

# The strength of traditional and self-pierced riveted joints

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**Abstract.** The objective of this study is to compare the strength of riveted joints fabricated by traditional riveting (with pre-drilled holes) and self-piercing riveting (SPR) for different types of joints. Riveted joints were produced using steel and aluminum alloy rivets and two types of sheet material: 235JR steel sheet and EN AW 6060 aluminum alloy sheet with the following dimensions: length  $l = 100 \pm 1$  mm, width  $b = 50 \pm 1$  mm and thickness  $g = 2$  mm. For all tested types of riveted joints (pre-drilled and SPR), 5 sets of joints were fabricated, each set containing 6 samples. The sets of joints differed with respect to the number of rivets (1, 2, 3, 4 and 6 rivets), joint type (single-, three- and four-riveted joints) and lap length. For all tested joints, the highest load capacity was obtained for self-pierced riveted joints, while the lowest – for pre-drilled joints with aluminum alloy rivets. In addition, it was found that the shear strength of self-pierced riveted joints is higher than that of aluminum and steel blind rivets.

**Keywords:** riveted joints, self-piercing riveting SPR, blind rivets, steel sheet, aluminum alloy sheet

## 1 Introduction

Assembly joints are an inherent part of human life and activity. In assembly joints individual structural components are assembled and can thus support loads. Depending on whether structural components are joined by a special fastener or not, it is possible to distinguish indirect and direct joints. In indirect joints, rivets or screws can be used as joining elements. In direct joints, no fasteners are used [1-3].

Rivet joints are indirect permanent joints. Riveting consists in joining shapes with thin sheet metals and brackets. This technique is also widely used to join leather and rubber with metal elements, e.g. in saddlery. This type of joints is based on the use of rivets as fasteners. The industry offers a wide variety of general purpose rivets of standard shape and

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size. Depending on the rivet shank shape, we can distinguish solid rivets, hollow rivets, tubular rivets, rivet nuts, blind rivets [4].

Solid rivets are used in metal structures such as bridges, cranes, boilers and towers. Hollow and tubular rivets are used in precision engineering for small structures and in the electrical industry to join brittle, soft or non-uniform materials.

The main advantages of riveted joints include [1,5-7]:

- vibration damping,
- no residual stresses,
- the possibility of joining different materials (metal-metal, metal-nonmetal),
- no interference in the structure of materials being joined (in cold riveting).

The disadvantages of riveted joints include [3,8-10]:

- permanent fastening of structures,
- weakening of joined materials due to hole drilling,
- high labor consumption,
- increased structure weight,
- difficulty in producing tight joints,
- relatively high costs of fabricating joints.

Over the years the technique of producing riveted joints has evolved as a result of modifying rivet geometry and material. This also led to changes in the production technology for riveted joints and the design of new machines and devices for riveting processes. The traditional process for producing riveted joints consists in piercing the materials being joined, placing a fastener in the hole and clenching the rivet. However, this method of producing joints means longer production time and causes difficulties with respect to obtaining the required accuracy and properties of joints. As a result of research on riveting processes, an innovative method for producing riveted joints has been developed, which is known as self-piercing riveting (SPR) [11-16].

Pierce riveting consists in joining materials under load. This leads to considerable savings in assembly departments owing to shorter operational time and improved quality of produced joints. Because material is cold-formed, structural components such as sheet metals and profiles are joined via force- and form-fit mechanisms. This type of joints does not require the pre-drilling of holes. One can distinguish several riveting techniques with or without material piercing [3,11,16-18]:

