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Technical Paper

Experimental investigation of the mechanical reshaping process for joining aluminum alloy sheets with different thicknesses

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ABSTRACT

In recent years, mechanical clinching technology has attracted more and more attentions. However, the high protrusion on the clinched joint may limit the application of the mechanical clinching technology. In the present study, a reshaping method for the clinched joint with different sheet thicknesses to reduce the protrusion height was investigated. The reshaping process is a complementary process for the clinched joint. A flat die and a bumped die were used to reshape the clinched joint. Al5052 aluminum alloy sheets with thicknesses of 2.0 mm and 2.5 mm were used in the present study. The interlock between the sheets was not damaged, and the sheets were still joined together after the reshaping process. The geometrical parameters, failure mode, tensile strength, shearing strength and energy absorption of the joints were investigated by experimental method. The neck thickness of the joint can be enlarged by the material flow in the reshaping process. Neck fracture mode is the main failure mode of the joint in this study. The reshaped joint produced by the Al5052 sheet with a thickness of 2.5 mm (upper sheet) and the Al5052 sheet with a thickness of 2.0 mm (lower sheet) has the highest average strength, and the clinched joint produced by the Al5052 sheet with a thickness of 2.0 mm (upper sheet) and the Al5052 sheet with a thickness of 2.5 mm (lower sheet) has the lowest average strength. The reshaping process not only can reduce the protrusion height, but also can contribute to increase the strength and energy absorption of the joint.

1. Introduction

For reducing the weight of the automotive body, some lightweight materials such as aluminum alloy and magnesium alloy are widely used on the automotive engineering [1–3]. However, it is difficult to join aluminum alloy by welding because of the natural surface oxide layer and high thermal conductivity [4,5]. In recent years, some mechanical joining technologies, such as mechanical clinching and self-pierce riveting, have been developed rapidly to join the lightweight materials [6–9].

A rivet is required in the self-pierce riveting process, which may increase the weight of the joint. Compared with mechanical clinching technology, self-pierce riveting process needs a higher forming load. In addition, the upper sheet will be impaled by the rivet, which may damage the sheet. There is no additional element needed in the mechanical clinching process [10,11]. Without the additional rivet, the weight of the clinched joint is lower than that of the self-pierce riveted joint.

A geometrical interlock is produced between the sheets by the material flow in the mechanical clinching process [12–14]. The sheets can be hooked together by the interlock [15]. The mechanical clinching technology has many advantages, such as low run time, cleanness of the process, simplicity and absence of subsidiary materials [16,17]. Plastic deformation is generated to produce the clinched joint [18,19], so the chemical characteristics of the materials have little effect on the quality of the joint.

The clinched joint is produced by the plastic deformation, so the mechanical strength of the clinched joint mainly depends on the joint geometry [20]. The joint geometry is mainly influenced by the geometrical parameters of the punch and dies, so many scholars conducted research on the study of the dies geometry. The effects of dies geometry on the clinched joint characteristics: neck thickness, interlock and maximum cross-tensile strength are inves-

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tigated [21]. In the parametrical study, the Taguchi method is used to design the experiments to investigate the mechanical clinching process with different geometrical parameters and levels. The cross-tensile strength of the clinched joint can be greatly increased by optimizing the dies geometry. Finite element analysis was performed to investigate the lock forming mechanism of the clinched joint [22]. In this study, the lock shape and parameters were influenced significantly by the die construction shape and geometrical parameters, especially the groove of the fixed die.

Mechanical clinching technology is used to join various material sheets [23]. Many materials, such as metals (aluminum [24], steel [25], titanium [26], magnesium [27]), polymers [28,29], composites with different fibers [30–33], and wood [34] have been successfully joined by mechanical clinching. The round clinching dies were used to join high strength structural steel [35]. In this study, 11 different clinching methods were investigated and proved to be effective. The experimental results showed that a round die was appropriate for all the high strength structural materials tested. The mechanical clinching method was applied to join aluminum alloy and high strength steel sheets [36]. The high strength steel sheets are easy to fracture around the corner where the sheets undergo larger plastic deformation because of the small ductility. In order to avoid the defects, the clinching dies were optimized to control the material flow of the steel sheets. Ductility of the material influences the probability that the sheets will fracture in the mechanical clinching process. Circumferential cracks may be produced during the offsetting phase, and radial cracks may be produced during the subsequent upsetting phase and flow pressing phase [37].

