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Review

Quality of self-piercing riveting (SPR) joints from cross-sectional perspective: A review

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ABSTRACT

Self-piercing riveting (SPR) is a method used for joining sheet materials by creating a mechanical interlock between the sheets. SPR is of increasing interest in automobile industries due to its suitability for joining lightweight, high strength and dissimilar materials. The quality of an SPR joint from cross-sectional perspective is primarily characterized by the amount of mechanical interlock known as rivet flaring. Other parameters, such as rivet head height, bottom thickness and effective length of the rivet in the bottom sheet are also considered as quality parameters. However, the many factors that determine the quality of an SPR joint are poorly described in the literature and, as a consequence, the opportunities to develop new product and optimize the process are limited. In this paper, several of the key parameters that affect the quality of an SPR joint are described and some assistive technologies that have the potential of improving the quality of a joint are discussed. This is a zone in the field of SPR joining which has plenty of research opportunities. Innovative progress will be achieved by a combination of techniques, together with industrial trials and laboratory simulations.

1. Introduction

The SPR process is used to attach similar or dissimilar sheet materials (Fig. 1) [1]. In this process a rivet penetrates the top sheet and creates an interlock between the top and bottom sheets by flaring the legs without perforating the bottom sheet. The spreading of the rivet leg is guided by its internal geometry [2] and by a die which is positioned below the bottom sheet [3]. A water tight seal is created as no piercing of the bottom sheet occurs and the forming joint is resistant to liquid and gas and, therefore, corrosion resistant [4]. Multiple material stacks with mixed materials and different grades can be joined by SPR and the inclusion of interlayered adhesive and sealant [5] is possible to improve the joint quality. The process is also able to join steel of up to 7 mm thick and aluminium of up to 12 mm thick [5]. The key advantages of SPR are listed in Table 1.

Although SPR has many advantages, there are a few disadvantages. SPR requires access to both sides of the joint and the button created by the joint may not be aesthetically acceptable [16]. An additional concern is that there is very limited performance data is available in the open academic

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Nomenclature

b	bottom thickness
BS	bottom seal
D_0	initial rivet diameter
D_d	die diameter
D_h	rivet head diameter
D_t	deformed rivet diameter
t_1	top sheet thickness
t_2	bottom sheet thickness
t_{eff}	effective length of the rivet in the bottom sheet
TS	top seal
u	under-cut
W	web thickness of rivet
x	rivet flaring
Y	head height
Z	die depth

literature [17]. Finally, the factors which affect the quality of SPR joints are poorly understood. More attention is needed in this intellectually challenging area.

This paper reviews/presents the unresolved issues in SPR joint formation and suggests ways to improve joint quality. A Scopus [18] search with key words ''self-piercing riveting'' and ''self-piercing rivet'' revealed 330 documents published between 2005 and 2017. The documents cited in this paper were chosen primarily from a cross-sectional quality perspective of SPR joints.

2. SPR joint quality

In general, the quality of an SPR joint is evaluated by examining a cross-section in the lab before the production. Fig. 2 shows the many possible attributes of an SPR joint and an SPR joint should have the four quality features (Table 2) and as shown in Fig. 2.

There are several factors known to affect the quality of SPR joint including die, rivet, punch materials and blank holder (Fig. 3).

2.1. Die

The optimization of the SPR process is achieved by altering the die parameters [23]. Die selection mainly depends on the ply materials hardness and thickness. A high die recess volume is required for a thick combination of joint in order to accumulate the large volume of the deformed material [24]. Generally two types of dies are used: flat and profiled. Profiled dies are mainly used for joining of soft material and to achieve a high rivet flaring; flat dies are mainly used for joining of hard sheet materials. In flat dies, diameter and depth are considered as the process parameters whereas in profiled dies two additional parameters are considered: height and sharpness of the die pip [21] (Fig. 4).

A die can greatly increase the joinability by increasing the rivet flaring and reducing crack in the bottom sheet [25]. For example, the effective length of the rivet in the bottom sheet (t_{eff}) increases with the increase in die depth for a flat die [14]. However, a deeper die may create cracks in the bottom sheet for low ductile materials. Haque et al. [14,26] showed that, for the same thickness of materials (2.5 mm + 2.5 mm), a 2.3 mm deep die (10 mm diameter) produced a crack-free joint for G300 (yield strength 300 MPa and hardness 198 HV) steel but severe cracks were observed for G450 (yield strength 450 MPa and hardness 270 HV) steel. The joint was optimized by using a shallower die (2.35 mm deep) with a larger diameter (11 mm). It should be noted that by optimizing the die parameters not only the cracks were reduced but also better rivet flaring (x in Fig. 2) was achieved. However, a lower static strength was observed for the same joint (2.5 + 2.5 mm G300) when a shallower (2.35 mm instead of 3.0 mm deep die) die was used [27]. Thus, it is recommended that a deeper die should always be used for relatively soft materials and a shallow die should be used when the ductility of the materials is reduced. The relationship between the rivet flaring (x) and the effective length of the rivet in the bottom sheet (t_{eff}) is unknown. We consider that there is a relationship between the rivet head height (Y), rivet flaring (x) and effective length of the rivet in the bottom sheet (t_{eff}) for the same process parameters because all the plastic deformation occurs within the enclosed die volume.

The joinability can also be increased by changing central pip height and sharpness for a profiled die. For example, rivet spread ratio (RSR), which is defined by the ratio of deformed and undeformed rivet diameter ($RSR = D_t/D_0$, Fig. 2), can be increased by using a sharp die pip. The above phenomenon/relationship was verified both experimentally [19,21] and numerically [28,29]. The amount of rivet flaring is measured by the difference between deformed and undeformed rivet

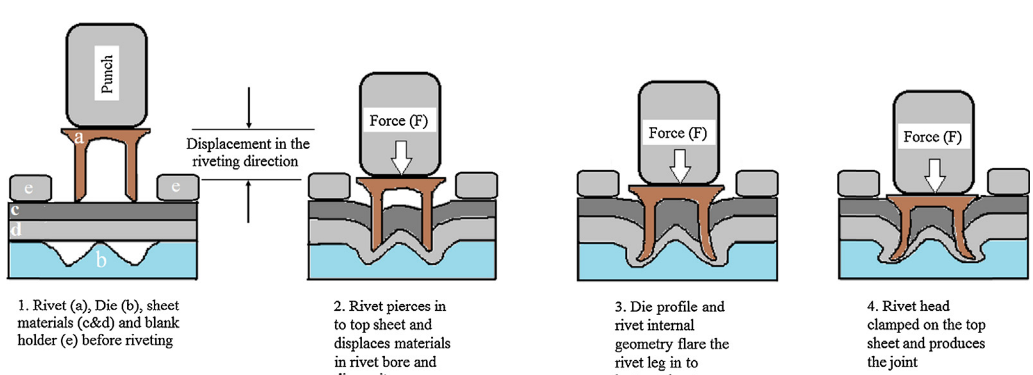

Fig. 1 – Mechanism of joint formation in SPR process; adapted and reprinted with permission [15].