- clinch rivet (CR) – this joining method consists in clinching rivets by stamping and involves the use of an additional solid fastener. A characteristic of this technique is that no sheet of material is pierced, which allows for joining elements with chemically-protected surfaces (e.g. against corrosion);
- self-piercing riveting (SPR) – this technique enables joining thin-walled elements made of strip and sheet materials using specially designed tubular rivets. In this method, the punch presses the rivet through the top sheet of material. As a result of the rivet geometry and applied punch load, the lower sheet of material is pressed onto the die. In effect, the rivet pierces the top sheet. After that, the lower sheet and the rivet undergo upsetting, which ensures that the deformed lower sheet of material adheres closely to the die surface. As a result, the sheets closely adhere to each other, which is essential as the joint quality depends on geometric match of the die shape to the rivet size and type.
- solid self-piercing riveting (SSPR) – this joining technique is similar to SPR, the difference lies in the punch geometry – in SSPR the rivet acts like a shearing punch. The punch presses on the rivet head leading to piercing of the sheet materials being joined. The excess material is removed through an opening in the lower die – the internal edge of this opening acts like a cutting edge and helps

pierce the lower sheet of material. Finally, a hole is cut in the sheet materials and the rivet is securely locked.

The objective of this paper is to compare the strength of SPR joints and that of joints with pre-drilled holes, for different types of joints.

## 2 Methods

### 2.1 Description of joined materials

Riveted joints were fabricated using EN AW-6060 aluminum alloy. This alloy has a relatively low tensile strength, so it is suitable for producing various types of sections. The other joined material was a sheet of non-alloy structural steel of S235JR grade. Due to its good mechanical properties, this steel grade is used for structural components that are exposed to high static and dynamic stresses. In addition, this steel has good machining properties, which allows for producing finished parts of complex shape by machining. Its chemical composition allows for producing high-quality welded joints. The tests were conducted on sheet materials described by the following dimensions: length  $l = 100 \pm 1$  mm, width  $b = 50 \pm 1$  mm and thickness  $g = 2$  mm.

### 2.2 Riveted joints

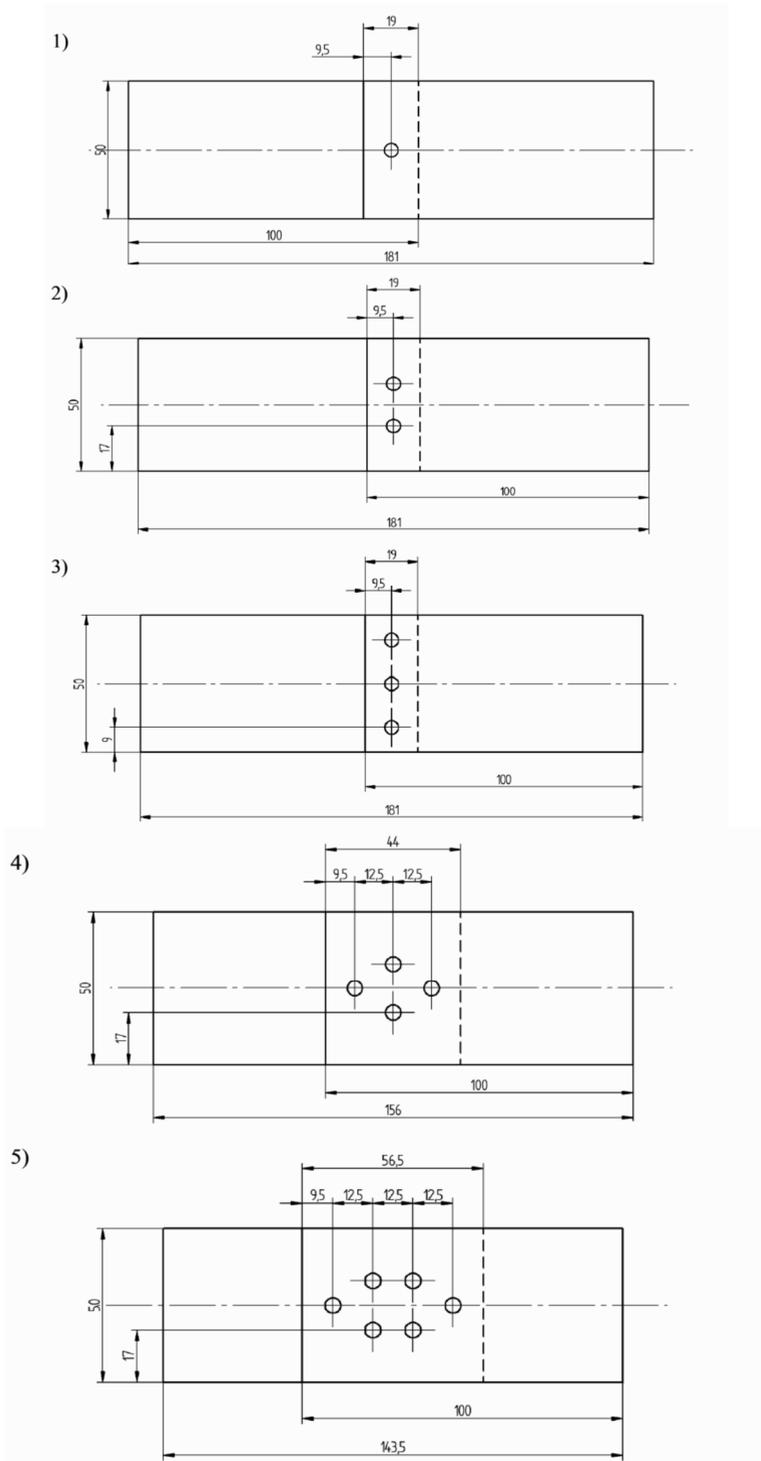
Experiments involved fabricating single-lap riveted joints by two methods: riveting with steel and aluminum alloy blind rivets and self-piercing riveting (SPR) with steel rivets. For every tested joint type 5 series of joints were fabricated, each series containing 6 samples. The series of joints differed in the number of rivets, joint type and lap length. The geometry of these joints is shown in Fig. 1.

