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RESEARCH PAPER

Spin-blind-riveting: secure joining of plastic with metal

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Abstract Based on a continuous trend towards lightweight design and the need of load-carrying joints between metals and fibre-reinforced plastics, Spin-Blind-Riveting (SBR) was developed at the Chair of Welding Engineering of Technische Universität Chemnitz. Through the combination of a rotated rivet and the application of a joining force, rivet connections can be fabricated without the need of predrilling the sheets. Tests were carried out with material combinations which are significant for lightweight constructions such as magnesium and aluminium alloys and glass fibre-reinforced polyamide in sheet thicknesses of 1 and 2 mm. Results show that the SBR process permits reliable rivet connections over a wide range of joining parameters. SBR joints combine high shear strength with low standard deviation of joint strength. Short joining time, high loadability and high reproducibility make Spin-Blind-Riveting an attractive new joining process for lightweight applications.

Keywords (IIW Thesaurus) Rivets · Mechanical fastening · Fibre-reinforced composites · Dissimilar materials · Combined processes · Plastics · Aluminium alloys · Magnesium alloys · Hybrid joining

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1 Introduction

Establishing joints of metals like aluminium, magnesium or steel with fibre-reinforced plastics is a steadily increasing requirement with regard to lightweight constructions. Conventional joining methods like welding or brazing are not applicable due to completely different thermo-physical characteristics of the base materials.

One solution is the use of mechanical fastening alternatives. Conventional techniques like screwing, solid riveting or blind riveting [1] need predrilled holes or two-sided access. For this purpose, new techniques, like self-piercing riveting, friction-stir riveting, flow drill joining or other equivalent methods, were developed [2–4]. Each of these techniques has specific advantages and disadvantages in terms of weight, strength, accessibility and costs.

In the course of this research, a new joining technology was established to use most of the advantages and additionally eliminate possible disadvantages of mechanical fastening processes. As advancement of blind riveting, "Spin-Blind-Riveting (SBR)" was developed. With this new technology, it is possible to join different materials without the necessity of predrilling. Therefore, a minimum preparation effort and less destruction of fibres can be guaranteed. Furthermore, only one-sided accessibility is required, the process can be easily automated and there are almost no restrictions in the combination of different materials. This makes the process highly attractive especially for sheet to sheet joints.

2 Spin-blind-riveting

Spin-Blind-Riveting (SBR) can be described as a combination of flow drilling and conventional blind riveting [5]. A metal sheet and a fibre-reinforced plastic (FRP) sheet are placed as

