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Concept for further development of self-pierce riveting by using cyber physical systems

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Abstract

The mechanical joining technique self-pierce riveting is becoming more and more important for high-volume car production. Therefore further developments regarding the flexibility and consistent quality of the mechanical joining technology are necessary. This paper shows a numerical analysis of the most influential tool parameters as well as the influence of varying boundary conditions on the joining result for self-pierce riveting. Furthermore a new concept for improving quality and flexibility of the process by using an advanced die system in combination with cyber-physical-systems is introduced.

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Keywords: mechanical joining; self-pierce riveting; cyber-physical-systems; sensitivity analysis

1. Self-pierce riveting

The mechanical joining technique self-pierce riveting with semi-tubular rivets (SPR-ST) can be separated in three steps and is shown in Fig. 1.

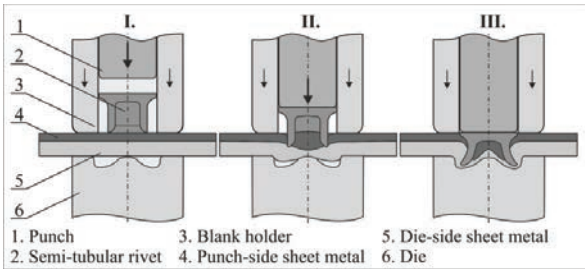

Fig. 1. Process steps of self-pierce riveting with semi-tubular rivet (SPR-ST) [1].

At first the parts and the rivet are positioned between punch, blank holder and die (Fig. 1, I.). Next, the punch presses the semi-tubular rivet into the parts. Due to the cutting edge of the rivet, a slug is punched out of the punch-sided part and enclosed inside the rivet (Fig. 2, II.). Following, the shape of the die causes the rivet to expand and creates an interlock. At the end, the cavity of the die can be completely filled with material (Fig. 1, III.). [1]

The main application area of self-pierce riveting is joining mixed compounds (e.g. steel and aluminum) and material combinations such as aluminum-aluminum. Up to four parts can be joined and the SPR-ST process is well suited to be combined with adhesive bonding (hybrid joining). [2]

SPR-ST joints are assessed on the basis of various characteristic values (Fig. 2). By these values proper joints are defined. The interlock between the rivet foot and the die-sided material is the most important value because it reflects directly on the joint strength.

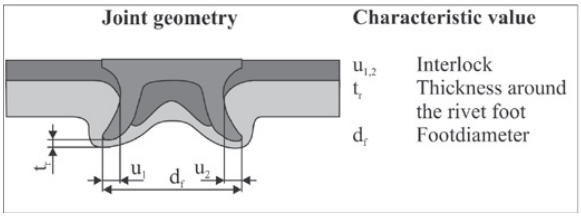

Fig. 2. Self-pierce riveting joint geometry with most important values.

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2. Simulation Model

In the here presented investigations the SPR-ST process of two 6xxx aluminum alloys with a thickness of t = 2.0 mm with a standard steel rivet C 5.3 mm x 5.5 mm is considered.

For the numerical investigations a 2D rotationally symmetric simulation model in DEFORM V11 was build up. To validate the simulation model a representative cross section and force displacement curve for one out of five experimental samples is compared to the results of the simulation (Fig. 3). The simulation is in good agreement with experiment, whereby the numerical model can be used for the following sensitivity analyses.

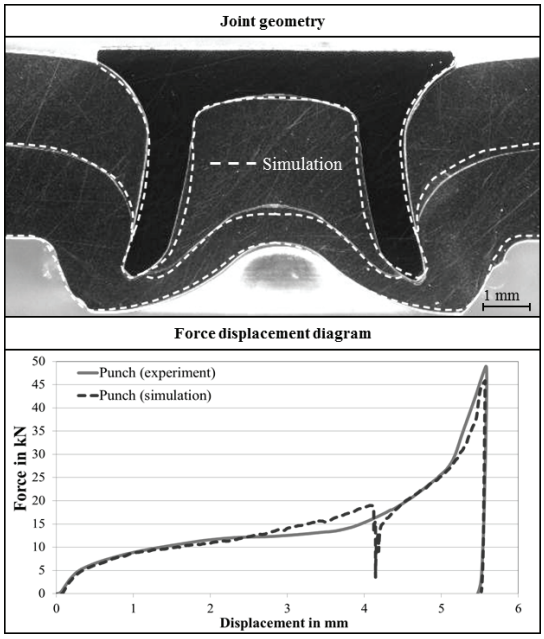

Fig. 3. Validation of the simulation model for SPR of EN AW-6016 T4 (t = 2.0 mm) in EN AW-6016 T4 (t = 2.0 mm).