The lap length, rivet spacing and edge distance were designed in compliance with the guidelines given in the literature on the subject, as shown in Table 1.

**Table 1.** Dimension calculation [19]

Design assumptions	Calculations, mm	Selected value, mm
Rivet diameter $d$ : $d = (1-2)g$	$(1-2)4=4-8$	5.0
Pitch $t$ : $t = (3+5)d$	$(3-5)5=15-25$	16.0
Spacing between rivet rows $a$ : $a = (0.6-0.8)t$	$(0.6-0.8)16=9.5-12.8$	12.5
Spacing between end rivets and edge $e_1$ (in loading direction): $1.5 \leq e_1 \leq 2d$	$1.5 \leq e_1 \leq 2d=$ $7.5 \leq e_1 \leq 10$	9.5
Spacing between end rivets and edge $e_2$ (perpendicular to loading direction): $1.5 \leq e_2 \leq 2d$	$1.5 \leq e_2 \leq 2d=$ $7.5 \leq e_2 \leq 10$	9.0
Rivet hole diameter $d_0$ : $d_0 = d + (0.1-0.2)$	$5 + (0.1-0.2)=$ $5.1-5.2$	5.2

To make sure that the above assumptions are applicable to finished products, the dimensional tolerance was set to  $\pm 1,5$  mm for  $t$ ,  $a$  and to 1 mm for  $e_1$ ,  $e_2$ .



**Fig. 1.** Top view of fabricated joints: 1) joint with one rivet, 2) single-riveted joint with two rivets, 3) single-riveted joint with three rivets, 4) three-riveted joint with four joints, 5) four-riveted joint with six rivets

### 2.3 Preparation of joints

Surface preparation is a vital part of the joining process because it has a significant effect on the strength properties of finished joints. To prevent as many structural defects as possible, all surface edges of steel sheets were ground with an abrasive disc to remove all grooves and surface irregularities produced during the cutting process. Further surface treatment of the sheet materials differed in terms of the applied joining method.

