load capacity for joints formed by various joining technologies. The mechanism of the joint failure during the test on the strength limit was also observed. For this analysis, four types of riveted joints were used: aluminium-steel blind rivet (BR), aluminium-steel blind hermetic rivet (BHR), aluminium alloy rivet for closing up (COUR) and solid self-piercing steel rivet (SSPR) – Fig. 2 and Tab. 1. The rivets had the same diameter of the cylindrical part ($d_r = 4$ mm), while the remaining geometry was selected for the total thickness of joined sheets ($d_{tot} = 4$ mm). In the case of the rivet for closing up the appropriate chamfer was performed in the holes. The DC01 steel sheets (material number 1.0330) and the EN AW-5754 aluminium alloy sheets (material number 3.3535) in the O/H111 state were used to prepare the lap joint specimens. The yield strength of these materials are respectively 160 MPa and 85 MPa, and the ultimate tensile strength 290 MPa and 220MPa. The sheet thickness (2 mm) was the same in all joints cases. The specimens (Fig. 2) were prepared with dimensions included in ISO standard (2013). The arrangements of sheet material of the lap joints were presented in Tab. 1.

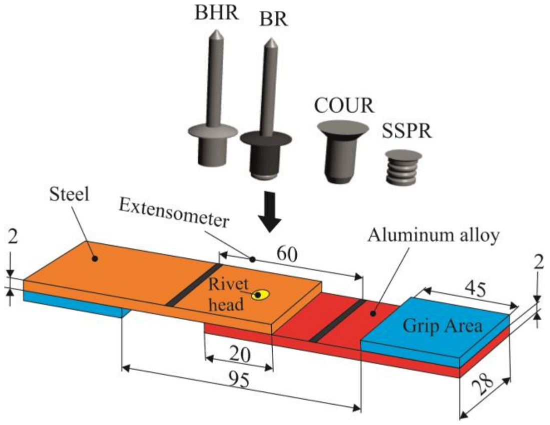

Fig. 2. Specimen dimensions and rivets denotation

In the case of the arrangements of hybrid material the primary rivet head was placed in the steel sheet (Fig. 2). The secondary rivet head was formed on the aluminium alloy sheet side. For this specimens a static tensile shear tests, with registration of the force-displacement diagrams, were performed on the Instron 3382 machine (Fig. 3). The traversing speed (the machine traverse speed) was 10 mm/min. There were seven samples prepared for each arrangement of sheets and types of rivets.

Tab. 1. The fasteners and the sheet material combinations used in riveted joints

Sheet material	Fastener			
	Blind hermetic rivet[1] (BHR)	Blind rivet[2] (BR)	Rivet for closing up[3] (COUR)	Solid self-piercing rivet[4] (SSPR)
DC01/DC01	1-1	1-2	1-3	1-4
DC01/5754	2-1	2-2	2-3	2-4
5754/5754	3-1	3-2	3-3	3-4

[1] ISO 15974:2003; [2] ISO 15978:2003; [3] ISO 1051:1999; [4] catalog number 492 000 007.900 (www.kerbkonus.com)

Fig. 3. The lap joints in the tensile shear testing

3. RESULTS

During the force loading of the lap joint the stress concentrations appear on the contact surface of the rivet and the hole (Fig. 4 a,b). The range and level of stress concentration depends on several parameters, including the clearance between the rivet and the hole. Rivet length, rivet diameter, hole diameter, and squeeze force are major parameters that affect the quality of formed rivets (Cheraghi, 2008; Szymczyk and Godzimirski, 2012). For the riveted joints, for example with blind rivet, the hole diameter is larger than the rivet diameter. The clearance between the rivet and the hole caused the rivet to tilt in the hole during the tensile shear testing (Fig. 4a). When the force load of the joint was increasing the contact surface was expanding. On the cylindrical surface of the rivet, at the hole edge, the sheet material was upset. At the same time there was a hole ovalization (Fig. 4 c). When the sheets bended the stress level decreased. The mechanism of the stress concentration was presented in Fig. 4 b. The second factor causing the stress concentration at the hole surface is the secondary bending which is a result of a different shape of the primary and secondary rivet heads. Non-uniform contact stress of the rivet is the result of the sheet deflection. During the