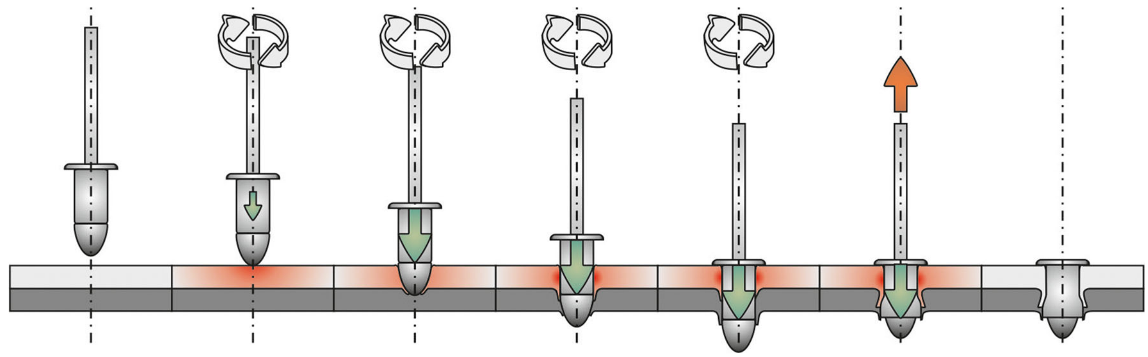

Fig. 1 Schematic of the SBR process

lap joint with the metal sheet placed on the top. The rivet is rotated with a high speed of 2000 rpm and more and simultaneously pressed onto the sheets by a penetration force. Due to the combination of rotation and pressure, friction heat is generated and the metal begins to plastify. The rivet begins to penetrate into the metal sheet while the displaced material is formed to a sleeve similar to flow drilling [5]. The formed sleeve from the metal sheet has a high temperature and is pressed against the FRP sheet. This one is also heated up by heat conduction so the thermoplastic matrix begins to melt in the joining area. The rivet breaks through the metal sleeve and also through the FRP sheet. Due to the melted polyamide matrix, the fibres are movable and can be displaced by the rivet instead of being destroyed. After the rivet is fully penetrated through both sheets, the rivet mandrel is pulled back and the mandrel head forms into the rivet body. In contrast to conventional riveting, no predrilling is necessary and the process is completely free of chip formation. SBR principle can be seen in Fig. 1.

Main process parameters are the following:

- Rivet geometry
- Rotation speed of rivet
- Joining force

One specific property of the joint is the formation of a sleeve due to material displacement in the upper metal sheet. This sleeve can transmit significantly higher shear loads than conventional rivet joints. Furthermore, SBR causes less damage to the fibres of reinforced plastic sheets because the material is heated up above the glass transition temperature of the thermoplastic matrix and fibres can be displaced instead of destroying them.

3 Experimental setup

The experimental setup was developed as shown in Fig. 2. The riveting process is based on a conventional blind riveting gun, but due to reasons of simplicity for the experimental setup, the specimen rotates by a rotary unit instead of the rivet. The joining force is induced by a pneumatic cylinder. Parameter settings are modified by a programmable control unit. In Fig. 2, also a macro section of the used rivet developed by Gesipa is shown. The mandrel head is made of steel and has a conical shape for an optimised penetration. The diameter of the rivet body is 4.8 mm. A support die with a diameter of 22 mm was used at the rotary unit.

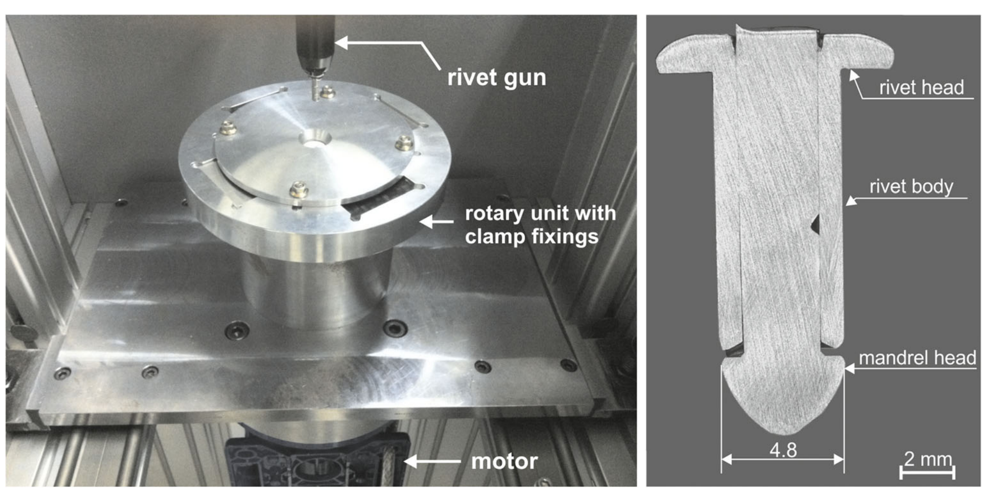

Fig. 2 *Left*: photographs of the experimental setup; *right*: macro cross section of the used blind rivet

Table 1 Used materials and strength level

Name	Description	Tensile strength (MPa)
Aluminium	EN AW-5754 (AlMg3)	190–240
Magnesium	ASTM AZ31B	>240
Plastic	Tepex® dynalite 102-RG600(2)/45 %	390–404

In the present study, aluminium EN AW-5754 and magnesium AZ31 were used as material for the metal sheets. For the FRP, Tepex® dynalite 102 was used which consists of a polyamide 6 matrix and glass fibres in twill weave as reinforcement. The used materials and their tensile strength are listed in Table 1. The sheet thickness for all materials was varied between 1 and 2 mm.