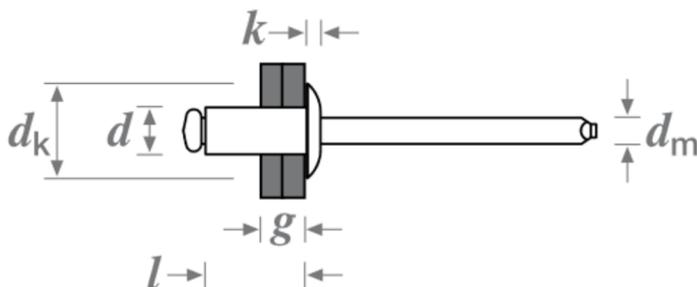
#### 2.3.1 Pre-drilled riveted joints

To make pre-drilled (traditional) riveted joints, a template was used (Fig. 2) as a guide for placing the rivet holes in specified points. After that, two drilling operations were performed in the points marked on the sheet: pre-drilling using a drill with a diameter of  $d = 3 \text{ mm}$  and actual drilling using a drill with a diameter  $d = 5.2 \text{ mm}$ .



**Fig. 2.** Template used a guide for placing rivet holes on sheet materials

Following the drilling operations, the samples were ground with 80-grit abrasive paper in order to remove surface irregularities and burrs produced during the drilling operations. After that, the samples were degreased. Next, the sheet materials were subjected to riveting. Two types of rivets were used. EN AW-6060 sheet joints were made using rivets made of aluminum alloy (aluminum – 3.5% magnesium alloy) with a carbon steel mandrel in compliance with DIN EN ISO 15977. In turn, steel sheet riveted joints were fabricated with carbon steel rivets according to DIN EN ISO 15979. The geometry of the two rivet types is shown in Fig. 3.

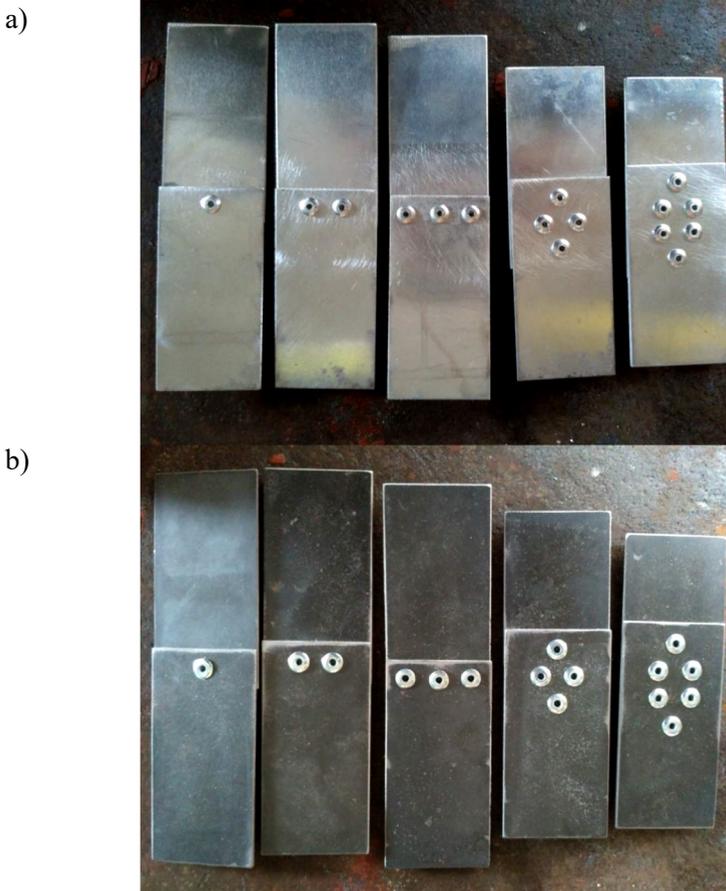


**Fig. 3.** Schematic design of a blind rivet

The key to the figure and the dimensions of rivets used in the experiments:

- $d$  - nominal diameter,  $d = 5$  mm,
- $g$  - thickness of elements to be joined,  $g = 4$  mm,
- $dk$  - rivet flange diameter,  $dk = 9$  mm,
- $dm$  - nominal mandrel diameter,  $dm = 2.64$  mm,
- $l$  - rivet shank length,  $l = 8$  mm,
- $k$  - rivet flange thickness,  $k = 1.6$  mm.