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tensile shear testing of the blind rivet joints and rivet for closing up joints in EN AW-5754 aluminium alloy the hole surface was deforming. The hole surface was deforming until the maximum rivet load capacity in the transverse cross-section was reached. Then the rivet material was fractured. For the aluminium alloy sheets the greatest hole distortions were observed (Fig. 4 c).

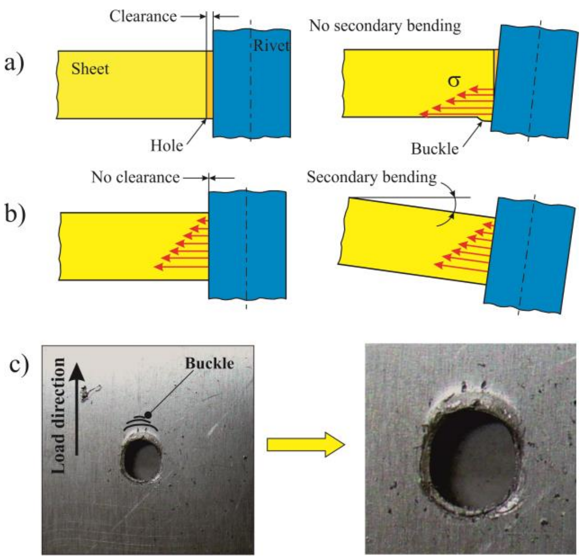

Fig. 4. The influence of the rivet on the hole surface:
a) without clearance, b) with clearance, c) deformed hole in the aluminium alloy sheet after the lap separation

In the case of SSPR joint there is no clearance between the rivet and the hole made by this rivet. The rivet head is only on one side of the rivet. Hence, there is a significant rivet rotation and sheet bending to allow the rivet to pull out from the joint. Thus, after the separation of the sheets of the lap joint the rivets are rotated and the rivet holes are significantly deformed (Fig. 5 and Fig. 6). For all arrangements of sheet material similar mechanisms of destruction of riveted joints with blind rivet were observed. The tubular part of the rivet was cut in the plane of the sheet contact. For the arrangement of joints of steel sheet and aluminium alloy sheet there was no difference in the deformation around the rivet hole (Fig. 7). The deformation of the sheet material (aluminium alloy sheets) around the rivet hole was observed in the tensile shear test of the riveted joint with blind hermetic rivet (BHR) – Fig. 4c. The closed part of the tubular rivet caused different sheet pressure on one side of the joint. In the tensile shear test the rivet was slightly rotated which caused the rivet hole deformation.

