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Investigations of strength and energy absorption of clinched joints

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ABSTRACT

With an increasing application of clinching in different industrial fields, the demand for a better understanding of the knowledge of static and dynamic characteristics of the clinched joints is required. In this paper, the clinching process and tensile–shear failure of the clinched joints have been numerically simulated using finite element (FE) method. For validating the numerical simulations, experimental tests on specimens made of aluminium alloy have been carried out. The results obtained from tests agreed fairly well with the computational simulation. Tensile–shear tests were carried out to measure the ultimate tensile–shear strengths of the clinching joints and clinching-bonded hybrid joints. Deformation and failure of joints under tensile–shear loading were studied. The normal hypothesis tests were performed to examine the rationality of the test data. This work was also aimed at evaluating experimentally and comparing the strength and energy absorption of the clinched joints and clinching-bonded hybrid joints.

1. Introduction

Advanced joining technology is an integral part of the manufacturing processes of lightweight structures. Many efforts have been spent to develop the suitability of various joining processes for application into lightweight structures [1–4]. Clinching has also been developed rapidly into a new branch of mechanical joining techniques [5,6]. Clinching is a high-speed mechanical fastening technique which is suitable for point joining advanced lightweight sheet materials that are dissimilar, coated and hard to weld. The use of clinching is of great interest to many industrial sectors including aerospace and automotive. This, together with increasing use of lightweight materials which normally are difficult or impossible to weld, has produced a significant increase in the use of clinching technology in engineering structures and components in recent years.

The static and dynamic behaviour of clinched joints has been the subject of a considerable amount of experimental and numerical studies. A study on the joining mechanism of clinching has been conducted by Gao and Budde [7]. Some basic terms, such as the mechanical contact chains and their symbols and the joint networks, were introduced to establish a basic theory for analysing the joining mechanism. In Zheng et al.'s paper [8], the extensible die clinching process has been simulated using finite element (FE) method. The material flowing patterns have been compared between the fixed grooved die clinching and the extensible die clinching. The process monitoring systems are able to distinguish between accidental and systematic process errors and can, therefore, keep unnecessary plant stops to a minimum and ensure high levels of plant availability [9]. The influence of process parameters in extensible die clinching has been systematically investigated by Lambiase and colleague [10,11]. Clinched joints were produced under different forming loads to evaluate the evolution of the joints' profile experimentally. The suitability and economics of clinching processes have been studied by Varis [12,13]. In another work, Varis pointed out several problems encountered in the long-term use of a clinching process and both the lack of systematic maintenance, and continuous follow-up were discussed [14]. Mori et al. [15] carried out a comparison between the static and fatigue behaviour of joints produced with clinching and self-piercing riveting.

The clinching process is a method of joining sheet metal or extrusions by localized cold forming of materials. The result is an interlocking friction joint between two or more layers of material formed by a punch into a special die. It is believed that the clinched joints act to augment the system damping capacity. In spite of the fact that the clinched joints have been widely used in manufacturing practice, the reports about energy absorption of the clinched joints have never been seen in previous literature. Recent work by present author and coworkers investigated the energy effect in the vibration analysis of the clinched joints [16]. Due to the

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complex clinched joint geometry and its three dimensional nature, it is difficult to obtain governing equations for predicting the mechanical properties of clinch joints. The experimental predictions are time-consuming and expensive. To overcome these problems, the FE method is increasingly used in recent decades. In this paper, the clinching process and clinched joint tensile–shearing have been numerically simulated using the commercial FE analysis software. Axisymmetric FE models were generated based on the Cowper–Symbols material models. An implicit solution technique with Lagrange method and *r*-self-adaptivity was used. For validating the numerical simulations of the clinching process and clinched joint tensile–shearing, experimental tests on specimens made of aluminium alloy 7075 were carried out. The structural analysis has also been performed for comparing load-bearing capacity and energy absorption of clinched joints and clinching-bonded hybrid joints.

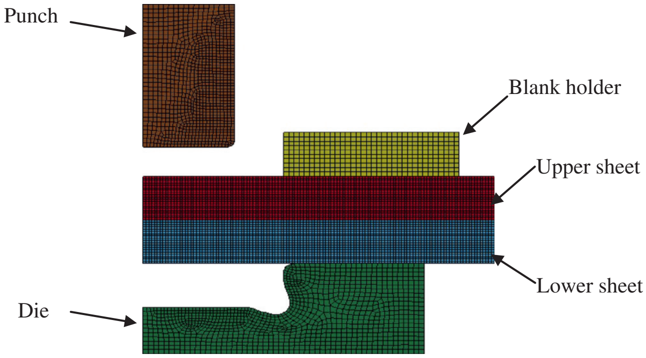

Fig. 2. FE model of clinching process.

