Thin-Walled Structures 120 (2017) 421–431

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Die-less clinching process and joint strength of AA7075 aluminum joints

Mostafa K. Sabra Atia*, Mukesh K. Jain

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

ARTICLE INFO

Keywords:
Die-less clinching
AA7075 aluminum
Temper
Material flow

ABSTRACT

AA7075 aluminum alloy sheets in different temper conditions (O, W and T6) were joined by die-less clinching. The material flow behavior, neck thickness and interlock characteristics during clinching were investigated by metallographic observations of clinched, cut and mounted samples. Blank holders of different shapes and dimensions were used to control the material flow. The effects of blank holder geometric parameters as well as forming forces on the shape of the formed interlock in clinching were studied. The highest strength temper state (T6) was shown to possess poor clinch-ability as it failed to clinch under most clinching conditions. This was attributed to its poor ductility and formability at room temperature compared to the other tempers. Lastly, mechanical performance of the formed joints was characterized by conducting single shear lap as well as peel tests. Various failure modes were observed for the different clinching conditions and material temper states.

1. Introduction

Vehicle weight reduction, increased fuel economy, and increased safety of the structures in transportation applications has led to much interest in lightweight higher strength structural aluminum alloys [1,2]. Suitable joining techniques to create such structures with aluminum sheets are required [1]. Generally, similar and dissimilar sheet metals can be joined by adhesive bonding, welding, and mechanical fastening [3,4]. Difficulty of welding high strength aluminum sheets and long times for adhesive bonding make mechanical fastening a process of much interest for joining of high strength aluminum sheets [5].

Among the different mechanical fastening techniques available in manufacturing, clinching is a common method of joining by forming in which two or more sheet metals are locally deformed using punch and die to form a geometrical interlock [6–8] as shown in Fig. 1. Clinching enables joining of two or more similar or dissimilar sheet materials where individual thickness can vary from 0.4 to 4 mm [9]. A clinched joint is formed entirely by the geometric interlock alone and without adding any additional physical component to the joint. A high throughput, low cost, clean and environmentally friendly manufacturing environment of the clinching process arises from no harmful light, heat or smoke emissions. Lastly, clinching offers a high tool life compared with the other joining techniques [4]. The main geometric parameters that affect joint strength are neck thickness "N" and interlock depth "U" [10], as shown in Fig. 1. Clinched structures can withstand loads in shear and axial modes [11]. The shear strength of a clinched joint is comparatively higher than its axial strength [11]. In general, clinching results in lower joint strength compared to riveting which can limit its use in certain high strength applications [12].

The main limitation of using the conventional clinching technique is that the process introduces surface steps on both surfaces of the joined sheets where one side consists of a protrusion and the other a pit. Effort has been made to reduce the protrusion height by reshaping the conventional clinched joint [13–15]. Countermeasure tooling has been used in this regard by Tong et al. [16]. The study showed a reduction of 50% in protrusion height without affecting the joint strength. Francesco et al. [17] utilized two steps clinching to join aluminum and a carbon fiber reinforced polymer (CFRP) where the first step included conventional clinching by using extensible dies while the second was a reshaping step using punch and flat die as shown in Fig. 2. The main disadvantage for this approach is the difficulty of aligning the flattening punch with the pre-formed joint. Borsellino et al. [6] proposed a solution consisting of flattening of the pre-formed joint using two flat anvils. In addition to eliminating the protrusion height, the flattened clinched joint was also found to withstand higher loads than the conventional clinched joints. Chen et al. used a pair of flat dies with (or without) a rivet to reduce the protrusion height of conventional clinched joint produced by extensible dies [18,19]. All of the above reshaping techniques suffer from increased cycle time due to the additional step that involves a different tool set.

To make clinching more aesthetically appealing a new approach called die-less clinching has been developed in which surface step exist

Abbreviations: T6, artificial peak aged state which represents the hardest temper; W-temper, solution heat treated state; O-temper, annealed temper state; N, neck thickness of the joint; U, interlock depth of the joint

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

http://dx.doi.org/10.1016/j.tws.2017.06.021
Received 21 March 2017; Received in revised form 29 May 2017; Accepted 19 June 2017
0263-8231/

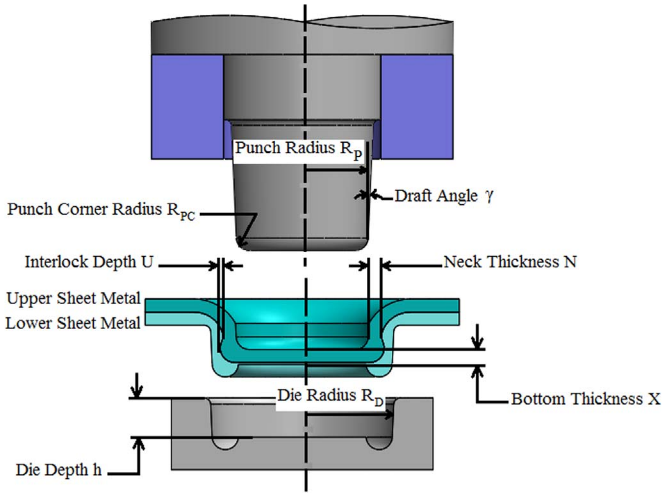

Fig. 1. Cross-section of a conventional clinched joint showing the geometry of the joint and different geometric parameters.