Following experimental investigations were carried out:

- Parameter study (joining parameters)
- Visual evaluation
- Mechanical testing

First of all, possible parameter sets had to be defined for every single material combination. This was carried out by a systematic variation of joining parameters, mainly rotation speed and joining force. The aim was an optimal combination of short penetration time, high process stability and good geometrical properties. To determine process stability and time, joining force and penetration force were simultaneously measured. Beyond process data, joints have been ranked using micro section analysis and visual assessment.

With one optimal set of parameters for every material combination, specimens were fabricated for shear tension tests after [6] (sheet dimensions 25×85 mm, overlap 35 mm) because in further investigations, the specimens have to be compared to joints fabricated by thermal joining in this dimensions. At least five specimens per combination were made and tested to observe their maximum load under shear tension (test device is shown in Fig. 3). In first testing, a guide against buckling was used to guarantee pure shear loading. In further work, tests without this guide will be done to get values for combined loads. The load tests were done with a Zwick Z050 with an extension rate of 1 mm/min. Test results were compared with conventional blind riveted joints. Therefore, the same rivet was used as for Spin-Blind-Riveting, just with predrilling and the use of a conventional blind riveting tool. Furthermore, the fracture behaviour was analysed, especially failure mode and location indicate, if a joint is satisfactory. Possible failure modes are lateral, shear-out and bearing failure (Fig. 3).

4 Results and discussion

In Fig. 4, cross sectional micrographs of a SBR joint between magnesium and GFRP sheet can be seen. Taken together, all material combinations were joint successfully. In high quality joints, rivet mandrel is not deformed during penetration and the sheet material in the joining zone is formed to a uniform sleeve. While aluminium sheets are slightly deflected around the SBR joint, magnesium sheets remain without deformation (Fig. 4). In all tests, the plastic was slightly melted and a flow into the joining geometry was observed. Fibres were partly fractured and partly deflected.

In Fig. 5, a specimen with removed rivet is shown. After separation of the sheets, sleeve formation as well as the slightly melting of the plastic sheet can be seen.

At a rotation speed of 3500 rpm or higher, all joints are of high quality with a stable process time. This rotation speed is recommended for all material combinations. Lower rotation speed can lead to an instable process. Main reason is the lowered friction heat and though a worse plasticization

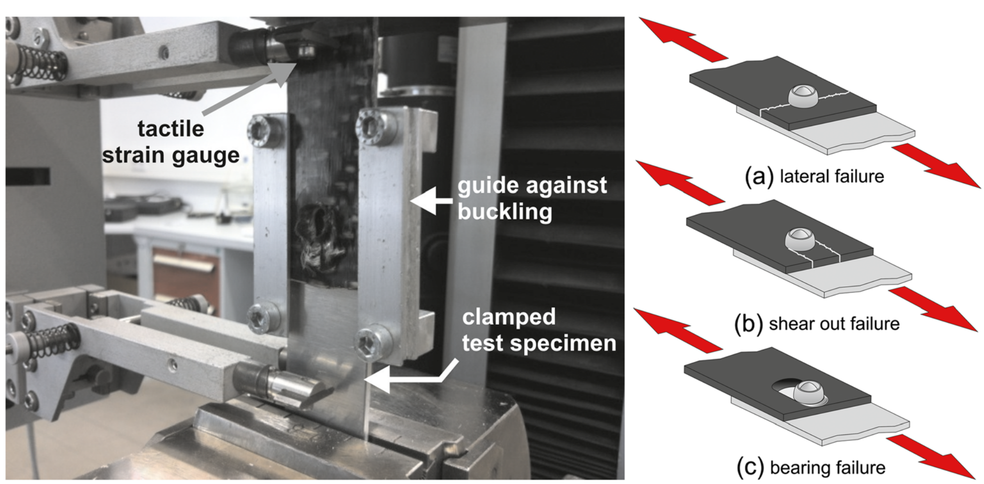

Fig. 3 *Left*: shear tension test; *right*: failure modes related to [7] divided in lateral (*a*), shear out (*b*) and bearing (*c*)