2. Computational and experimental studies of clinching process

2.1. Numerical simulation of clinching process

A 2D axisymmetric model was generated using the commercial FE software LS-Dyna. The von Mises yield criterion, the piecewise linear isotropic strain-hardening rule, and the associated flow rule were adopted in the plastic domain. Since clinching process involves large deformation, elements may become severely distorted. Distorted meshes are less accurate and may accordingly introduce numerical difficulties. For avoiding numerical problems due to mesh disturbances, the efficacious approach is to use an erosion or element kill technique. The element kill technique corresponds to the progressive removal of the fully damaged elements. When the elements are removed, the interfaces between the sheets and other parts become rough. For getting smoother interfaces, a small element size is required. However, a small element size increases the number of elements in the simulation and the time of the simulation. To take the whole situation into account, an implicit solution technique with Lagrange method and *r*-self-adaptivity has been used.

As shown in Fig. 1, a single lap clinched joint comprises an upper sheet, lower sheet. The sheet materials tested were 7075 aluminium alloy sheets of dimensions 110 mm length × 20 mm width × 2 mm thickness and were clinched together in the central part of lap section. The mechanical properties of the aluminium alloy sheets were as follow: Young's modulus, $E = 68$ GPa; Poisson's ratio, $\upsilon = 0.33$.

Fig. 2 shows the FE model of clinching process. The punch, blank holder and die were modelled as rigid bodies, while the sheets were modelled as elasto-plastic materials. The piecewise-linear plasticity material model which adopts the Cowper–Symbols model to consider the influence of strain rate was used. The relationship between the Cowper–Symbols model and yield stress is shown in the following equation:

$$\sigma_y = \left[1 + \left(\frac{\dot{\varepsilon}^t}{C}\right)^{\frac{1}{p}}\right]\left(\sigma_0 + f\left(\varepsilon^P_{eff}\right)\right) \tag{1}$$

where σ_0 is the yield stress in constant strain rate, $\dot{\varepsilon}^t$ is the effective strain rate, C and P are the parameters of strain rate; $f(\varepsilon^P_{eff})$ is the hardening coefficient which is based on the effective plastic strain.

The friction between different parts in the model has an influence on the results of the simulation and the best value of the friction is not consistent for all the simulations. In the lack of experimental data, tentative values of the Coulomb friction coefficient between different parts in the model were assumed as follows: $f = 0.25$ punch-upper sheet, $f = 0.15$ upper sheet-blank holder, $f = 0.15$ upper sheet-lower sheet, $f = 0.25$ lower sheet-die. These values were kept constant for all simulations in this study.

The clinching process was simulated by applying a specified downward initial velocity to every node within the punch. Fig. 3 shows the FE simulation of clinching process and Fig. 4 shows the pressure-time curve of typical element in the simulation.

2.2. Clinching process tests

A clinching equipment RIVCLINCH 1106 P50 system was employed as clinching machine. All clinched joints were made with constant pre-clamp (5 kN) and setting (50 kN) load. A clinched joint was cut from the centreline of the clinch point perpendicular to the length of the specimen. Fig. 5 shows the cross-section comparison between simulations and tests of clinching processes. A reasonable agreement between the simulations and the tests was found. However a little difference between the simulation prediction and experimental measurement can be observed

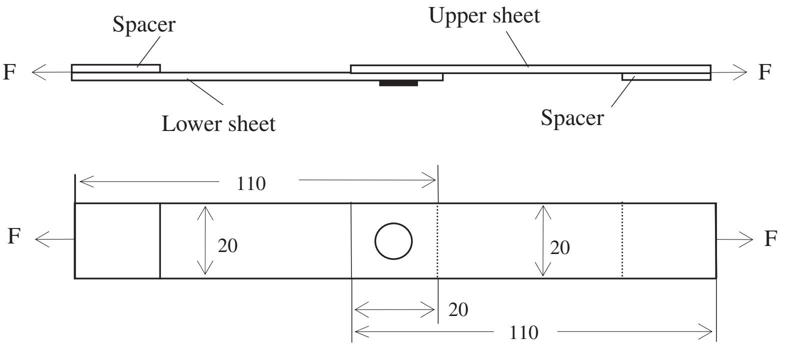

Fig. 1. Configuration and boundary condition of a single lap clinched joint (dimensions in mm).