Research in Impulse Joining of Self Pierce Riveting[*]

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Abstract

Results are shown in impulse joining of aluminium sheets with self-pierce-riveting. Two institutes are testing impulse-riveting with different setting velocities of the punch – up to 10 m/s by using pneumatic cylinders and about 100 m/s by using a propellant charge.

One aim focus consists in riveting without a C-frame against a flat anvil instead of using a C-frame with a contoured die. So accessibility is increased and disadvantages of occurring misalignments are avoidable.

The strength properties of the realised joints are tested.

Keywords

Mechanical joining, Impulse-joining, Self-pierce riveting, Aluminium

1 Introduction

Mechanical joining of metal sheets has become more and more important in the automotive industry. One major part concerning joining in the automotive industry is self-pierce-riveting (SPR).

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The standard tool is based on a C-frame. With increasing throat depth and joining forces the C-frame has to be built in a massive manner. Otherwise misalignments occur between die and punch what leads to decayed joints. With these massive constructions, robot-handling of C-frames is often not feasible anymore. At the moment realised deep-throats for C-frames are about 600 mm. Additional accessibility is limited with C-frames.

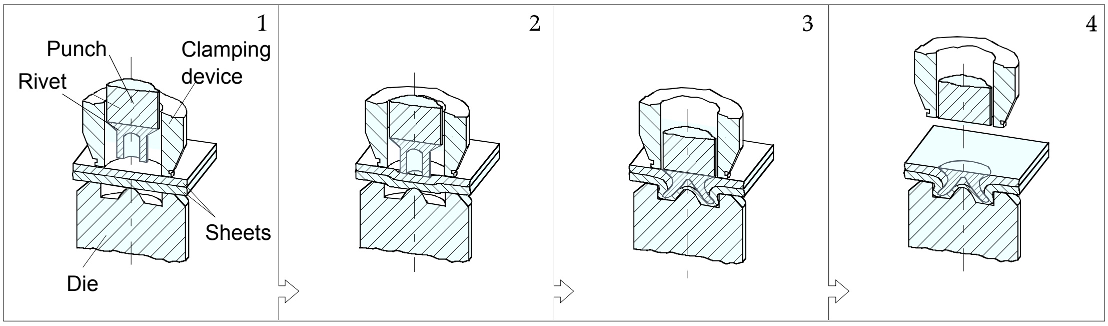
An alternative is the use of the impulse technology for joining rivets. By using the inertia of the system it is possible to work with low-stiff C-frames or without C-frames. If one works without C-frames, one must get the occurring misalignments under control.

Riveting with different joining velocities is studied by two institutes.

2 SPR-Setting

The standard SPR-procedure is based on setting velocities of about 0.005 to 0.01 m/s using a punch / contoured-die system on a C-frame. There are four steps to be proceeded:

1. The sheets are positioned to be joined together,
2. The punch pushes the rivet, which cuts through the upper-plate
3. Rivet spreads in the bottom-plate
4. Tool opens and plates are ejected



Positioning Rivet setting Rivet spreading Finish

Figure 1: *SPR-procedure [1]*

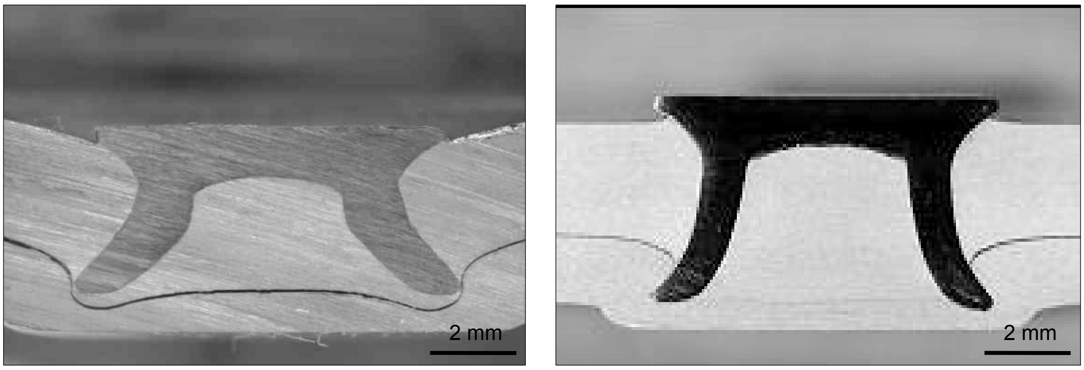
As mentioned above the aim is to work without a C-frame. In order to avoid decayed joints with misalignments > 0.2 mm, one works against a flat anvil. Replacing the contoured die by the flat anvil there are only minimal eccentricity requirements (< 1 mm). There are two main advantages in using a flat anvil:

1. One “flat die” for different joining operations, instead of one for each
2. High tolerances against misalignments between punch and die
3. The state of stress is predominantly compression. Thus also less ductile materials can be joined.

An attempt to eliminate the contoured die by using the flat anvil with the conventional setting speed (0.005 m/s) does not lead to functional and respectively optimal results as shown in figure 2, left image. As you can see the rivet set with the significant lower setting velocity did not even cut through the upper-plate. The right image shows a joining result with setting speed of about 120 m/s. The conventional set rivet has been strongly compressed, while with the impulse-technique set rivet has cut the upper-plate and spread rightly in the bottom-plate.

Conventional velocity v = 0.01 m/s

High velocity v > 100 m/s



Upper plate: AlMg4.5Mn; thickness 2.5 mm
Bottom plate: AlMg4.5Mn; thickness 1.5 mm
Rivet: C5.3x6H4

Upper plate: AlMg4.5Mn; thickness 2.5 mm
Bottom plate: AlMg4.5Mn; thickness 1.5 mm
Rivet: C5.3x6H4

***Figure 2**: Influence of the setting speed to the quality of the joint by using a flat anvil*

3 Experimentals

The research at the Laboratory of Materials and Joining Technologies (LWF) in Paderborn is based on propellant charges for riveting with setting speed greater than 100 m/s while the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) uses pneumatic cylinders for accelerating the punch to about 10 m/s. Figure 3 shows the difference between the two acceleration principles.

Two different material-combinations were examined [2]. The first represents the preferred combination for Standard-SPR: “thin to thick” - a thin upper-plate is jointed with a thick bottom-plate. In

Figure *4* the influence of the different velocities to the riveting process is shown. By using the same rivet, the difference is small.

The second material combination (“thick to thin”) shows in

Figure *5* small differences. The higher velocity induced a hardly smaller undercut and a slightly lesser compression of the rivet than the lower velocity.