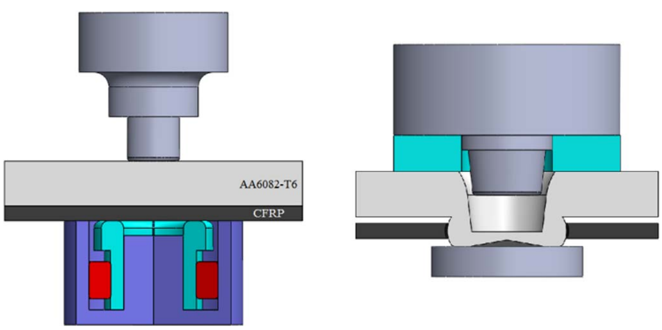

Fig. 2. shows two steps clinching process. The first step (on the left side) is a conventional clinching process by using extensible die. The second step (on the right side) is a reshaping process by using punch and flat die. Adjustable ring was used to adopt the height of reshaping.

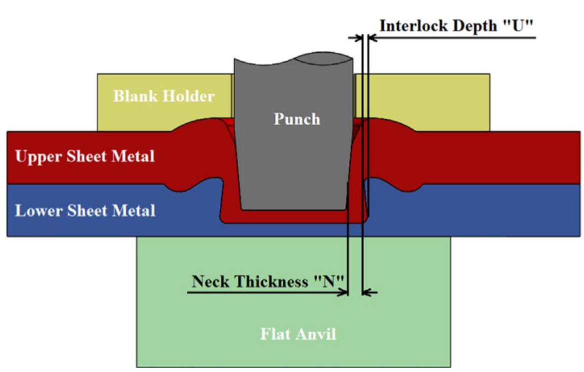

Fig. 3. A schematic of cross-section across a single-step die-less clinched joint showing the main geometric parameters of the joint.

only on one side, often on the unexposed side of the joint [20,21]. Die-less clinching is a one-step process using a punch and a flat anvil, as shown below in Fig. 3. The design groove in the blank holder is a key factor in controlling the material flow in order to form the geometric interlock. The use of flat anvil in one-step die-less clinching eliminates the need for good alignment between the punch and the anvil as well as keeping joining time as short time as possible. Neugebauer et al. [22] showed that a very small protrusion is formed in die-less clinching compared to the conventional clinching. The combined movement of blank holder and punch makes the tooling for die-less clinching more complex [16].

In general clinch joining is a well-accepted and widely used process for joining ductile sheet metals. The joining greatly depends on formation of a permanent interlock by application of plastic work [23]. In recent years, much effort has been made to extend clinching process to join higher strength (and lower ductility) sheet materials. Lambiase et al. have utilized a heater gun to locally increase ductility of AA6082-T6 sheets for joining using conventional clinching [24–26]. Xiaocong et al. [27] have preheated the sheet metal by using oxyacetylene flame gun in order to perform conventional clinches on TA1 titanium sheets. Abe et al. [28] have used a counter pressure of a rubber ring to conventionally clinch ultra-high strength steel sheets. Neugebauer et al. [20] have taken the advantage of using flat anvil in the die-less clinching process to heat the reduced ductile magnesium sheet metal from underneath the anvil using cartridge heating.

Three failure modes are generally encountered in performance testing of clinched joints [29]. These include (i) button failure due to plastic deformation on the formed interlock, (ii) unbuttoning failure due to neck fracture, and (iii) combined failure due to combination of plastic deformation and neck fracture.

Present work presents a new simple tool design for die-less clinching process for joining two similar sheet metals as well as a parametric study of the new tool in terms of load versus displacement characteristics during the clinching process. The material flow and joint interlock characteristics in different temper states have been investigated by observing the cut cross-sections of the joints with optical microscope. In addition, shear and axial strengths and failures modes of the joint have been assessed by using single shear and peel tests.

2. Material and experimental procedure

2.1. Material

One-step die-less clinch joints were performed on 1.27 mm thickness sheets made of 7075 aluminum alloy. The sheets were initially in T6 – temper, a peak aged condition that yields the hardest state (or the largest ultimate tensile strength). Two more tempers were subsequently obtained by annealing, a partially annealed state at 413 °C for 1 h (O1 temper) and a fully annealed state at 413 °C for 3 h (O2 temper). Lastly, another heat-treatment was carried out at 480 °C for 3 h followed by water quenching to obtain the solution heat treated metastable state (W-temper). Also, mechanical properties at each temper state were obtained by conducting tensile test according ASTM standard (E8/E8M) using an Instron universal testing machine at a cross-head speed of 1 mm/min (see Table 1). In order to save used material, sub-size sample

Table 1
Mechanical properties of AA7075 aluminum alloy at different temper states.

No.	Temper		Mechanical properties				
	Designation symbol	Description	0.2% yield strength (MPa)	Ultimate strength, σ_{Ult} (MPa)	Max % Elongation	K (MPa)	n
1	T6	As-received	620	695	12	976.9	0.1102
2	W	Solution Treated	230	434	25	823.4	0.2852
3	O	O1-Partially Annealed	175	295	15	485.9	0.2071
4	O	O2-Fully Annealed	135	245	17	428.7	0.2141