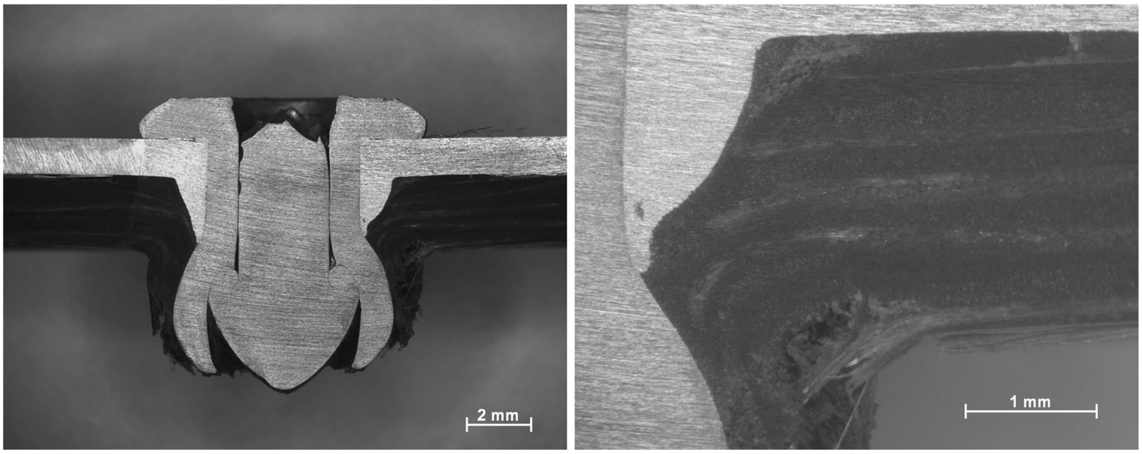

Fig. 4 Cross-sectional micrographs of SBR joint with 1 mm magnesium and 2 mm plastic (*left*: general view; *right*: magnified view of sleeve formation)

especially for magnesium, which needs temperatures of over 200 °C to be formable [8].

At high rotation speed values, joining force can be varied between 800 and 3000 N. This value has no influence on process stability but on the time needed for penetration of the rivet through the sheets. This value describes the span between process start and the time when the rivet head touches the sheets so the rivet has fully penetrated them. Rivet movement and time were measured by the control unit and an inductive displacement sensor. In Fig. 6, the influence of rotation speed and joining force on penetration time can be seen. For a rotation speed of 3500 rpm and higher, the penetration time repeatable with a low deviation of ten percent at constant parameters. At lower rotation speed, the value deviates more strongly due to instable process.

The achieved forces until fracture of SBR joints for shear tension loading compared to conventional riveted joints are given in Fig. 7. It can be concluded that the strength of the joints mainly depends on the thickness of the sheets. All combinations fail in the plastic sheet base material. Characteristic failure appearance can be seen in Fig. 8. The predominant failure mode is of type C, bearing, referring to the different classes given in Fig. 3. Also the force-elongation diagram shows the typical profile of a bearing failure. After reaching