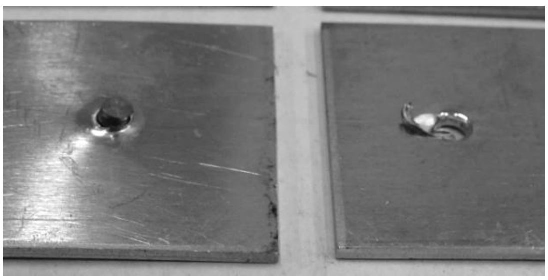

Fig. 5. SSPR joints of the aluminium alloys sheets after the laps separation

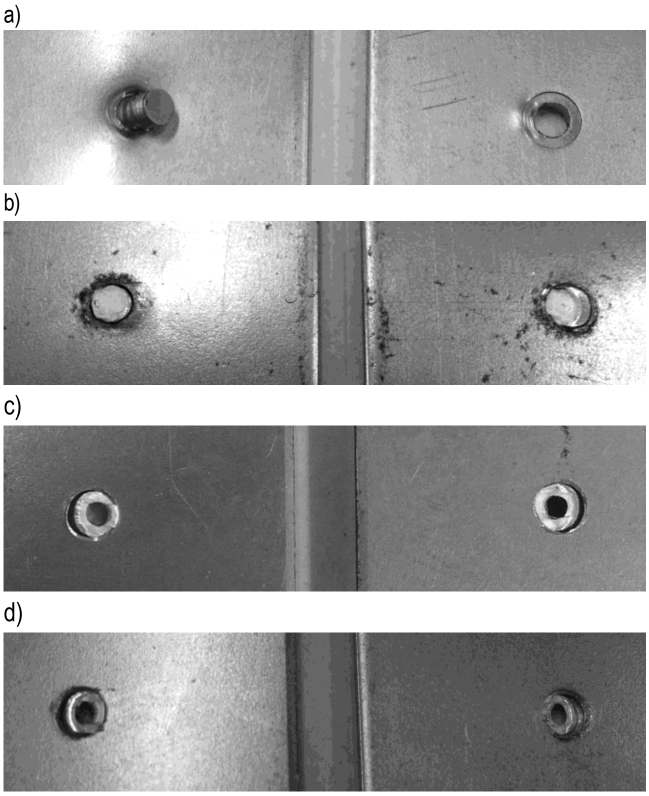

Fig. 6. Sheet metal surfaces after the tensile shear testing. Lap joints (DC01 sheet material) with: a) solid self-piercing steel rivet, b) aluminium alloy rivet for closing up, c) aluminium-steel blind hermetic rivet, d) aluminium-steel blind rivet

Fig. 7. COUR joints in the steel and aluminium alloy sheets after the laps separation

For a particular type of the rivet and for the three different arrangements of sheet material the similar values of the maximum load force were obtained (Fig. 8 a and Fig. 8 b). The different load-elongation diagrams were observed (Fig. 8 a-d). The highest values of the dissipated energy (area under the load-elongation diagram) were obtained for the EN AW-5754 aluminium alloy sheet, and the lowest values for the DC01 steel sheets (Fig. 8 a and Fig. 8 b), in the case of blind rivet joints. For the lap joints with rivet for closing up similar forms of the load-elongation diagrams were obtained. Thus the value of the dissipated energy was on the similar level for each arrangement of the sheet material. The fastener had such low strength in comparison to the joined sheets that during the tensile shear testing its strengthened material was fracturing in the same way. In the design processes of the riveted joints the condition that the sheet surface load capacity is higher than the rivet load capacity is assumed. This relation allows to predict the strength of the joint which is based on the rivet

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strength condition, with respect to certain proportions between the sheet thickness and the hole diameter – the condition takes form do≤3,2t (t – the sheet thickness). If the relation is satisfied, the maximum joint load capacity can be calculated from the tensile shear condition. Designers of the thin-walled structures often have dilemmas what type of the rivet to use to maintain the appropriate joint load capacity. Sometimes they use the types of rivet which are already available in a company, without paying attention to the rivet diameter and sheet thickness. The failure mechanism presented above do not include the fourth type of riveted joints – with solid self-piercing rivet (SSPR). As the rivet punches a hole in the sheets, it needs to have considerable hardness – about 58 HRC. For this type of joints the rivet is rotated and pulled out from the bottom sheet (there is no rivet shearing) (Fig. 5 and Fig. 6 a). In the case of aluminium alloy sheets the lowest values of the shearing force were obtained (Fig. 8 d). The joint load capacity for this joints does not depends on the rivet material but on the mechanical properties of joined sheet material.

