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A new joining by forming process to produce lap joints in metal sheets

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ABSTRACT

This paper proposes a new joining by forming process to produce lap joints in metal sheets. The process combines partial cutting and bending with mechanical interlocking by sheet-bulk compression of tabs in the direction perpendicular to thickness. The lap joints are flat with all the plastically deforming material contained within the thickness of the two sheets partially placed over one another. The design of the lap joints is performed by a simple analytical model and the overall concept is validated by means of numerical modelling and experimentation. Destructive shear tests demonstrate the effectiveness and performance of the new proposed lap joints.

1. Introduction

Lap joints are widely used to assemble surfaces from individual sheets or plates partially placed over one another (Fig. 1).

Arc and resistance welding (Fig. 1a and b), brazing (or soldering) (Fig. 1c) and friction stir welding (Fig. 1d) are among the most commonly used welding processes to produce lap joints in metal sheets. However, its utilization is limited when the sheets to be joined are made from dissimilar materials and is also costlier than alternative processes if weld inspections are required. Welding processes are additionally constrained by distortion and residual stresses arising from the expansion and contraction of the welds and adjacent base metals during the heating-cooling cycles. Clamps, jigs and fixtures that lock and hold the sheets in position during welding are commonly utilized to minimize distortion.

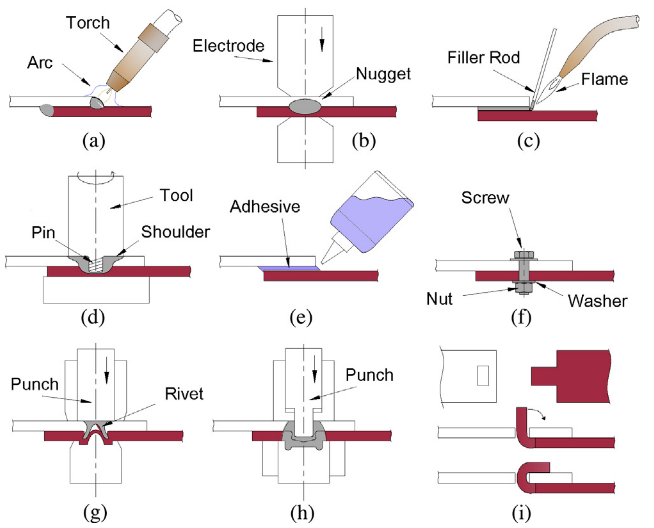

Fig. 1. Processes for producing lap joints in sheets or plates: (a) arc welding, (b) resistance welding, (c) brazing (or soldering), (d) friction stir welding, (e) adhesive bonding, (f) fastening (or riveting), (g) self-piercing riveting, (h) clinching and (i) bending of tabs.

Lap joints produced by adhesive bonding (Fig. 1e) overcome the welding difficulties in joining sheets made from dissimilar materials but its utilization is constrained by temperature, ageing due to weathering, long curing times and cautious surface preparation. Clamps, jigs and fixtures are also employed to ensure a uniform pressure across the adhesive bonded area of the lap joints during curing time.

Mechanical fastening comprises the utilization of threaded fasteners (or rivets) (Fig. 1f) whereas joining by forming [1] comprises a wide range of processes such as, self-piercing riveting (Fig. 1g), clinching (Fig. 1h) and bending of tabs (Fig. 1i). The fastened joints are easy to assemble and disassemble, are free from thermal after-effects and curing time requirements and can be used to connect metallic and non-metallic sheets. However, they are limited by the maximum force that they can safely support and by aesthetic and dimensional requirements.

Self-piercing riveting, clinching and bending of tabs avoid the forces to be concentrated at the points of fastening but the resulting joints are not hermetic upon loading (due to the open nature of the joints) and, therefore, are not recommended to be used in environments with water, moisture and other fluids. Moreover, some of the lap joints produced by forming can experience loosening during impact or material stress relaxation and can also be sensitive to fatigue failure upon cyclic loading.

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Bending of tabs (Fig. 1h) require no additional filler materials and accessories and is the easiest and most economical way to produce lap joints in sheets that will permanently or semi-permanently attach to one another [2]. However, there are a couple of shortcomings that prevent its widespread utilization:

- the thickness of the sheets is usually in the range of 1 to 5 mm in order to facilitate bending of tabs;
- the sheets must have good ductility and fracture toughness in order to avoid cracking when the bending radius is too small;
- the elastic spring back of the sheets must be small so that the tabs will not recover after being bent;
- the fixtures should not have aesthetic and dimensional constraints because the lap joint surfaces are not flat due to the protrusion of the bent tab beyond the upper (and sometimes lower) sheet surfaces.

In a recent investigation authors proposed a joining by forming process that is capable of avoiding material protrusions when fixing two metal sheets perpendicular to one another by means of tee joints [3]. Under these circumstances, the purpose of this paper is to present a new joining by forming process for producing strong lap joints with all the plastically deformed material contained within the thickness of the two sheets. The process avoids the aesthetic and dimensional limitations that are often negatively pointed to fasteners and to material protrusions of self-piercing riveting, clinching and bending of tabs.

2. Analytical modelling

The new proposed joining by forming process combines partial cutting and bending with mechanical interlocking by sheet-bulk compression [4] of tabs from the two sheets partially placed over one another (Fig. 2). In this work, the tabs were cut from the sheets by means of wire electro discharge machining. However, cutting and bending of tabs can be performed faster and cheaper by lancing in a single step.