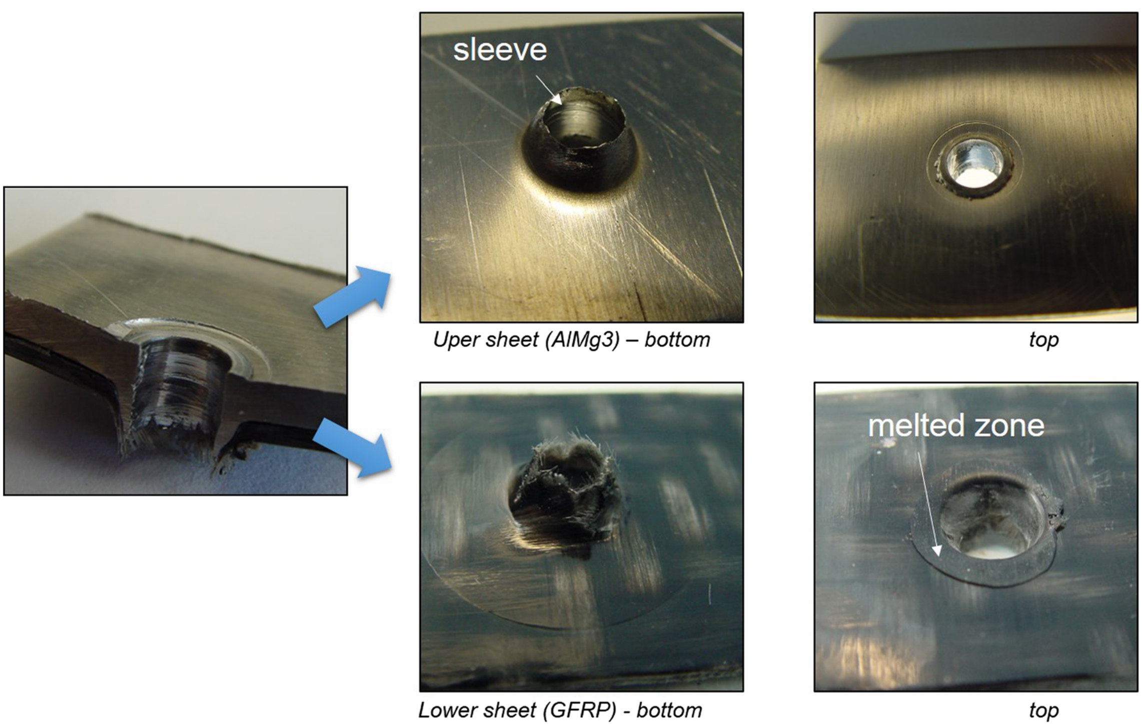

Fig. 5 Separated sheets after SBR process (2 mm aluminium, 1 mm GFRP)

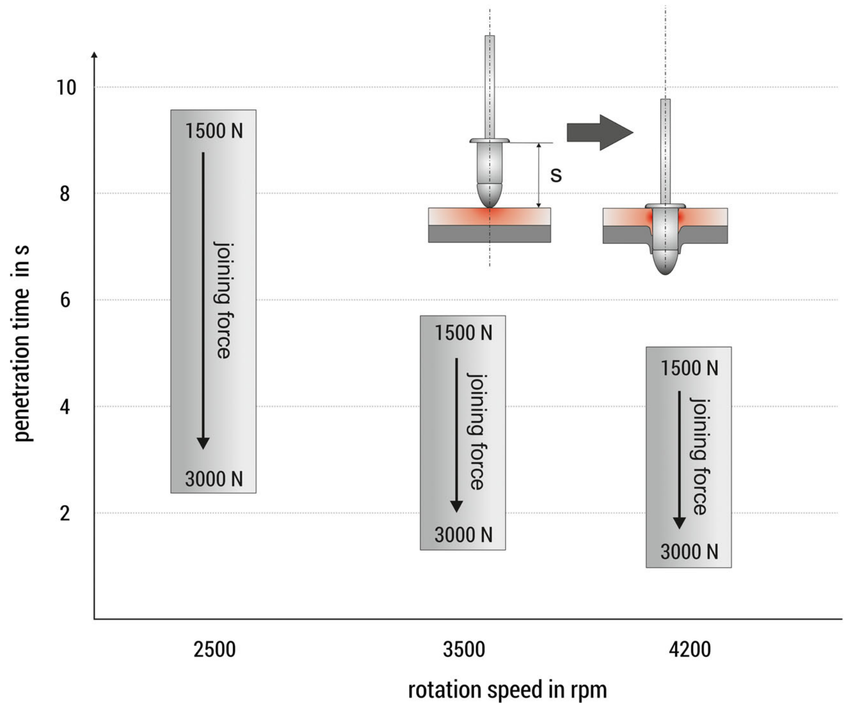

Fig. 6 Penetration time of the rivet through 2 mm aluminium and 2 mm GFRP depending on rotation speed (*x*-axis) and joining force (upper and lower limits of the diagram bars)

the maximum force, the rivet is pulled through the plastic sheet so the joint does not fail in a catastrophic way, but in a gradual way. Compared to conventional riveting, maximum force is up to 68 % higher resulting from the formed sleeve in SBR process. Despite the big differences in strength, the failure mode is identical at SBR and conventional riveted joints. The higher the sheet thickness, the higher the diameter of the sleeve which results in an increased strength. Therefore, joints with high sheet thicknesses have more benefit from the process. For all shear tests with at least five specimens per material combination, standard deviation was under 6 %.