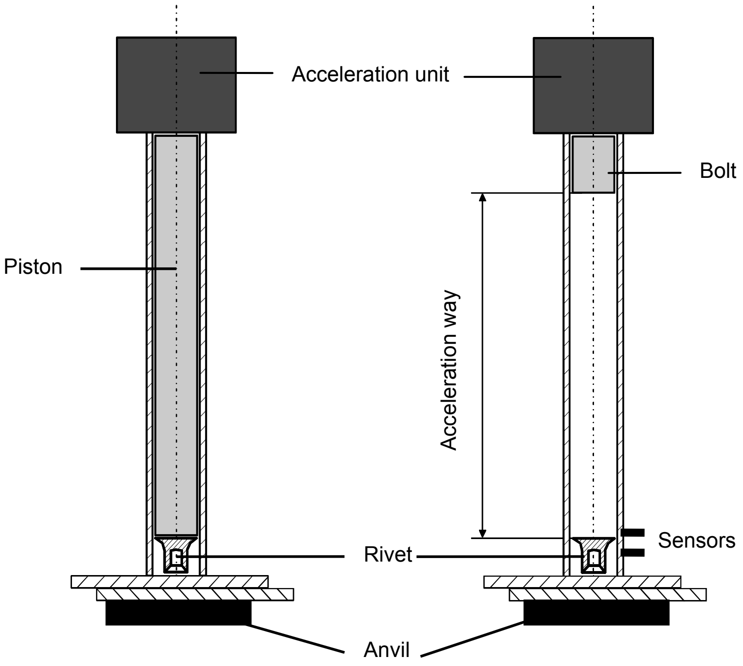
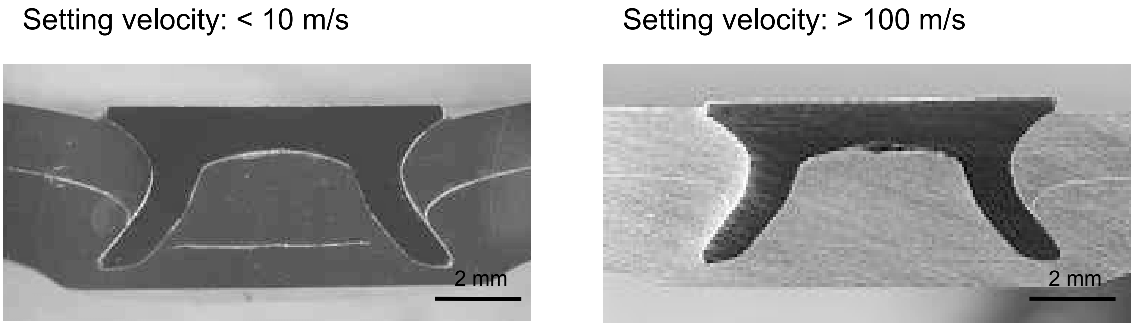


***Figure 3**: Comparison of the two acceleration principles, the left image shows the “piston” system (v < 10 m/s), the right image shows the “bolt” system (v > 100 m/s)*



Setting velocity: < 10 m/s

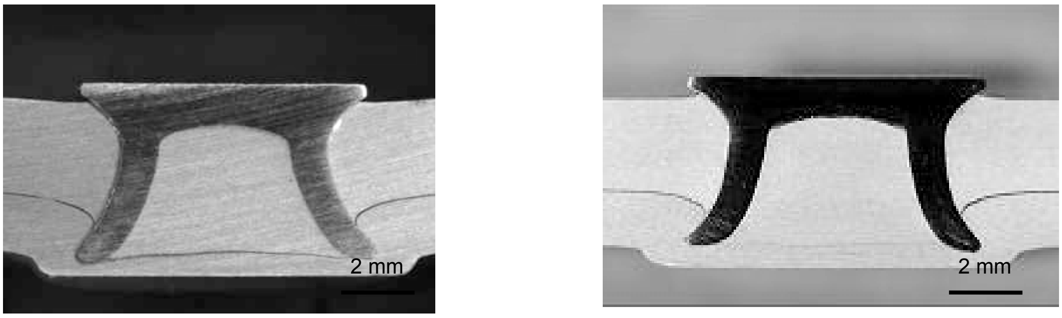
Upper plate: AlMg4.5Mn; thickness 1.5 mm
Bottom plate: AlMg4.5Mn; thickness 2.0 mm
Rivet: C5.3x5H4

Setting velocity: > 100 m/s

Upper plate: AlMg4.5Mn; thickness 1.5 mm
Bottom plate: AlMg4.5Mn; thickness 2.0 mm
Rivet: C5.3x5H4

***Figure 4**: Influence of different setting velocities to the quality of the joint*

The strengths of the impulse set rivets against the flat anvil are on akin levels to these conventional set against a contoured die. In Figure 6 the results are shown of a shear strength analysis under quasi-static load. There are only low differences between the extreme high (> 100 m/s) and the high velocity (< 10 m/s). The higher performance of the conventional procedure “thick to thin” is based on the higher width of the joint caused by the contoured die.



