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Mechanical properties of the two-steps clinched joint with a clinch-rivet

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ABSTRACT

In the present study, mechanical properties of the two-steps clinched joint with a clinch-rivet were investigated. The two-steps clinching method includes two steps, mechanical clinching and upsetting with a clinch-rivet. The protrusion of the joint was upset to reduce the protrusion height with different upsetting forces. This method contributed to increase the strength and reduce the protrusion height of the clinched joint. Extensible dies were used to perform the mechanical clinching process, and a pair of flat dies was used to perform the upsetting process. AL6061 sheets were used to carry out the experiment. The upsetting forces were set to 25, 30, 35, 40 and 45 kN respectively to generate different two-steps clinched joints. Forming force, geometrical parameters, material flow and mechanical properties of the two-steps clinched joint were investigated by an experimental method. According to the achieved results, the cross-tension and tension-shearing strengths of the two-steps clinched joints with different upsetting forces were all higher than those of the conventional clinched joint. The strength of the two-steps clinched joint with an upsetting force of 35 kN was the highest of all. The average cross-tension strength of the two-steps clinched joints with an upsetting force of 35 kN was increased by 25% compared with the conventional clinched joints, while the average tension-shearing strength of the two-steps clinched joints was increased by 128%. The two-steps clinched joint could absorb more energy than the conventional clinched joint in the failure process. The two-steps clinching method was proved to be effective and reliable.

1. Introduction

In order to reduce the automobile weight, various high strength low density metal alloys are used to build automobile body. Aluminum alloy is the most widely used low density alloy in automobile body panels. The use of aluminium alloy sheet is more and more because of its low density and anti-corrosion property. Welding and adhesive bonding can be used to join aluminium and steel. Zhang et al. (2015) used MIG-TIG double-sided arc welding-brazing to join steel and aluminium. However, it is not suitable for welding method to join coated sheets. A clean surface of the sheet is required in the adhesive bonding process, and adhesive is also required as auxiliary. The cost of production may be increased by these requirements.

Self-pierce riveting has been widely used to join metal sheets in recent years. Cai et al. (2005) investigated the assembly dimensional prediction for joining aluminium sheets by self-pierce riveting. Calabrese et al. (2015) investigated the failure of the joint produced by self-pierce riveting after salt spray test. The corrosion degradation has an important influence on the failure behaviour of the joint. Xing et al. (2015) investigated the joints produced by mechanical clinching and self-pierce riveting. The results showed that the joint produced by self-pierce riveting has superior static strength.

Mechanical clinching is a metalworking process which can connect aluminium alloy sheets effectively without any splashes, flashes or harmful light. Moreover, mechanical clinching can be used to join coated sheets with no damage to the surface. Jiang et al. (2015) used mechanical clinching to join AA6111 aluminium and galvanized SAE1004 steel. Consequently, mechanical clinching has become a hot topic in the academic research of joining technology.

He et al. (2015) investigated the energy absorption, failure modes and load-bearing capacity of different clinched joints with extensible dies. Mucha and Witkowski (2014) investigated the

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strength of the clinched joints with different forming technology and load conditions. Xu and Zhao (2014) used different materials including the Q235, AL5052, and AL6061 to study the strength of the round clinched joint which may be affected by the tool geometry, mechanical properties of the material and sheet thickness. Lee et al. (2010) proposed a new design method of mechanical clinching dies to join aluminium alloy sheets. Kim (2013) conducted static and fatigue tests to evaluate the strength of the mild steel clinched joints.

The common problem of joining aluminium alloy or high strength steel (highly employed in automotive industries) is represented by the material formability and development of cracks during the joining process. Lambiase et al. (2015) used mechanical clinching method to join aluminium alloy sheets with reduced ductility. The sheets were preheated to increase the material formability, which was proved to be effective to prevent the cracks on the joint. Abe et al. (2014) investigated the joining of high strength steel with low ductility by mechanical clinching. The clinched joint with high strength steel sheets has superior fatigue strength. Lambiase (2015a) investigated the material flow and mechanical properties of the joint with heat-treatable AA6082-T6 sheets. The material flow was improved by the pre-heating condition, and the mechanical properties of the joint were enhanced.

In order to prevent the crack on the joint, some failure and damage behaviour of the clinched joint should be investigated. Lambiase and Di Ilio (2016) built a damage model to predict the fracture during the joining of AA6082-T6 by mechanical clinching. The model was validated experimentally and proved to be effective. It is significant to improve the mechanical properties of the clinched joint by optimizing the clinching dies. Zhao et al. (2014) used modified Rousselier model to investigate the failure behaviour of the joint by numerical and experimental methods. The model could capture the failure behaviour of the joint effectively.