5 Conclusions

1. A new process for joining metal and plastic sheets without the necessity of hole drilling based on blind riveting was

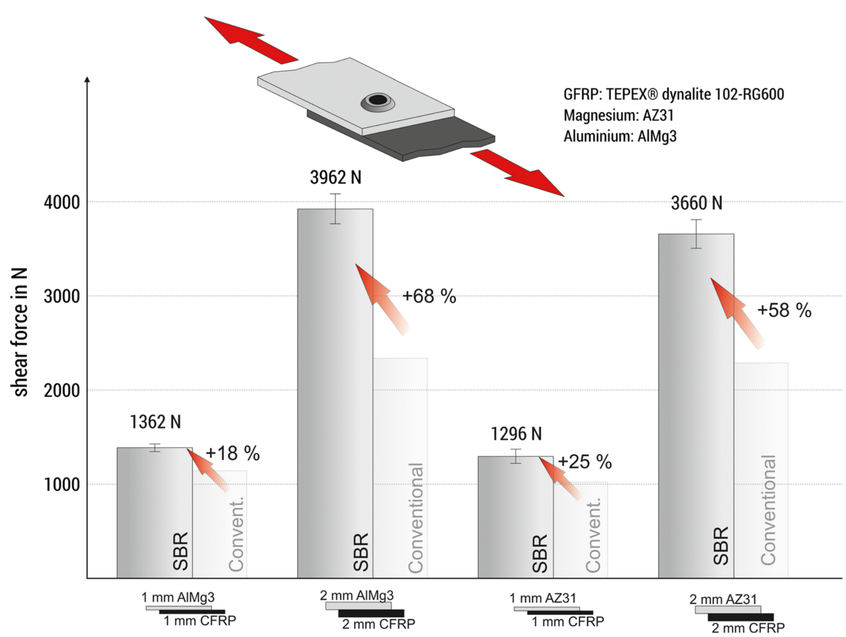

Fig. 7 Maximum forces until fracture on shear tests for the combination of aluminium or magnesium and plastic

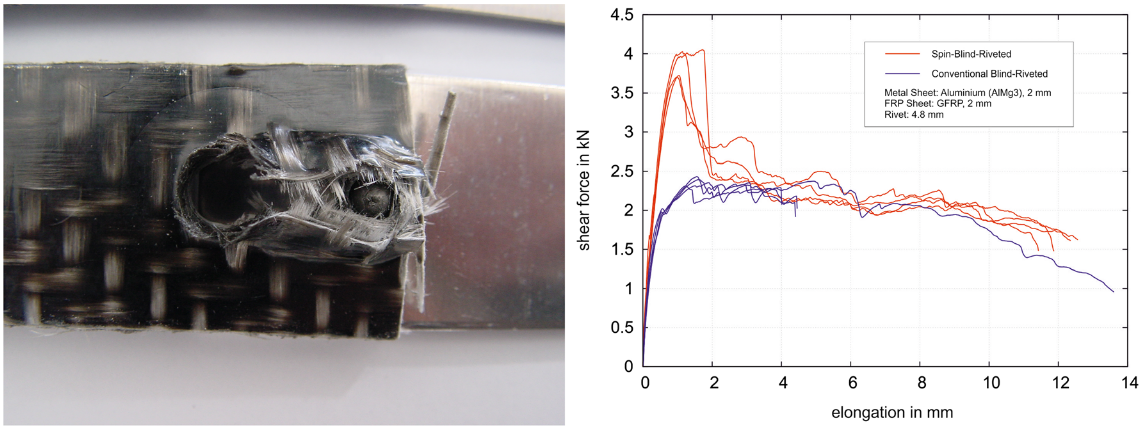

Fig. 8 *Left*: fracture appearance for shear test; *right*: force-elongation diagram for 2 mm aluminium and 2 mm GFRP

developed. A large number of metal (Al, Mg) to plastic joints were successfully riveted using an experimental setup.

2. Magnesium and aluminium sheets can be safely joined with fibre-reinforced plastic in process times of a few seconds
3. The joining parameters, rotating speed, joining force and preheating time can be varied in a wide range. Rotating speed should not be less than 2500 rpm. With a joining force from 800 up to 3000 N, it is possible to use the process with automated systems like industrial robots.
4. The joints show good strength properties at small standard deviation so that this process becomes attractive for use in applications with high demands in reliability.

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