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Original Research Article

The numerical analysis of the effect of the joining process parameters on self-piercing riveting using the solid rivet

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ABSTRACT

This paper presents the numerical modeling of the self-piercing riveting using the solid rivet. The joint forming capabilities were presented using the FEM analysis, on the example of two steel sheets made of DC01, and on the example where the upper sheet was made of DC01 and the lower sheet was made of EN AW-AlMg3 aluminum alloy. The numerical analysis of the joint forming was performed using sheets of identical thickness of 1.5 mm and at conventional tool movements.

The effect of the layout change and the number of grooves in the universal rivet on the stress distribution were determined.

In this paper, the groove filling with the joined sheet material depending on selected factors of the joining process was also compared. The capabilities of joining with a different tool movement solution were presented. The correctness of the numerical model was validated based on metallographic researches and the force characteristics of the process.

1. Introduction

The SPR (self-piercing riveting) is a sheet joining technology. The SPR is being intensively developed to cover more material groups. The SPR belongs to the sheet joining technology [1–7]. The SPR features a number of advantages. No pre-drilling is one of the most important advantages. However, the SPR has a limited usage. It cannot be used to join hard materials. The hard materials can be joined by the laser assisted self-piercing riveting (LSPR) [8]. The material which is hard to deform is preheated before joining. Another possibility to join hard materials can be a self solid piercing riveting (SSPR) [9–11]. The SSPR may be used for joining both hardened and soft materials and for various mechanical property combinations of the joined layers [12].

In some cases, the SSPR technology may replace the aluminum alloy spot welding. Nowadays, this is the most frequent joining method used in the automotive industry [13]. In the hybrid joint, the rivet may stabilize the pressure condition while the glue is curing. The rivet is the reinforcing element once the glue is completely cured.

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Table 1 – The ridge-rivet configuration models.

		Rivet				
		KerbKonus		Modified		
		A	B	C	D	E
Ridge width, *f* [mm]	0.5	–	–	C1	–	–
	0.75	A2[a]	B2[b]	C2	–	–
	1.0	–	–	C3	D3	E3
	1.6	–	–	C4	–	–

[a] Rivet no. 492 100 004 900.
[b] Rivet no. 492 000 004 900.

In the conventional forming, a punch and a blank holder are the only moving elements. In order to achieve more effective forming, the punch and die must move. This issue was presented initially by Neugebauer et al. [9]. Neugebauer stated that two movements of the tools slightly increase the maximum joint strength. The forming force generated by the riveting machine drive deforms significantly the riveting press frame [14]. Increasing the joint's shearing strength for identical sheet arrangement requires to increase the pressing force at the classic layout of tool movement [15]. While joining various materials using the die ridge of identical geometry, the sheet material plastifying occurs sooner or later. As a result, the rivet grooves may be poorly filled by the joined material. This affects the tightness and rigidity of joint.

Thus, the detailed analysis of the SSPR joint forming should be performed. The FEM modeling is relatively fast and economically efficient analyzing method. The forming process analysis based on FEM shortens the way to create optimal joint forming conditions [16–18].

2. Numerical modeling of the SSPR process

The numerical simulation of the SSPR joining process enabled to research the effect of rivet type (universal and special) on stress distribution in the finished joint's material.

A FEM model of the sheet joint was developed on basic geometry of the universal rivet (number 492 100 004 900) and special rivet (number 429 000 004 900) offered by KerbKonus [12]. The above mentioned rivets are recommended by the manufacturer to join sheets of specified thickness.

The strength of the SSPR joint made with an universal rivet is slightly higher comparing to the one with special rivet [11]. Thus, the author decided to perform the FEM analysis of the effect of rivet geometry change on joint forming process for an universal rivet.

The effect of the layout change and number of the grooves in the universal rivet on the stress distribution and groove filling with the sheet material were researched.

The FEM modeling with the universal rivet was also performed in order to track the effect of the die edge width and the tool movement change on filling the rivet grooves with the sheet material. The effect of the rivet head geometry change on the residual stress change was researched.

2.1. *Variable process parameters*

The FEM modeling was performed in two stages: the first one includes the forming and stress distribution analysis for basic model of the tool movements with the universal (model A2) and the special rivet (model B2) – see Table 1.

The second stage includes the selected variable factors of SSPR joint forming process based on data obtained in the first stage.

- For DC01 sheet, the forming process was modeled at various die ridge width and geometry models according to "C1"–"C3" and "D2" models, as presented in Table 1 and Fig. 1;
- for the rivet-ridge layout acc. to "C3" model, the tool movement order was changed while forming the joint (for *h* = 0.5, 0.3 mm) – see Figs. 2 and 3;
- the joint forming was performed for the upper sheet was made of DC01 (material number 1.0330 according to EN 10130) and the lower sheet made of EN AW-AlMg3-H111 aluminum alloy (material number EN AW-5754 according to EN 485–2) and the rivet-ridge layout acc. to "C3" and "C4" model.

2.2. *Rivet-material, geometry model*

The basic FEM geometrical model of the joint forming process (Fig. 3) was developed basing on the experimental data. The die and punch with blank holder were selected for joints of diameter 4 mm. The cutting edge rounding radius was set to

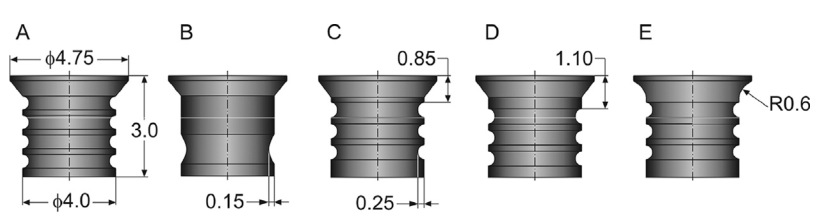

Fig. 1 – Basic models (A and B) and rivet shape model's geometry changes (C–E).