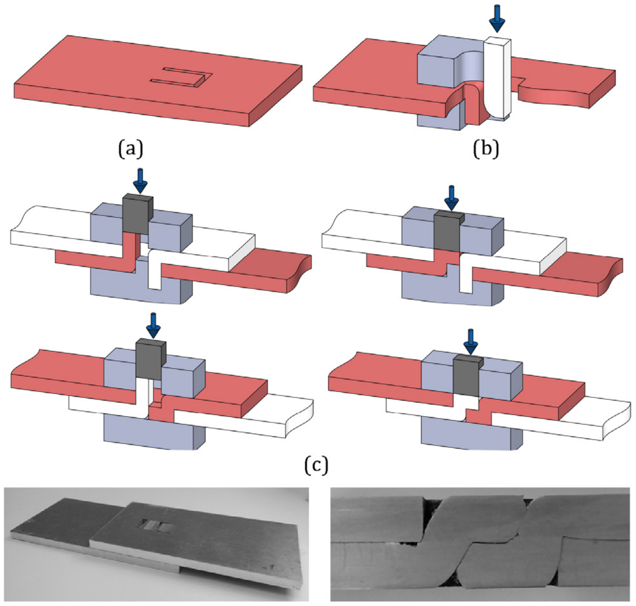

Fig. 2. The new proposed joining by forming process: (a) partial cutting, (b) bending, (c) mechanical interlocking by sheet-bulk compression and (d) photograph with a cross section detail of the joint.

The analytical model for designing the new lap joints considers plastic deformation of the tabs to be homogeneous and isotropic under plane strain conditions. It is also assumed that the thickness t of the tabs remains constant and that their bent radius r can be neglected. Since the volume of the tabs does not change during plastic deformation, the cutting length L to be performed on the two sheets can be written as a function of their thicknesses t and clearance c between the bent tabs, as follows, (refer to Fig. 3b for notation),

$$L = c + t_i + t_j \tag{1}$$

Eq. (1) is plotted in Fig. 3a as a black solid line with a slope equal to '+1' and a vertical-axis intercept equal to the thickness $t_i + t_j$ of the lap joint. Conversely, the tab heights h to be compressed along the thickness direction are given by,

$$h_i = h_i^f + t_j = c + t_j \tag{2}$$

where h_i^f is the free tab height of a sheet with thickness t_i.

Because, compression of the tab heights h_i is limited by plastic instability (buckling) of the thinner tab (say, t_i),

$$h_i = c + t_j < h\ (t_i)_{buckling} \tag{3}$$

It is possible to write the clearance c between the bent tabs as a function of the critical height $h\ (t_i)_{buckling}$ to buckle of the thinner tab, as follows,

$$c < h\ (t_i)_{buckling} - t_j \tag{4}$$

The above equation provides the workability limit due to buckling and sets the process window to the grey region (assuming, $h\ (t_i)_{buckling} > t_j$) depicted in Fig. 3a. The critical height $h\ (t_i)_{buckling}$ is to be determined experimentally.

Under these circumstances the design values for the new proposed lap joints are given by the portion of the black solid line that is located inside the grey region (e.g. point 'P' in Fig. 3a).

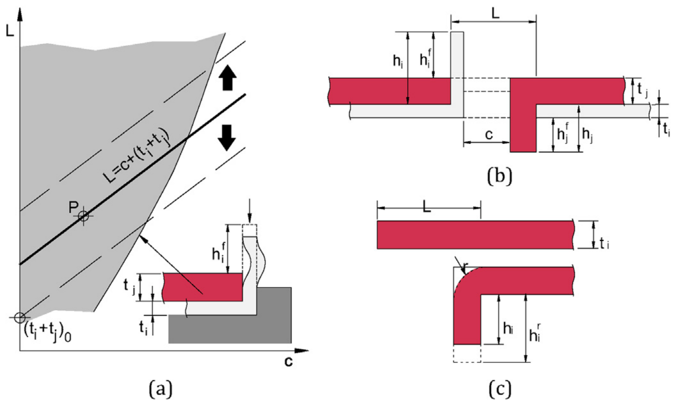

Fig. 3. Process window: (a) cutting length L of the tabs as a function of the clearance c between the two bent tabs, (b) main notation of the plane strain analytical model and (c) additional notation when considering the bending radius.

To conclude, it is worth noting that in case the bent radius r is taken into consideration (Fig. 3c) there will be a shifting of the neutral axis towards the inner bent radius and, therefore, the corresponding tab height h_i^r of a sheet with thickness t_i becomes larger than h_i given by Eq. (2). The consequence of this is that the free tab height h_i^f will increase and point P will become closer to the right-hand side (i.e. closer to the edge of the process window).

3. Experimental and numerical modelling

3.1. Material stress-strain curve

The experiments were performed in aluminium EN AW 5754 H111 sheets with 2.5 and 5 mm thickness in the 'as-supplied' condition. The stress-strain curve of the material was determined by means of tensile and stack compression tests. The tensile test specimens were cut out from the supplied sheets at 0, 45, and 90° with respect to the rolling direction and the stack compression test specimens were assembled by pilling up discs with 10 mm diameter that were also cut out from the supplied sheets. The