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Clinch-bonded hybrid joining for similar and dissimilar copper alloy, aluminium alloy and galvanised steel sheets

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ABSTRACT

Clinch-bonded hybrid joining technology has been applied increasingly in different manufacturing disciplines. In this study, specimens of both similar and dissimilar sheets of H62 copper alloy, aluminium alloy and galvanised steel sheets were prepared in single-lap and T-joints. Tensile-shear tests and peeling tests were carried out for studying the load-bearing capacity and energy absorption of different clinch-bonded hybrid joints. The failure fractures were studied by a scanning electron microscope to characterise the different failure modes. Results show that the shear strength of the specimens, which results mainly from the adhesive, is better than their peeling strength, which is closely related to clinched structures. The mixed neck fracture exhibited the highest shear strength, and a better ability to absorb energy could be obtained by decreasing the material strength of the lower sheets in the tensile-shear test. In the peeling test, it was found that the best energy absorption ability could be achieved by the failure mode of upper sheet tearing, and improving the strength of the lower sheets resulted in greater joint peeling strength.

1. Introduction

In the present manufacturing engineering industry, a variety of metallic materials are used to satisfy the different working environments and requirements. Copper and copper alloys, which possess excellent electric and thermal conductivity, good process forming, and corrosion resistance, are widely used in industrial fields such as electronic engineering and mechanical manufacturing [1]. Along with rapid industrial development, as well as increasingly severe energy and environmental problems, lightweight becomes a matter of concern in designing and manufacturing process. Aluminium alloys characterises low density and high strength, and it has easy access to lightweight [2]. Because of its low cost and reliable performance, steel constitutes a large proportion of industrial materials used in the world even today [3]. Nowadays, these metals are largely chosen for use in aerospace and automotive engineering, as well as other manufacturing disciplines. To enable the reliable joining of materials, and to make full use of the excellent properties of dissimilar materials, it is necessary to research material joining of dissimilar sheets.

Welding is nowadays the most widely used method of joining metal, and is successfully applied for joining similar metals. However, the welding of dissimilar metal materials could lead to welding defects, resulting from significant differences in physical and chemical properties, and reducing the comprehensive properties of joints. With the development of material-joining technology, some new methods, such as self-piercing riveting (SPR), adhesively bonding and clinching with no pollution issues, low energy requirements, and high efficiency have emerged [4–6].

Clinching has rapidly developed into a new type of mechanical joining technique, used in the automotive and aerospace industries, over the last thirty years [7,8]. The failure mode of clinched joints determined by tensile-shear tests, and the influence of clinching-process parameters on joints, were studied by Varis [9,10]. Oudjene et al. [11,12] improved the strength of clinched joints by changing the geometrical shape, and also optimised die parameters by using the least square method and the response surface analysis. In the study of Paula et al. [13], the influence of technological parameters on clinching moulding and static strength were explored, and the distribution of stress in plastic deformation areas was observed from a microscopic perspective. Lee et al. [14,15] established an intensity model of a tensile-shear test for clinched joints based on die geometrical parameters, and then researched its influence on clinched properties of dissimilar sheets of aluminium and steel. The stress state of clinched interlock structures under tensile and shear forces was analysed by Mucha et al. [16–18], who also compared the strength of clinching with that of spot welding. The clinching process parameters optimisation using finite

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element (FE) simulations is continuously developing. The finite element method was applied for the assessment of punch load in the clinching process [19–21]. The die wear experimental data were compared with the results of FEA numerical simulation, which substantiated the fact that the dominant part of wear is localized in the radius area surrounding the die cavity [22]. The application of X-ray micro-diffraction to study the local changes in austenite content in clinching joints was presented by Krzton et al. [23]. The effects of blank holder geometric parameters and forming forces on the formed shape of the interlock in clinching were studied in different temper conditions [24]. Coppieters et al. [25] presented an analytical approach to estimate the pull-out strength of clinching joint though a new experimental setup and a FE model. The clinched joint of cold rolled steel was tested at different fatigue loads by Kim [26], and the results showed that the load amplitude, which reached the fatigue limit of 2.5 million cycles, was 50% of the static load stress.

Mori and colleagues [27,28] compared the fatigue properties of spot welding, SPR and clinching, and found that the fatigue properties of SPR and clinching were better than that of spot welding. Lambiase and colleagues [29–32] explored the influence of extensible die clinched-process parameters on joints' structures. They also reduced moulding stresses, and improved the clinching joining property of AA6082T6 aluminium alloy by a variety of methods: reducing depth of the lower die, preheating treatment, and changing the shape of the punch. Jayasekara et al. [33] analysed the influence of die parameters on joint-moulding quality, and considered elastic-plastic, rigid-plastic, and Coulomb friction in FE analyses. Chen et al. [34–39] investigated a new clinching reshaping method, by using a pair of flat and bumped die to reduce the button height, a flat surface can be created by the improved clinching process to increase the joint strength of clinching. Besides, a compressing technology was investigated with experimental method.