The rivets were clenched with a bimanual riveting machine. The use of this machine ensured the stability of clenching, suitable clamping load and correct forming of the rivet head. After clenching, rivet joints were fabricated, as shown in Fig. 4.



**Fig. 4.** Pre-drilled riveted joints with blind rivets: a) aluminium alloy, b) steel

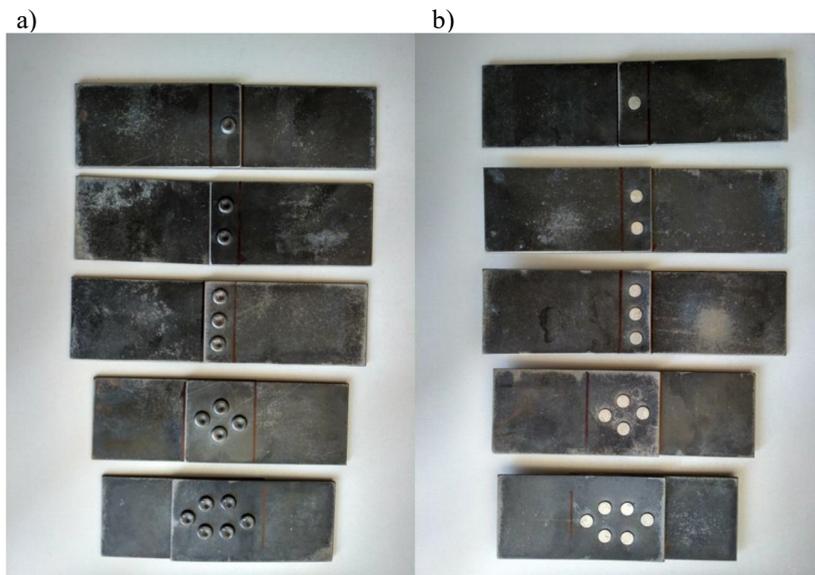
### 2.3.2 SPR joints

Following the grinding of their edges, the steel sheets were ground all over in order to remove grooves and inclusions on the contact surfaces. After that, the sheet samples were degreased and wiped with a dry cloth.

In the self-piercing riveting process, rivets with a 5 mm length and 5 mm diameter were used. These rivets had a shank of type P and a head of type SK made of hardened steel

coated with ALMAC. Their hardness is classified as H2 ( $HV = 410 \pm 30$ ). In the catalogue, this rivet type is described as: rivet  $d = 5$  mm, P-SK type.

The tests were performed on a die marked as FM 085 2123. The geometry and dimensions of both the rivet and the die are protected data (know-how) of Bollhoff Fastenings Ltd. To clench the rivets, the punch load was set to 50 kN. The riveting process was performed with a machine provided with a standard C-type frame and a belt feeder for rivets. Fig. 5 shows the joints produced by self-piercing riveting.