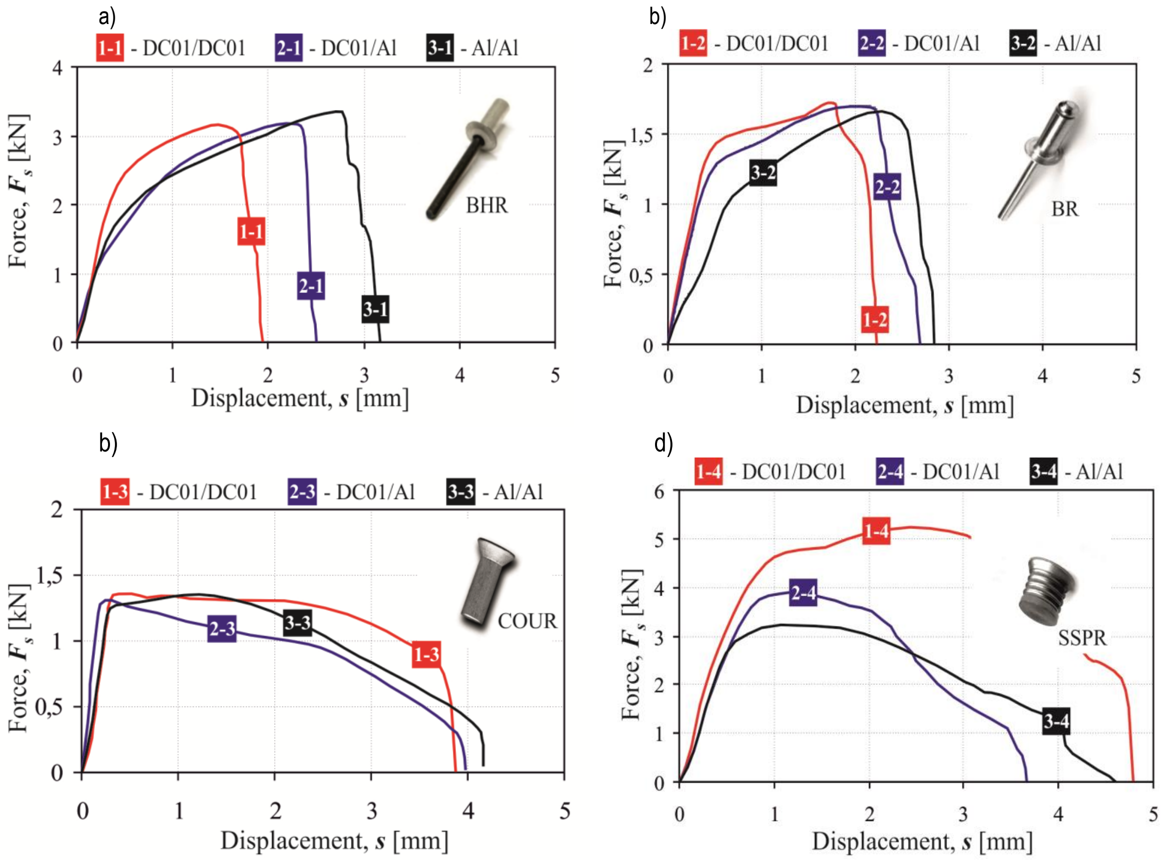

Fig. 8. Load-elongation diagrams from the lap joints tensile shear testing (BHR - blind hermetic rivet, BR - blind rivet, COUR - rivet for closing up, SSPR - solid self-piercing steel rivet)

The ability of transferring the shearing force was illustrated for the steel sheet joint specimens (Fig. 9 a). The highest value of the shearing force was obtained for the SSPR joints, and the lowest value for the aluminium alloy rivet for closing up. The joint with solid self-piercing rivet had a greater strength during the tensile shear testing than the joints with blind rivet and rivet for closing up. For the SSPR joints the differences in the shearing force were obtained for different arrangements of the sheet material (Fig. 9 b). The average value of the shearing force for the DC01 sheet material was 5.26 kN, and for the EN AW 5754 aluminium alloy sheet material was 3.42 kN. The change of the shearing force in this case was 35 %. For other joints (with blind rivet and with rivet for closing up) there were no significant differences in the strength of joints for all arrangements of sheet material (Fig. 10). To analyze the structure of the joint load capacity the selected indicators of the strength of the lap joint from the ISO standard (2013) were presented. The highest value of dissipated energy for the SSPR joint was obtained for the steel sheets material, and the lowest value for the arrangement of the hybrid sheet material (Fig. 8 d). The change of the bottom sheet material from steel to aluminium alloy resulted in the reduction of dissipated energy by 58 %.