Adhesion as a joining technique progressed rapidly with the development of high strength adhesives in recent years. Ojalvo and Eidinoff [40] studied the stress distribution of single-lap adhesive joints with different adhesive-layer thicknesses, and also introduced G-R theory to extend basic calculation methods of joints. The stress singularity order was solved using a FE method by Van Tooren and Krakers [41]. The singularity index shows the shape of singularity stress field, and analyses the stress intensity factor which expresses the size of the stress field. Apalak et al. [42] used three-dimensional (3D) FE analysis and back-propagation artificial neural networks to study the 3D free-vibration performance of adhesive joints. The natural frequency, vibration mode, and frequency response function of single-lap adhesive joints in cantilever beam structures were studied systematically [43–45].

Clinching is a specific technology that does not use rivets, and whose cost and weight are significantly lower than SPR and traditional riveting, especially used in large-scale applications. However, its static strength is relatively low. With adhesion, stress concentration is efficiently avoided to acquire better strength and higher fatigue resistance, due to surface-to-surface contact. As a result of adhesives' high sensitivity to temperature and humidity, the joints failures could occur in an instant, leading to potential safety hazards. In order to avoid adhesive failure resulting from the environment, and improve the strength of clinched joints, a new mechanical-joining technology, combining adhesion and clinching, has been proposed, the so-called clinch-bonded hybrid joining [46,47].

A few studies on clinch-bonded hybrid joining have been carried out since its inception, and these focused primarily on the origins, including technological processes, energy absorption, and strength factors. The joining properties of SPR, welding, and clinch-bonded hybrid joints were compared by Moroni et al. [46]. They highlighted the obvious superiority of clinch-bonded hybrid joints on joining strength and energy absorption. Single-lap joints were prepared with special processing, where the adhesive layer solidified before clinching, and then tensile-shear tests were carried out by Balawender et al. [48], who believe that adhesives play an important role in the joining strength of clinch-bonded hybrids. Lee et al. [49] analysed the properties of clinch-bonded hybrids on aluminium alloy sheets by using a cohesive zone model, and certified the feasibility in a practical application. Based on multi-objective optimisation, the technological process of clinch-bonded hybrid joints with dissimilar sheets of steel and aluminium alloy was presented by Chen et al. [50], who also reported that clinch-bonded hybrids double the joining strength of clinched joints. From the study of He [51], we can see that he comprehensively reviewed clinching techniques including tool design, join-ability of lightweight sheets, hybrid and modified clinching processes. The failure loads and modes for three types of joints: adhesive bonding, bolt fastening and adhesive-bolt hybrid joining were compared by Kweon et al. [52], and it was found that hybrid joining improves joint strength when the mechanical fastening is stronger than the bonding. When the strength of the bolted joint is lower than that of the bonded joint, bolt joining contributes little to the strength of the hybrid joint.

In conclusion, the research of clinching and adhesion joining technology, including processing parameters, mechanical properties, and reference discussions, has been comprehensively conducted. For clinch-bonded hybrid joining, previous publications mainly discussed the preliminary technology with single-lap sheets, and focussed primarily on traditional material joining in similar configurations. In present study, specimens of clinch-bonded hybrid joints with similar sheets of H62 copper alloy and dissimilar sheets of H62 copper alloy with Al5052 aluminium alloy and galvanised steel were prepared and two types of joints, single-lap joints for shear strength and T-joints for peel strength, were manufactured with all combinations of sheets. The mechanical properties of the joints were comprehensively evaluated by analysing joint loads, energy absorption values, and failure modes, in the two types of joints.

2. Specimen preparation

2.1. Materials and specimen configuration

The sheet materials used in this study were H62 copper alloy, Al5052 aluminium alloy, and Q215 galvanised steel with 1.5 mm thickness. According to GB/T 228–2002 Indoor tensile testing of metallic materials, the material performance test, using an MTS Landmark Servo-hydraulic Test System, were conducted to obtain their mechanical properties with extensometer gauge length of 20 mm and elongation rate of 2 mm/min. The results are presented in Table 1. The stress-strain curves are showed in Fig. 1.

To obtain better joint strengths in clinched joints with dissimilar sheets, it is widely accepted that the sheet with the greater strength is regarded as the upper sheet, and the sheet with the lower strength will be the lower sheet. The upper sheet with greater strength can embed and flow adequately into the lower sheet with lower strength under punch pressure because of material strength difference, which means that the joint could form sufficient plastic deformation and provide greater mechanical-interlock force during the tensile-shear and peeling tests. From Table 1, the upper and lower sheets can be identified, and the nomenclature used in this paper is defined in Table 2.

Two types of joints, single-lap joints for shear testing and T-joints

Table 1
Mechanical properties of sheet materials.

Materials	Young's Modulus (GPa)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
H62	110	424.5	340.3	30
Al5052	69.5	229.9	211.5	12
Q215 Galvanised Steel	191	365.6	337.8	32.7