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ScienceDirect

Procedia Engineering 183 (2017) 213 – 218

Procedia Engineering

www.elsevier.com/locate/procedia

17th International Conference on Sheet Metal, SHEMET17

Design of stamping processes of pinless FSWed thin sheets in AA1050 alloy for motomotive applications using FEM

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Abstract

In the present paper, the cold stamping of friction stir welded AA1050-O thin sheets, obtained using a pinless tool, was studied. A preliminary investigation allowed to define the weldability window, in terms of the rotational and welding speed values, leading to joints with the desired mechanical properties. Then, the constitutive behavior of both the parent material and welded zone was characterized by means of uniaxial tensile tests. The constitutive equations obtained by analyzing the experimental results were implemented into the FEM code used to simulate the cold stamping process of FSWed blanks. The virtual prototypes were validated by performing stamping experiments of the FSWed blanks and comparing the predicted and measured results in terms of sheet thickness, and major strain vs. minor strain data.

Peer-review under responsibility of the organizing committee of SHEMET17

Keywords: Aluminium alloys; Friction stir welding; Formability; Stamping; FEM

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1. Introduction

In recent years, demand for lightweight structures has risen substantially in an effort to reduce weight, fuel consumption and environmental impact of vehicles such as cars, motorcycles and others. In the manufacturing of sheet metal assemblies, lightweight structures can be effectively obtained using Tailor Welded Blanks (TWBs) fabricated by joining together, from one side or double side, two or more sheets of different gages or grades [1]. The

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Peer-review under responsibility of the organizing committee of SHEMET17
doi:10.1016/j.proeng.2017.04.023

desired geometry can be obtained by stamping TWBs with an optimized thickness distribution. Among the welding technologies that can be used, friction stir welding (FSW) is characterized by several advantages over fusion welding techniques in terms of environmental impact, mechanical properties and post welding formability. However, the thickness reduction in butt joints, resulting from the forging effect of the tool shoulder, and the microstructural changes occurring during welding could limit the attitude of FSW blanks to be cold stamped. As a consequence, in order to achieve sound parts with the desired geometry, it is necessary to accurately design all the manufacturing phases, from FSW to stamping. To this end, the finite element method (FEM) can be used to optimize the entire manufacturing cycle. One of the aspects that critically affect the effectiveness of the FE simulations of the cold stamping phase is the precise characterization of the rheological behavior of the FSWed zone since it can be the weakest area of the assembled part [2]. As a matter of fact, depending on the initial temper state of the sheet material, the strain hardening and the microstructural transformations produced by friction stir welding can strongly affect the plastic flow behavior of the deforming material. If the strain hardening coefficient (n) of the welded material is higher to the one of the parent material, the sheet thinning in the FSWed zone will be less pronounced than that in the parent material and the cold stamping will be able to provide sound parts.

In this framework, the present work aims at investigating cold stamping of FSWed AA1050 aluminium sheets obtained using a pinless tool. A preliminary investigation allowed to define the rotational and welding speed values used in the FSW experiments. Then, the constitutive behavior of both parent material and welded zone was characterized by uniaxial tensile tests. The constitutive equations were implemented into the FEM code used to simulate the cold stamping process of FSWed blanks. Finally, the FE simulations were validated by comparing the predicted results with those measured on cold stamped parts.

2. Material and procedures

2.1. Material

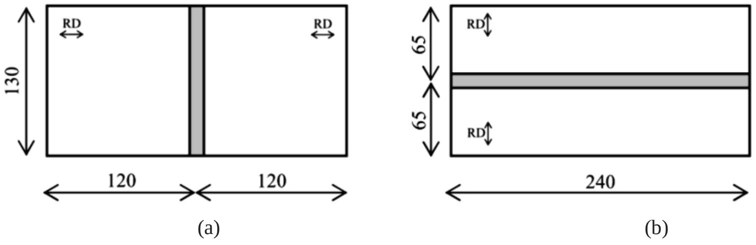
The material studied was the low strength AA1050 aluminium alloy characterized by excellent corrosion resistance, high ductility and highly reflective finish. The alloy was supplied in the annealed temper state (O) in order to take advantage of its high deep drawability [3].