**Fig. 5.** SPR joints - view from the side of die (a) and punch (b)

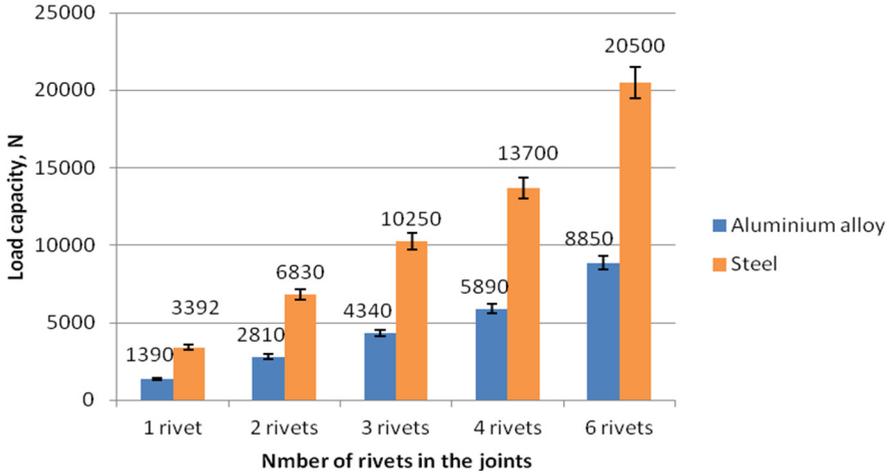
## 2.4 Strength tests

The failure load for individual riveted joints was measured with the Zwick/Roell Z150 testing machine. The use of this machine enabled the measurement of fundamental parameters and, at the same time, ensured high measuring accuracy.

## 3 Results of strength tests

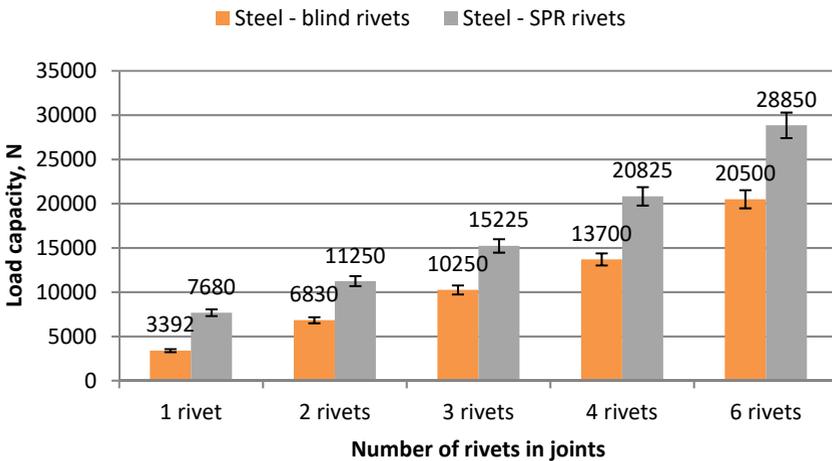
### 3.1 Load capacity of riveted joints

Fig. 6 compares the load capacity of all pre-drilled riveted joints. The analysis of the data in Fig. 6 reveals that the pre-drilled steel riveted joints (with steel blind rivets) have a higher load capacity than riveted joints of aluminum alloy steel sheets (with aluminum alloy blind rivets). This trend was observed for all tested types of joints. It was also observed that in order to equalize the load carrying capacity of the joints with aluminum alloy rivets with that of steel rivets, the number of aluminum alloy rivets must be over twice as high as that of steel rivets.



**Fig. 6.** Load capacity of pre-drilled riveted joints for aluminum alloy and steel sheets

Fig. 7 shows the results of load capacity of riveted joints for steel sheets in a function of the rivet type.



**Fig. 7.** Load capacity of steel sheet riveted joints versus rivet type and number

Analyzing the data given in Fig. 7 it can be observed that the load capacity of all SPR joints is higher than that of joints with blind rivets made of steel. The difference in load capacity of individual joints ranges from 4288 N to 8350 N. The load capacity is the lowest for single-rivet joints and it increases with increasing the number of rivets in the joints.