3. Sensitivity analysis for geometrical parameters of the die

One of the most influential input parameter for an SPR-ST joint is the geometry of the die [3]. To achieve knowledge about the systematic interactions between joining result and die geometry a sensitivity analysis regarding the different die parameters (Fig. 4) is carried out.

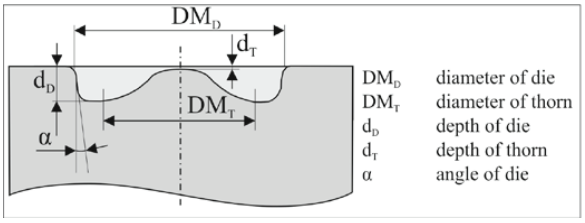

Fig. 4. Variated geometrical parameters of the die.

The ranges in which these parameters vary can be seen in Table 1. All other geometric parameters of the die have constant values. These values are similar to the reference die of the validation. The design of experiments (DoE) was calculated on the base of an advanced latin hypercube sampling (ALHS) [4], where 51 different designs are generated. All analyses which were made, as well as the compiled ALHS, are executed with the software OptiSlang 4.1.

Table 1. Variated parameters and ranges first sensitivity analysis.

Parameter	Minimum value	Maximum value
DM_D in mm	9.00	11.00
DM_T in mm	7.50	8.50
d_D in mm	1.20	2.00
d_T in mm	0.20	0.60
α in °	5.0	15.0

Additionally to the geometrical output parameters interlock, thickness around the rivet foot of the die-sided blank and foot diameter of the rivet (Fig. 2), the maximal joining force and the damage value of the die-sided blank at the end of each simulation are evaluated. The used damage criterion normalized Cockroft & Latham $D_{normC\&L}$ is based on first principal stress σ_1, equivalent stress (*von Mises)* σ_v and effective strain φ_v [5]:

$$D_{normC\&L} = \int_0^{\varphi_v} max\left(\frac{\sigma_1}{\sigma_v}, 0\right) d\varphi_v \quad (1)$$

The quality of the prognosed models for these output parameters is measured by the Coefficient of Prognosis *(CoP)* [6]:

$$CoP = 1 - \frac{SS_E^{Prediction}}{SS_T} \quad (2)$$

The numerator $SS_E^{Prediction}$ in equation (2) is the sum of squared prediction errors, the denominator SS_T is equivalent to the total variation of the output parameter. If the CoP is large, it means that the predicted errors are small and a good prognosis of the output parameter can be made. [6]

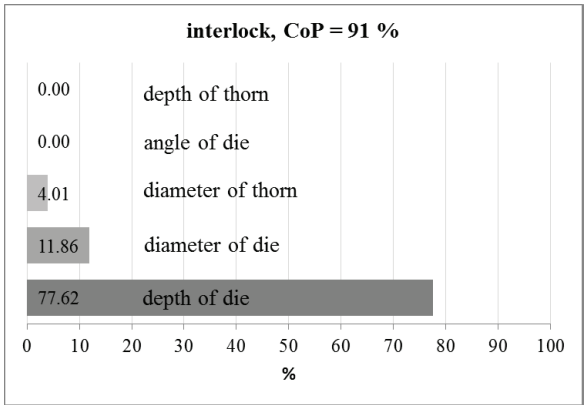

Fig. 5. Geometrical influences of the die on interlock.

Fig. 5 shows, that a varying of interlock is mainly influenced by a varying of the depth of die d_D (78 %) at the