Setting velocity: < 10 m/s

Upper plate: AlMg4.5Mn; thickness 2.5 mm
Bottom plate: AlMg4.5Mn; thickness 1.5 mm
Rivet: C5.3x6H4

Setting velocity: > 100 m/s

Upper plate: AlMg4.5Mn; thickness 2.5 mm
Bottom plate: AlMg4.5Mn; thickness 1.5 mm
Rivet: C5.3x6H4

Figure 5: *Influence of different setting velocities to the quality of the joint*

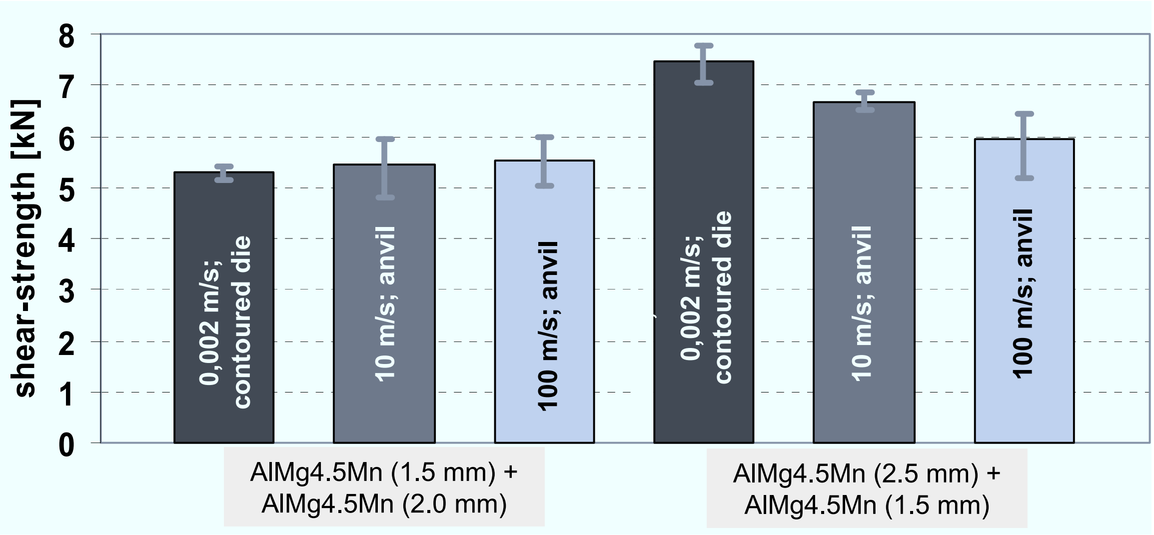


Figure 6*: Comparison of shear-strength under quasi-static load*

4 FE-Analysis

FE-Analysis for different velocities is problematic on the one hand because of missing data for strain-rate-depending flow curves and on the other hand it is no central question.

Much more interesting is the question of the rivet geometry. It is improbable that standard SPR-geometry is also the correct one for impulse joining. A rivet development as before usually "trial and error" is extremely time consuming and expensive. At this point FE - analysis has clear advantages.

A goal of the investigation is to meet a statement about numeric modeling the high-speed joining process described sufficiently exactly, in order for the process development a computational predicting of new process parameters to make possible. That applies particularly to rivet geometry, since the experimental variation of these process parameters is the central point.

SPR-FE-Analysis is state of the art [4]. The simulation of the impulse riveting makes special demands:

- Material data for very large material deformations depending of strain-rate
- Material separation with the cutting process

A simple formula for material data is used, [5]:

$$k_{f_2} = k_{f_1} \left(\frac{\dot{\varphi}_2}{\dot{\varphi}_1} \right)^m \qquad (1)$$

$i = 1$	quasi-static load
$i = 2$	$\dot{\varphi}$ = 20,000s-1
k_{f_i}	yield stress
$\dot{\varphi}_i$	strain rate
m	for aluminum m = 0.05, [6].