2.2. Friction stir welding experiments

Butt joints were obtained by means of friction stir welding of sheet blanks in AA1050-O using a CNC machining center. Owing to the small sheet thickness (1.57 mm), the FSW experiments were performed using a pinless tool, in H13 tool steel, with a shoulder diameter of 8 mm [4].

The rotational speed (ω) and welding speed (v) were kept constant and equal to 800 rpm and 300 mm/min, respectively. Such values were obtained by analyzing the results shown in a previous work that has allowed the definition of the weldability window [3]. The tool plunging and nuting angle were imposed equal to 0.1mm and 2°, respectively.

In all the FSW experiments, the welding line was perpendicular to the rolling direction. Two different sheet assemblies, characterized by different welding line orientations, were produced (Fig. 1).



(a) (b)

Fig. 1. Friction stir welded sheet assemblies with different welding line orientations: (a) transversal and (b) longitudinal.

2.3. Uniaxial tensile tests

The plastic flow behavior of both parent material (PM) and welded material (WM) was evaluated by means of the uniaxial tensile test. The PM specimens were machined from the sheet with the loading direction parallel to the rolling one; the FSWed samples were cut from the blanks with the loading direction parallel to the welding line (Fig. 2). Tensile testing was performed at room temperature according to the ASTM E8/E8M and BS EN 895.

The results, in terms of true stress (σ) vs. true strain (ε) curves, were used to calculate the strength coefficient (K) and strain hardening coefficient (n) of the Hollomon's equation.

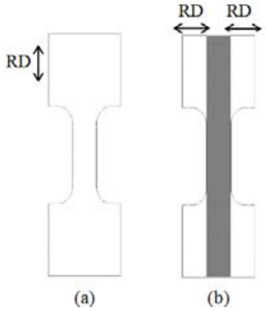


Fig. 2. Tensile samples: (a) parent material and (b) FSWed material.

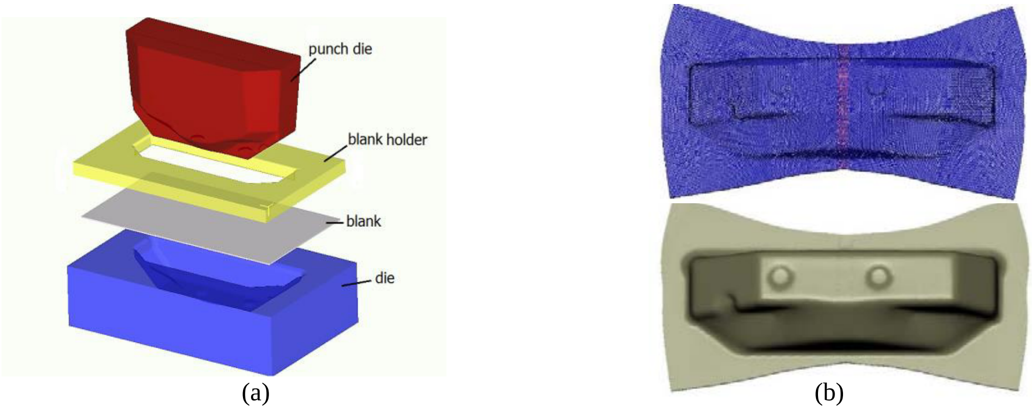
2.4. FEM analysis

The FE simulations of the cold stamping process performed on the FSWed blanks were carried out using the Deform 3D® commercial code. Deform® is an FE code developed primarily for the bulk forming industry, such code has a built-in heat transfer module that can accurately model heat transfer related processes. This provides an obvious advantage for its use in hot and warm stamping. However, as a result of the use of brick elements, the simulation time is slightly high compared to other codes like Autoform, Pam-Stamp, LS-Dyna etc. These codes use shell elements and therefore the simulation time is reduced but with detriment of the through thickness information. In this study, the average simulation time was 5h using a PC with an Intel Core™ i7-3630QM CPU, 16GB Ram and SS Hard drive. The tool set consists of the draw punch, shaping die and blank holder (Fig. 3a). In the finite element discretization, the blank was divided into 265000 tetrahedron elements with 65000 nodes (Fig. 3b). Friction was modelled using the constant friction model (m-model): $\tau = m\,\mathrm{K}$, where τ is the shear stress, k the shear yield strength and m the frictional shear factor [5]. In the present study, two different m values, typically used in cold stamping of Al alloys, were adopted: m=0.4 at the unlubricated die-sheet and sheet-blank holder interfaces, and m=0.12 at the lubricated punch-sheet and sheet-die interfaces.