When the arrangements of the sheet material were changed the biggest differences of strength of the joints were obtained for the SSPR joints (Fig. 10 a). For the BHR joints the values of the shearing force were similar but the dissipated energy, the displacement measured at the maximum shear load and the total displacement had different values (Fig. 10 c). In the case of joints with rivet for closing up the small differences in the values of the shearing force were obtained. Larger differences were obtained for the dissipated energy and dissipated energy of maximum shear load (Fig. 10 d).

Factor determining the use of the SSPR joints may be the economic aspects. By using of this type of the rivet joints, in the joining process, the additional preparing and finishing operations (as in the case of joining process with use of the conventional rivets) are eliminated. The SSPR joints strength is lower than strength of other joints. To increase this joints strength the joint forming force should be increased.

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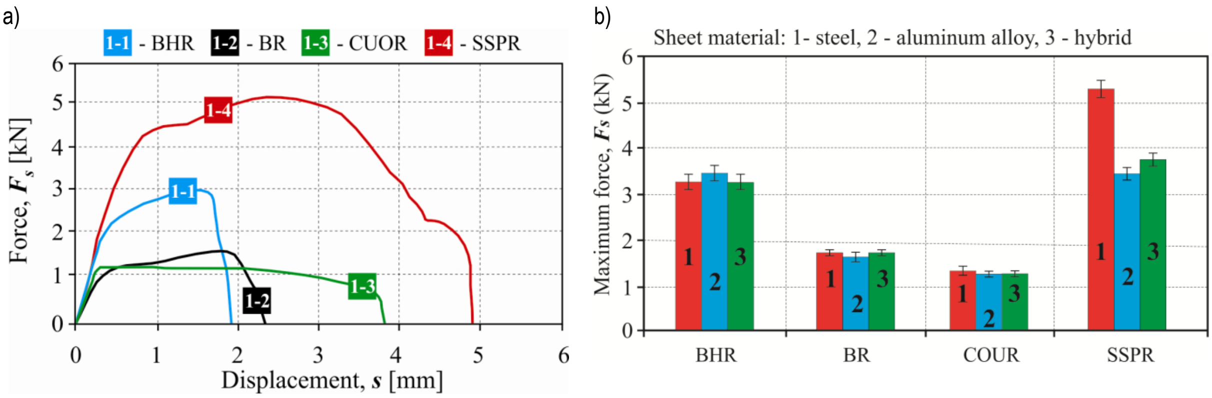

Fig. 9. Load-elongation diagrams from the steel (DC01/DC01) lap joints tensile shear testing – (a), and the mean values of the maximum shearing force – (b)

