Thin-Walled Structures 127 (2018) 500–515

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Finite element analysis of material flow in die-less clinching process and joint strength assessment

Mostafa K. Sabra Atia*, Mukesh K. Jain

Department of Mechanical Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7

ARTICLE INFO

Keywords:
Clinching
Die-less clinching
FE simulation

ABSTRACT

In the present work, a numerical investigation of the effect of the blank holder parameters on material flow and the final geometry of the die-less clinched joint is conducted. Various blank holder designs as well as different process parameters are used to obtain clinched joints. Axisymmetric finite element (FE) model was developed to simulate die-less clinching experiments. A hybrid material model with a weight function between the two common used hardening laws, Swift and Voce, was utilized to better represent the material behavior in the FE model. Another hybrid material model, referred to as extended-Voce model, was also utilized in the FE simulation and the results compared with the weight function approach. The weight function material model resulted in smaller geometric interlock compared with the experiment, whereas, the extended-Voce model led to better prediction of experimental geometric interlock with an error of less than 5%. The results showed that the interlock forms due to a large material flow in the axial and radial directions. The interlock can be maximized by controlling the material to flow in radial direction instead of axial direction, by decreasing blank holder depth. Also, distortion of the bottom of the die-less clinched joint can be avoided by achieving a bottom thickness of at least 10% of the total sheet thickness. Lastly, finite element models were also developed to predict the joint strength in shear and peel failure modes.

1. Introduction

Adhesive bonding, welding, and mechanical fastening are the main techniques for joining of sheet materials [1]. Mechanical fastening provides some advantages over the other two techniques in terms of efficiency, cost, quality and appearance of the joints [2]. Mechanical joining can be further divided into two categories, (i) joining by using consumable parts such as rivets, and (ii) joining by forming such as hemming and clinching. Clinching is a rapid and clean process where two or more sheets are locally deformed by using punch and die to form a geometrical interlock [3–5]. Clinching can be carried out with or without metal cutting [6]. In fact, the recent clinching operations involve no metal cutting and only redistribution of the material by plastic flow in the vicinity of the clinched region during geometrical interlocking. As shown in Fig. 1(a), the neck thickness N, interlock depth U and bottom thickness X are the main geometric parameters of the clinched joint [7]. The X-parameter, first introduced by Varies [6,8], is a useful parameter for inspection of the joint.

In general, the main limitation of conventional clinching is the creation of surface steps on both sides of the clinched joint. Many attempts have been made to decrease the height of the protrusion of the conventional clinched joint by subsequent reshaping [10–12]. In this regard, a countermeasure tooling was employed by Wen et al. [13] to reduce the protrusion height by 50% of the conventionally clinched joint without affecting the strength of the joint. Lambiase et al. [14] have conventionally clinched carbon fiber reinforced polymer (CFRP) to aluminum using extensible dies and followed the process by a second step of reshaping utilizing a punch and a flat die. Difficulty of aligning the pre-formed joint with the flattening punch represents the main disadvantage for this approach [9]. Borsellino et al. [3] suggested utilizing two flat anvils instead. The study showed a promising result in not only in reduced protrusion height but also in increased joint strength compared to the conventional clinched joint without reshaping. Chen et al. [15,16] used a pair of flat dies with (or without) the addition of rivet to decrease the height of the protrusion of the conventional clinched joint. Chen et. al. [17] have utilized flat and bumped dies to reshape the conventionally clinched 5052 aluminum sheets with different thicknesses. All of the above reshaping techniques resulted in an increase in the processing time because of the extra step that utilizes a different tooling.

In order to make clinching more aesthetically appealing, and without increasing the joining time, a new clinching technique called

* Corresponding author.
E-mail address: atiam@mcmaster.ca (M.K.S. Atia).

https://doi.org/10.1016/j.tws.2018.03.001
Received 28 August 2017; Received in revised form 10 February 2018; Accepted 1 March 2018