The mechanical properties of the clinched joint are also investigated in recent years. The tension-shearing strength and energy absorption of different clinched joints were investigated in the failure process [38]. The clinching-bonded hybrid joints and the traditional clinched joints were compared in terms of the strength and energy absorption. An experimental investigation was conducted on the mechanical clinched joints realized with the extensible dies and fixed dies under different forming conditions [39]. Absorbed energy, stiffness, maximum cross-tensile and tension-shearing strength of the joints with different dies were investigated. The results showed that the clinched joints with the extensible dies have better mechanical performance than those with the fixed dies. An analytical model was built to predict the strength of the clinched joint [40]. Cross-tensile strength could be estimated by the analytical method.

However, there is a high protrusion on the clinched joint, which may limit the use of the mechanical clinching technology in the visible areas. It is required to show a smooth surface on the automobile body. A new joining technology named dieless clinching was proposed to form a lower protrusion [41]. However, the movement of the punch should be controlled precisely in the joining process, which may increase the complexity of the operation. Another joining technology named flat-clinching was also investigated to produce the joint without a protrusion [42]. A reshaping rivet was optimized to reduce the protrusion height and increase the strength of the clinched joint [43,44]. This method was proved to be effective. However, an additional rivet was required in the mechanical reshaping process, which may increase the weight of the joint. Another reshaping method without additional elements was also proposed [45]. This method is effective to reduce the protrusion of the joint, but the strength of the join cannot be increased obviously. It is important to explore some new joining method to reduce the height of the protrusion. In addition, the metal sheets with different thicknesses are used to build the automotive body [46,47]. The mechanical joining of the sheets with different thicknesses also should be investigated.

In order to reduce the protrusion height, a reshaping method for the clinched joint with different sheet thicknesses was investigated

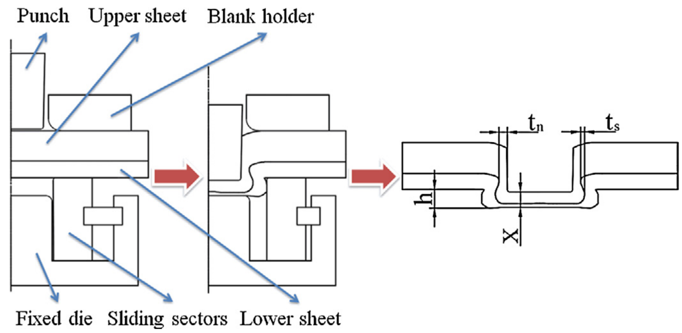

Fig. 1. Mechanical clinching process.

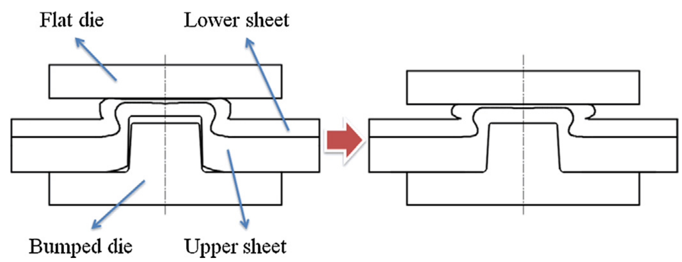

Fig. 2. Mechanical reshaping process.

in this paper. The reshaping process is a complementary process for the clinched joint. A flat die and a bumped die were used to reshape the clinched joint. Al5052 aluminum alloy sheets with thicknesses of 2.0 mm and 2.5 mm were used in the present study. The interlock between the sheets was not damaged, and the sheets were still joined together after the reshaping process. The geometrical parameters, failure mode, tensile strength, shearing strength and energy absorption of the joints were investigated by experimental method. The reshaped joint can be used in the visible areas where a lower protrusion is required.

2. Principle of the joining process

2.1. Mechanical clinching process

As shown in Fig. 1, the clinched joint is produced after the mechanical clinching process. Extensible dies are used to perform the mechanical clinching process. The extensible dies consist of the punch, fixed die, blank holder and sliding sectors. The punch can move downward to press the sheets to generate localized plastic deformation between the sheets. An interlock between the sheets can be produced by the plastic deformation. With the mechanical interlock, the upper sheet and the lower sheet can be hooked together with a high strength. Neck thickness (t_n), interlock (t_s) and bottom thickness (X) are three main geometrical parameters of the joint. The sheets are joined together by the mechanical structure, so the geometrical parameters of the clinched joint have an important influence on the tensile strength, shearing strength and energy absorption of the joint. After the mechanical clinching process, a high protrusion (h) is produced on the clinched joint.

2.2. Mechanical reshaping process

The high protrusion will limit the use of clinched joint in the visible areas. In order to reduce the protrusion height, a mechanical reshaping process is performed to reshape the clinched joint. As shown in Fig. 2, a flat die and a bumped die are used in the mechanical reshaping process. The flat die is taken as the top die, and the bumped die is taken as the bottom die. Firstly, the clinched joint is