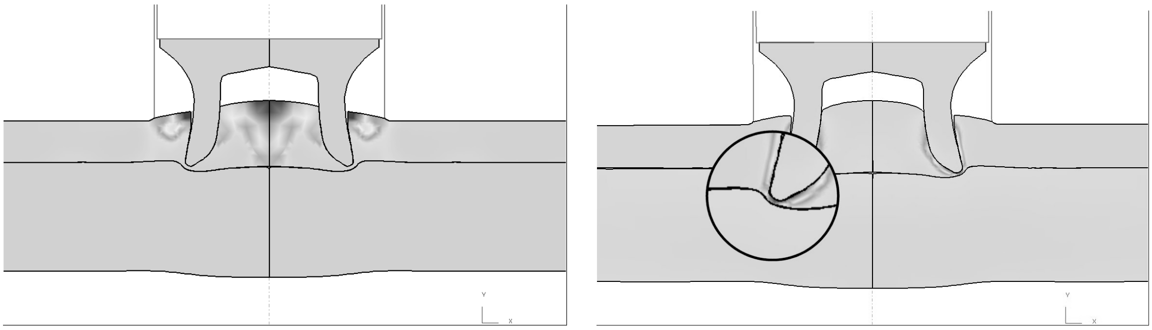
The following crack criterion was used [7]:

$$\varphi_B = \varphi_{BT} . e^{-b\left(\frac{\sigma_M}{\sigma_V}\right)} \qquad (2)$$

φ_B	strain until crack
σ	effective stress (v. Misses) / hydrostatic stress

The sizes φ_{BT} and b are material constants. They were measured on the basis of existing material data [7] and by test calculations. For the upper sheet metal b = 1.0 and φ_{BT} = 3.0 were used. The validity of these values has to be confirmed in deep-going investigations.

In Figure 7 different crack-criteria are shown.



Standard criterion Cockroft & Latham

Frobin-criterion [7]

***Figure 7**: Comparison of different crack-criteria*

In Figure 8 is shown the distribution of effective strain with impulse-SPR with flat anvil.

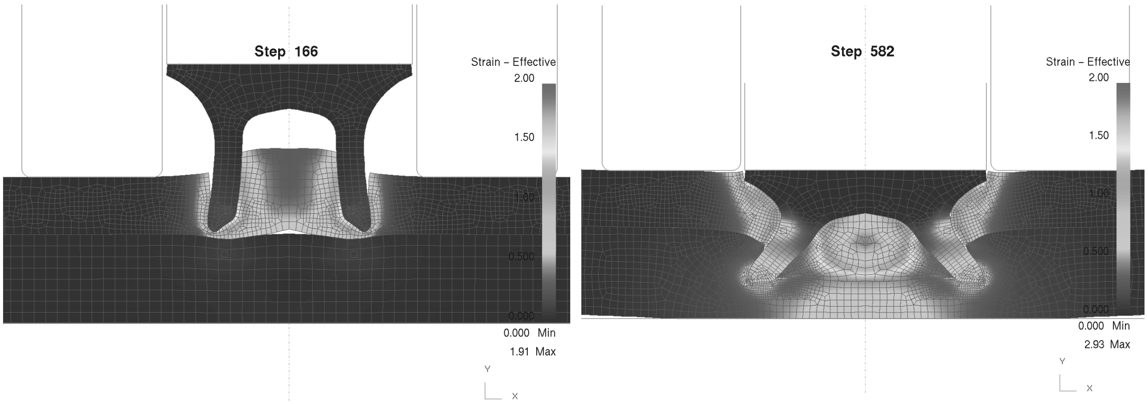


***Figure 8**: Distribution of effective strain with impulse-SPR*

5 Conclusions

The experiments prove the positive influence of high velocities in SPR-process. Using a flat anvil as counter-die leads to advantages in process stability (no contoured die; high stability against misalignments), accessibility without C-frame, joinability of brittle materials. The experiments proved the feasibility of joining especially of aluminium alloys with the standard rivet geometry. Changes of the rivet-geometry are imaginable in FE-analysis. Thus if necessary a new rivet geometry can be developed.

6 References

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