### 3.2 Comparison of the shear strength of riveted joints

The shear strength of tested riveted joints was determined in compliance with Equation (1) [19], and the results are given in Fig. 8.

$$\tau = \frac{F}{\frac{\pi d_0^2}{4} \cdot m \cdot n} \leq k_t \tag{1}$$

where:

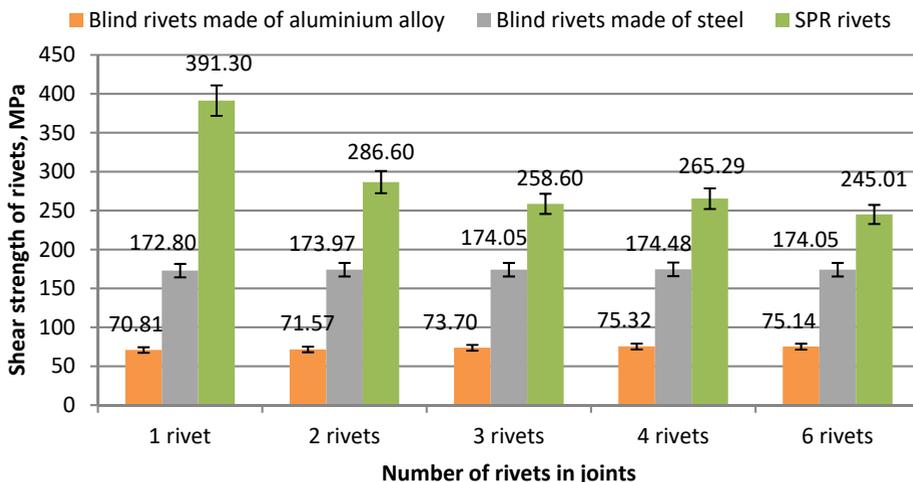
$k_t$  - the maximum shear stress;

$F$  - the external force;

$d_0$  - the diameter of a rivet hole (clenched rivet);

$m$  - the number of shear sections in one rivet; for single-shear rivets –  $m = 1$ ,

$n$  - is the number of rivets (in lap joints – all rivets).



**Fig. 8.** Shear strength of tested riveted joints

Based on the results given in Fig. 8, the following can be observed:

- the shear strength of SPR rivets is higher than that of joints with blind rivets made of aluminum and steel;
- the shear strength of joints with blind rivets is proportionate to the number of applied rivets, which means that the load force is uniformly distributed over all rivets;
- the shear strength of SPR joints is not proportionate to the number of rivets, in particular the shear strength of single-rivet joints seems to be overestimated, which may result from the deformation of sheets and partial tensile loading of the rivet.

### 3.2 Comparison of maximum stresses in joined sheet materials

Maximum stresses in the sheet materials being joined were calculated from the tensile strength condition (2) [19], taking account of weakening of the section of sheet materials due to rivet holes, the most prone to damage being the section that crosses through the first rivet row.

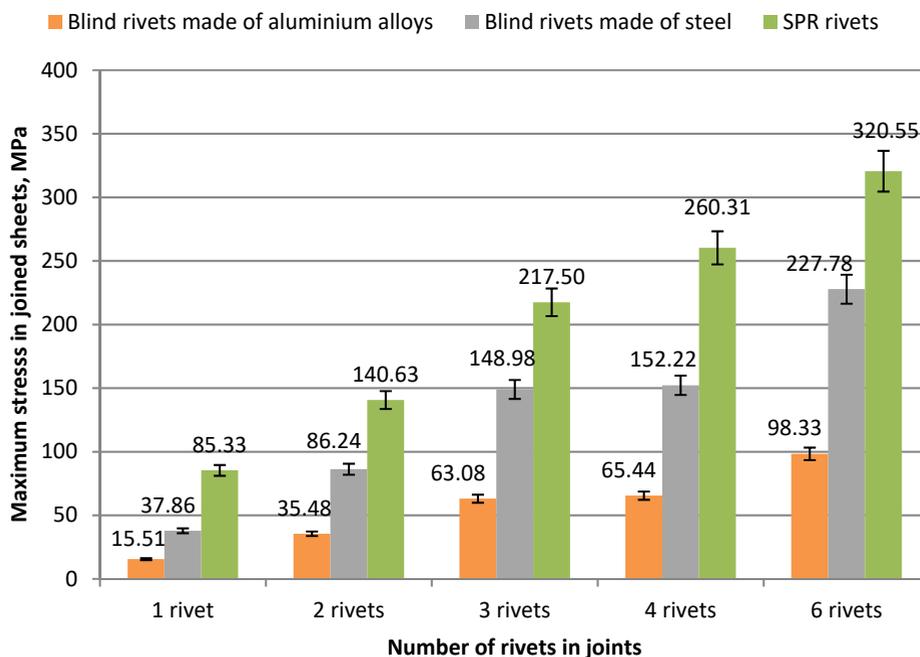
$$\sigma_r = \frac{F}{g(b_g - n_1 \cdot d_0)} \leq k_r \tag{2}$$