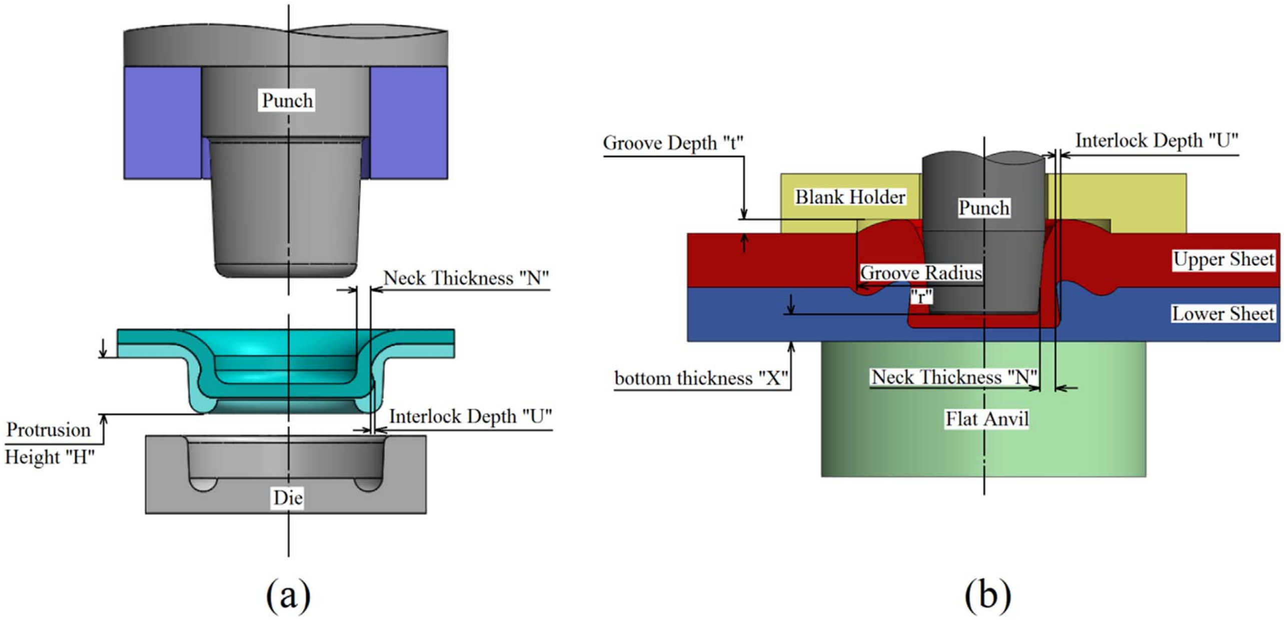

Fig. 1. Scheme drawings showing the various geometric parameters in; (a) conventional clinching and (b) die-less clinching [9].

Table 1
Mechanical properties of AA7075 aluminum sheet in T6 and O-temper states.

Mechanical properties from uniaxial tension tests				
Temper Designation	Material state	0.2% Yield strength (MPa)	σ_{UTS} (MPa)	Total Elongation (%)
T6	As-received	580	695	9
O	Annealed	175	295	15

die-less clinching has been developed. Die-less clinch joining is a one-step joining by forming process in which a punch, blank holder, and a flat anvil are used as shown in Fig. 1(b). In die-less clinching the surface steps occur only on one side of the formed joint, often on the punch side of the joint [9,18]. However, a tiny protrusion may be formed on the anvil side of the formed joint [19,20]. The designed groove in the blank holder in die-less clinching plays an important role in controlling the flow of the material to form the geometric interlock [9]. The usage of flat anvil instead of a die in die-less clinching not only improves the aesthetic appeal of the joined components but also reduces the joining time and die alignment issues. The main disadvantage of die-less clinching is that the process requires a combined movement of blank holder and punch that makes the tool set more complex [13].

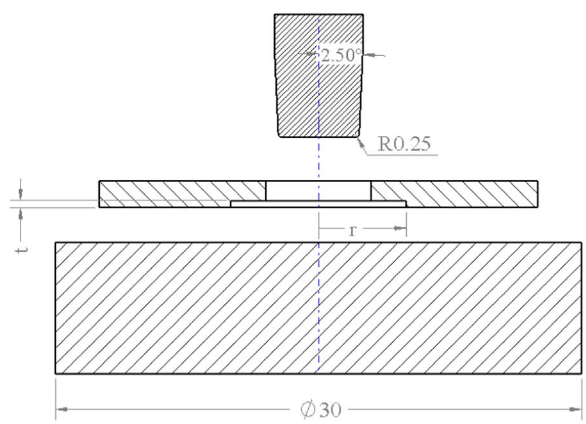

Fig. 3. A 2D drawing of die-less clinching tools showing fixed and variable dimensions of punch, blank holder and flat anvil. All dimensions are in mm.

Unlike conventional clinching, the stress state at the bottom of the die-less clinched joint showed a reduction in the crack sensitivity of the combined sheets by minimizing the amount of tensile stress during the deformation (this region is in fact under compression) [21]. The comparison of the stress distributions showed that there is significant

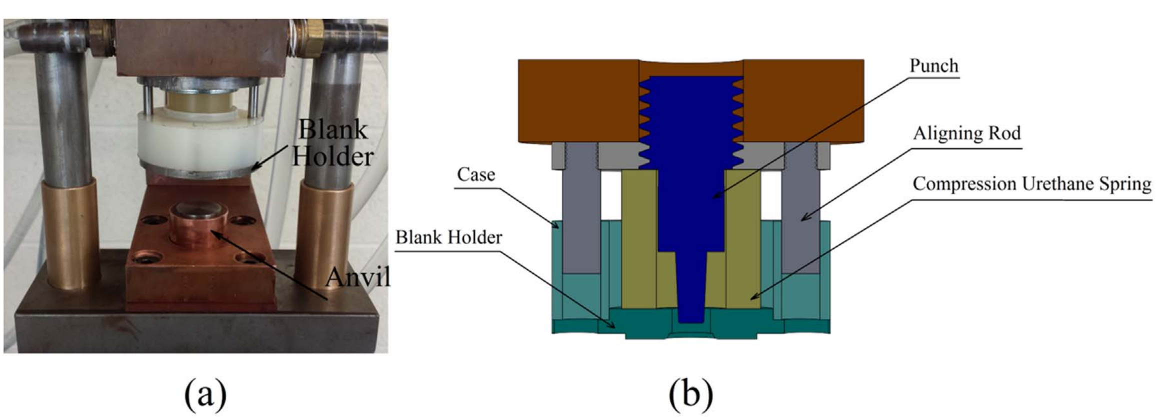

Fig. 2. Die-less clinching tool set-up; (a) photograph for the installation of the tooling and (b) schematic drawing showing the punch, blank holder shape and compression urethane spring.