In addition, the mechanical clinching can also be used to join nonmetal sheets. Lambiase (2015b) used mechanical clinching method to join polymer sheet and metal sheet with different tools, such as grooved, flat, split and rectangular dies. Round split dies had a better performance for joining polymer sheet and metal sheet. Lambiase and Di Ilio (2015) investigated the clinching process of plastic-metal hybrid joint. The mechanical properties of the joints with different operating conditions were assessed by the tension-shearing tests.

Mechanical clinching has many advantages in joining various materials, such as aluminium, magnesium, titanium and high strength steel. It will be more widely used in the automobile body panels. However, it is important to show a smooth appearance on the automobile body. The high protrusion above the clinched joint may restrict the application of conventional mechanical clinching on the automobile body. Conventional mechanical clinching cannot be applied in the functional surfaces and visible areas where a lower protrusion height is required. It is meaningful to explore new methods to reduce the exterior protrusion height.

Gerstmann and Awiszus (2014) introduced recent developments in flat-clinching which can create a one-sided planar surface. There is no protrusion extending out of the sheet by using this joining technology. However, a larger force is required on the blank holder to fix the sheets in the flat-clinching process. The flat-clinching process is a backward extrusion process. The material flow for producing the interlock is in the opposite direction with the movement of the punch. Without the larger force on the blank holder, the material will flow to other directions, which cannot produce the interlock. Neugebauer et al. (2008) introduced the development and application of dieless mechanical joining method which can produce a lower protrusion on the surface of the sheet. Nevertheless, it is complex to control the movements of the punch, blank holder and anvil. In order to reduce the protrusion height, Wen et al. (2014) used a pair of contoured dies to reshape the clinched joint by upsetting the protrusion. However, the upsetting dies which are complex should be designed specially.

In the current study, a two-steps clinching method was investigated. AL6061 sheets were used to produce the clinched joint. In the first step, a clinched joint was produced by the mechanical clinching method. In the second step, the clinched joint was reshaped with a clinch-rivet by upsetting the protrusion extending out of the joint. Extensible dies were used in the mechanical clinching process, and a pair of flat dies was used in the upsetting process. The clinch-rivet which was embedded in the pit of the joint was applied to control the material flow in the second step. The upsetting forces were set to 25, 30, 35, 40 and 45 kN respectively to generate different two-steps joints. Forming force, geometrical parameters, material flow and mechanical properties of the two-steps clinched joint were investigated by an experimental method. The two-steps clinching method can be applied in the functional surfaces and visible areas where a lower protrusion height and higher joint strength are required.

2. Mechanism of two-steps clinching

The two-steps clinching method is an improvement of conventional mechanical clinching. The process of the two-steps clinching is shown in Fig. 1. It includes two steps, mechanical clinching and upsetting with a clinch-rivet.

In the first step, a conventional clinched joint is created using mechanical clinching method with extensible dies. The extensible dies consist of the punch, blank holder, sliding sectors, ring rubber and fixed die. Lambiase and Di Ilio (2013) investigated the material flow in the mechanical clinching process. The main deformation of the joint is produced in the cavity volume which is surrounded by the punch, sliding sectors and fixed die. The purpose of the deformation is to generate a mechanical interlock between the sheets. Initially, the punch is controlled to move downward to upset the sheets as shown by the red arrow. The displacement of the punch is controlled strictly to get an appropriate bottom thickness. Then the metal sheets tend to deform along the movement direction of the punch after the punch contacts the upper sheet. The material flow will push the sliding sectors to slide along the radial direction as shown by the blue arrow. The cavity volume is enlarged with the movement of the sliding sectors. The sheets material will spread along the radial direction after the lower sheet contacts the fixed die. The punch continues moving downward until the mechanical interlock is produced between the upper and lower sheets. The ring rubber was used to make the sliding sectors return to the original position after mechanical clinching process. The interlock is used to join the upper and lower sheets together.

In the second step, the conventional clinched joint is reshaped by upsetting the protrusion. A pair of flat dies is used in the second step. Initially, the conventional clinched joint is placed between the dies after the clinch-rivet is embedded in the pit of the clinched joint. The lower flat die is fixed and the upper flat die is controlled to move downward to upset the protrusion as shown by the green arrow. The clinch-rivet which can control the material flow of the joint is also upset to enlarge the interlock. The protrusion height is reduced by upsetting the protrusion with different upsetting forces. Then the two-steps clinched joint is generated with a lower protrusion height. The upsetting force on the upper die was controlled strictly to produce the two-steps clinched joint.

The first step, conventional mechanical clinching, has been studied by many scholars form different aspects. The clinching method has been approved effective. However, for the second step, upsetting with a clinch-rivet, there is still a lack of depth and systematic