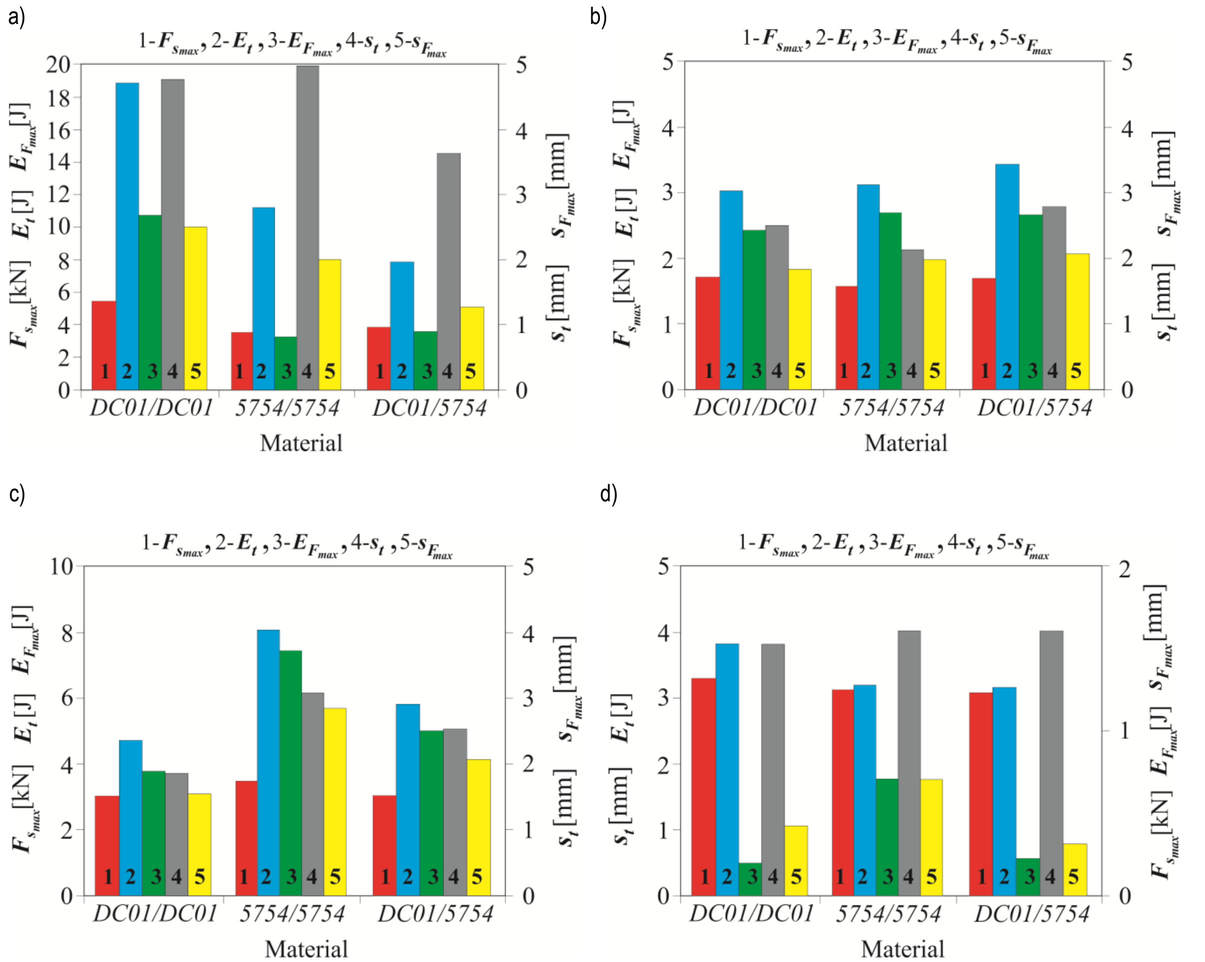

Fig. 10. The structure of the strength of the lap joint in the tensile shear test: a) SSPR, b) BR, c) BHR, d) COUR. $F_{S_{max}}$ – maximum tensile shear load; E_t – dissipated energy; $E_{F_{max}}$ – dissipated energy up to maximum shear load; S_t – total displacement; $S_{F_{max}}$ – displacement at the maximum shear load

4. SUMMARY

The joint load capacity should not be analyzed by taking into account only maximum joint force load, but by analyzing other parameters of the load-elongation diagram for the tensile shear testing. In the ISO/DIS 12996 standard the dissipated energy, for certain specific values of the load force, is proposed as a one of the joints parameter. For the three joints systems (with blind rivet, with blind hermetic rivet and with rivet for closing up) there is some dependence with similar joints strength and different dissipated energy. In the case of conventional joints (BR, BHR, COUR) the joint ability to transfer the load is depended on the fastener strength. The main factor that determines the maximum joint strength is the sheet material.

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