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Investigation of mechanical behavior of the reshaped joints realized with different reshaping forces

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ABSTRACT

In recent years, mechanical clinching has drawn more and more attentions in the field of thin-walled structures. However, the exterior protrusion on the joint may restrict the use of this joining technology in the visible areas. A reshaping method was investigated to reduce the protrusion height in this paper. The protrusion was compressed by a pair of flat dies in the reshaping process. The neck thicknesses, interlocks, bottom thicknesses, protrusion heights and diameters of the reshaped joints with different reshaping forces were gotten to show the material flow of the joints. All the neck thickness and interlock were enlarged with the decrease of the protrusion height. When the reshaping force was set to 30 kN, the protrusion height was reduced from 1.69 to 0.38 mm. The average cross-tensile strength was increased from 986.5 to 1133.8 N, and the average tension-shearing strength was increased from 1536.4 to 2285.9 N. Neck fracture mode was the main failure mode in the strength tests. The cross-tensile strength, tension-shearing strength and energy absorption of the reshaped joints are all higher than those of the clinched joint. The reshaping method was proved to be reliable and effective.

1. Introduction

In order to reduce the weight of engineering structures and compounds, aluminum alloys have been widely applied in the engineering field. However, it is difficult to join aluminum alloy sheets by spot welding because of the oxide layer on the sheet surface, low melting point, high thermal conductivity, etc. [1–3]. In recent years, mechanical clinching technology has drawn more and more attentions because of its superior mechanical properties [4–8]. This joining technology can be used in manufacturing thin-walled structures, especially in the automotive field. Local metal deformation is generated between two or more sheets to make the sheets joined together in the mechanical clinching process. In the joining of lightweight metal sheets, which may be dissimilar or coated, mechanical clinching has more advantages than the spot welding. Moreover, unlike other traditional joining methods, mechanical clinching does not use additional inserts which may increase the weight of the joint.

Mechanical clinching technology has been used to join various material sheets [9,10]. Titanium sheets which have excellent ductility, strength, and corrosion resistance have been widely applied in the aerospace engineering. The titanium sheets and other metal sheets can be joined together by the mechanical clinching technology [11]. The joining of titanium sheets and other metal sheets also has a high application value in aerospace engineering and metallurgical industries. Hybrid polymer-metal structures are widely used in automotive, transport and naval industries in recent years [12]. It is difficult to join polymer sheet and metal sheet by spot welding. However, mechanical clinching technology can be used to join the polymer sheet and metal sheet [13]. The glass fiber reinforced polymer sheet and aluminum sheet were joined together by the mechanical clinching method [14]. Different dies including split, grooved, flat, and rectangular dies were investigated to join AA6082-T6 sheet and polymer sheet [15]. The polymer-metal hybrid joint produced by round split dies has the best performance in the shear and peeling tests. Magnesium sheets can be joined by dieless clinching process and dieless rivet-clinching process to decrease the heating time [16]. The joining of high strength structural steel sheet and aluminum sheet is widely used in the automotive structures. Mechanical clinching technology also can be used to join high strength structural steel sheet and aluminum sheet with a high strength [17,18].

The ductility and formability of the sheet have an important influence on the mechanical clinching process [19]. A localized deformation occurs near the punch round corner in the mechanical clinching process. Reduced ductility of the material and improper geometrical parameters of the clinching dies may lead to the cracks on the neck of the upper sheet. Two effective solutions to solve the problem are the preheating of the metal sheets and optimization of the geometrical parameters of the clinching dies

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[20,21]. The preheating process can increase the formability of the metal sheets. The pre-straining of the sheets may result in the work hardening which decreases the ductility of the metal sheets [22]. A good balance between the neck thickness and interlock should be achieved by optimizing clinching dies and the process parameters. Numerical model describing the ductile damage has been developed to optimize the geometrical parameters of the clinching dies so as to improve the mechanical properties of the clinched joint [23].

Conventional mechanical clinching has many advantages, such as no pre-treatment process, no smoke, no spark, no damage on the sheet surface and so on. This joining technology will be widely applied to join metal sheets in the engineering field. In the mechanical clinching process, localized plastic deformation of the two sheets is generated in the cavity of the extensible die. So there will be a high protrusion above the sheet. Because of the obvious protrusion, the use of clinched joint will be restricted in the visible areas and functional surfaces where a relatively lower protrusion height is needed. It is important to explore some new joining or reshaping technologies to reduce the protrusion height.