where:

$b$  - the width of sheet [mm];

$g$  - the thickness of sheet [mm];  
 $n_1$  is the number of rivets in the section;  
 $k_r$  - for a sheet material or plates.

The results of maximum stresses in joined steel sheets versus the type of riveted joint are given in Fig. 9.



**Fig. 9.** Maximum stresses in joined sheets in tested rivet joints

Examining the results given in Fig. 9 it can be observed that the stress increases in the steel sheets being joined with increasing the number of rivets, irrespective of the rivet type. The yield stress of riveted joints for steel sheets was exceeded in joints with 4 and 6 steel SPR rivets ( $R_{eH} = 235$  MPa). As for the riveted joints with aluminum alloy rivets, the yield stress of the joined materials was not exceeded ( $R_{eH} = 150$  MPa).

#### 4 Summary and conclusions

The study investigated joints fabricated by traditional riveting and piercing riveting. Pre-drilled riveted joints were fabricated with blind rivets for two reasons: firstly, the design of clenched blind rivets is similar to that of rivets used in pierced riveted joints, and, secondary, the clenching of blind rivets is simple to perform. Given these features, blind rivets are a very popular type of rivets used in assembly processes. Two series of pre-drilled joints: joints with aluminum alloy rivets and steel rivet joints were made, in order to estimate which of them can support higher loads. Self-pierced riveted joints were fabricated using steel rivets, which made it possible to compare the strength properties of these joints with those of pre-drilled joints with steel rivets.

The analysis of the strength test results led to the following conclusions:

- for all tested riveted joints and joint types the highest forces were obtained for self-pierced riveted joints while the lowest – for pre-drilled riveted joints with aluminum alloy rivets;
- the mean shear strength increases with the increasing the number of rivets located in a line perpendicular to the axis of the tensile force – the highest shear strength was obtained for the joints with 3 rivets for all tested types of riveting;
- when the number of rivets was increased from 3 to 4, this led to a 43% decrease in the shear strength of every joint type due to an increase in the lap surface;
- compared to 3-rivet joints, the shear strength of 6-rivet joints is lower by 33% for pre-drilled riveted joints and by 38% for SPR joints, which results from a change of the lap surface;
- SPR joints have higher shear strength than blind rivet joints made of aluminum and steel alike;
- the strength of blind rivet joints is proportionate to the number of applied rivets, which means that the load force is distributed uniformly over all rivets;
- the stress in joined sheet materials increases with increasing the number of rivets, irrespective of the fastener type;
- in the case of riveted joints for steel sheets, the yield point of the joined materials ( $R_{eH} = 235$  MPa) is exceeded in joints with 4 and 6 steel SPR rivets;
- the elongation at maximum tensile force increases with the increasing the number of rivets in pre-drilled riveted joints due to an increase in the maximum force;
- as for the standard deviation of load capacity, the deviation is smaller for pre-drilled riveted joints than that obtained for self-pierced riveted joints, which indicates a higher repeatability of this measure.

Based on the above conclusions, it has been found that the use of the innovative technique of self-piercing riveting combined with the use of SPR rivets leads to higher strength properties of the product and high repeatability of the joining process compared to traditional riveting techniques.

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