Flat-clinching technology was developed at Chemnitz University of Technology to join sheets with a flat plane in recent years [24]. There is no protrusion on one surface of the joined sheets. By controlling the force and displacement of the punch and blank holder, dieless joining technology also can produce a joint with a lower protrusion [25]. A reshaping method was used to get a lower protrusion of the clinched joint [26]. A pair of contoured dies should be designed and produced specially for the reshaping process.

In order to reduce the protrusion height, a reshaping method by compressing the protrusion with flat dies was investigated in this paper. The neck thicknesses, interlocks, bottom thicknesses, protrusion heights and diameters of the reshaped joints with different reshaping forces were gotten to show the material flow of the joints in the reshaping process. The strength, failure mode and energy absorption of the clinched joints after reshaping were investigated by experimental method. The reshaping method is a helpful supplement of the mechanical clinching process. It can be used in the areas where a lower protrusion height of the joint is needed.

2. Mechanism of the mechanical clinching and reshaping technology

Fig. 1 illustrates the mechanical clinching process to form a clinched joint. In the mechanical clinching process, extensible dies are used to generate an appropriate localized plastic deformation between the metal sheets to form the joint. An interlock is generated between the top sheet and the bottom sheet. The two sheets are hooked by the interlock. The extensible dies consist of the fixed die anvil, punch, blank holder and movable die sectors. The parameters of the extensible dies have important influence on the profile and geometry of the clinched joint. The cross-tensile strength, tension-shearing strength and energy absorption depend mainly on the profile and geometry of the clinched joint. Neck thickness (t_n), interlock (t_s) and bottom thickness (X) are the three main parameters of the clinched joint. An initial clinched joint is formed in the mechanical clinching process.

Fig. 2 illustrates the subsequent reshaping process to compress the clinched joint. In the reshaping process, a pair of similar flat dies which have simple structures is used to compress the protrusion on the bottom sheet. Plastic deformation occurs mainly in the joint, so blank holder is not needed. Firstly, the connected sheets which are joined by the mechanical clinching are placed on the bottom flat die. The protrusion side is adjusted toward the center of the top flat die. Secondly, a maximum force is set as the stop condition on the top die, then the top flat die is controlled to move down to compress the protrusion with a uniform velocity. When the force of the top die achieves the pre-set value, the top flat die stops moving. The profile and geometry of the joints are modified with the reduction of the protrusion height in the reshaping process. The top sheet and bottom sheet are still hooked with each other at the joint.

3. Procedure of experiment

3.1. Specimens preparation

In recent years, Al5052 aluminum alloy which is an excellent structural alloy is widely used in different applications including civil, transport, automobile structure as well as drink vessels. The metal sheets used in present study were Al5052 aluminum alloy plates with a nominal thickness of 1.85 mm. All the sheets used for mechanical clinching were cut from a unique plate along the initial rolling direction. The Al5052 sheets used in the tests were cut into rectangular strips with 25 × 80 mm (width × length). The chemical components of Al5052 sheet materials used in the study are shown in Table 1. The mechanical properties of Al5052 were measured on Instron 5982 testing machine. According to the testing results, the poisson's ratio of the material Al5052 is 0.33, the tensile strength is 235.2 MPa, and the elastic modulus is 62.7 GPa. Material flow stress is described by Hollomon model as $\sigma = 351\ \varepsilon^{0.12}$. The elongation at break is 18%. Al5052 aluminum alloy sheets have excellent ductility, which is an essential

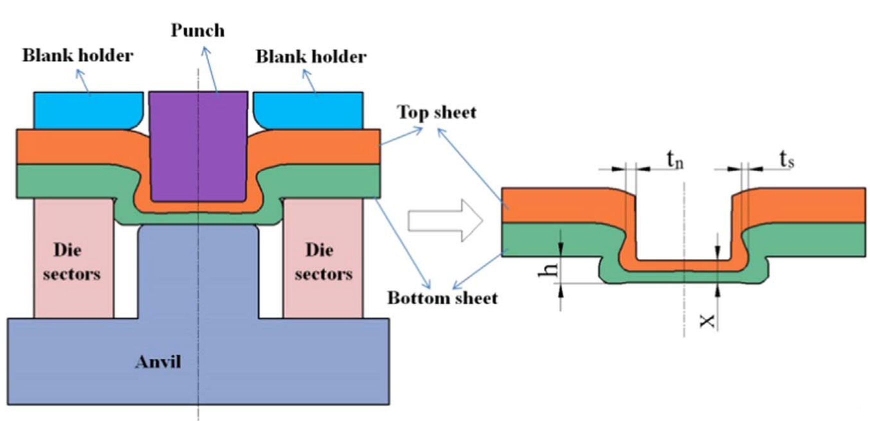

Fig. 1. Mechanism of mechanical clinching technology.