The initial geometry of the assembled blank was drawn by taking into account for the thickness reduction caused by the tool sinking applied in the FSW process. Furthermore, the plastic flow behavior of the FSWed blank was characterized by different constitutive parameters depending on whether the PM or WM zone is considered (Fig. 3b).

2.5. Stamping of FSWed blanks

Cold stamping trials were performed at Cams S.p.A., located in Fara Filiorum Petri (Chieti-Italy), using a double effect deep drawing hydraulic press with a load capacity of 300 tons and a blank holder pressure up to 140 bar. No lubricant was used at the die-sheet and sheet-blank holder interfaces whilst the punch-sheet and sheet-die interfaces were lubricated using oil-water emulsion. The strain distribution after stamping was evaluated by placing a regular line grid, with 1.5 mm in line distance, on the surface of FSWed blanks before stamping, and measuring major and minor strains. The thickness distribution in the different zones of the deformed sheet was measured by longitudinally and transversally trimming the stamped parts by means of 3D laser cutting. Finally, the effect of the welding line arrangement on the sheet thickness distribution was investigated by stamping both typologies of the FSWed assemblies shown in Fig. 1.



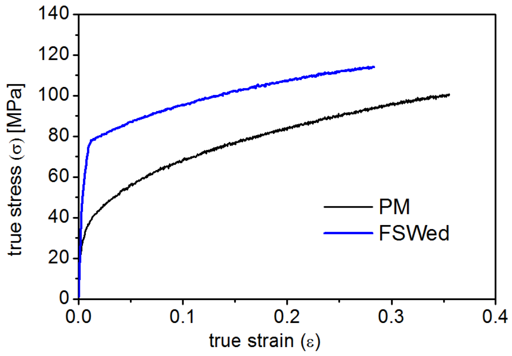
(a) (b)

Fig. 3. (a) Tool geometry of the stamping process, and (b) typical meshed and final configuration of the stamped transversal FSWed blanks predicted by FE simulations.

3. Results and discussion

Fig. 4 shows the plastic flow behavior of both AA1050-O and FSWed blanks. It can be seen that, for a given true strain, the true stress of the latter is higher than that of the former; furthermore, the strain to failure of the WM is lower than that of the PM. The discrepancy between the σ value of the FSWed and that of the parent materials decreases with increasing the ε value (Fig. 4a). Such behavior can be attributed to the different strain hardening coefficients obtained on the WM and PM, as shown in Fig 4b. In fact, owing to the strain hardening imposed by friction stir welding, the n value of the WM is lower than that of PM thus leading to a slower increase in σ with ε.

Fig. 5 shows the critical regions of the welded assemblies exhibiting the most severe strain state and, consequently, the lowest sheet thickness. The highest thinning value, equal to about 20% of the initial sheet thickness, is obtained in the zone A along the welding line of the part obtained by stamping the FSWed blank with the welding line perpendicular to the short side of the die (Fig. 5a). As far as the central region of the stamped component is concerned (Fig. 5b), the FSWed blank obtained with the welding line parallel to the short side of the die shows a quite uniform sheet thinning along the welding line from point 1 to 5; since it is similar to the tool sinking applied in the FSW process, it indicates the reduced severity of strain state in such region. As points 6 and 7 are concerned, the sheet thinning increases due to the increase in the severity of the strain state. The comparison between predicted and measured thicknesses shows the excellent capability of the FEM model to simulate the cold stamping of FSWed blanks. To this purpose, Fig. 5 shows that the highest discrepancy between predicted and measured thicknesses is equal to about 5%.

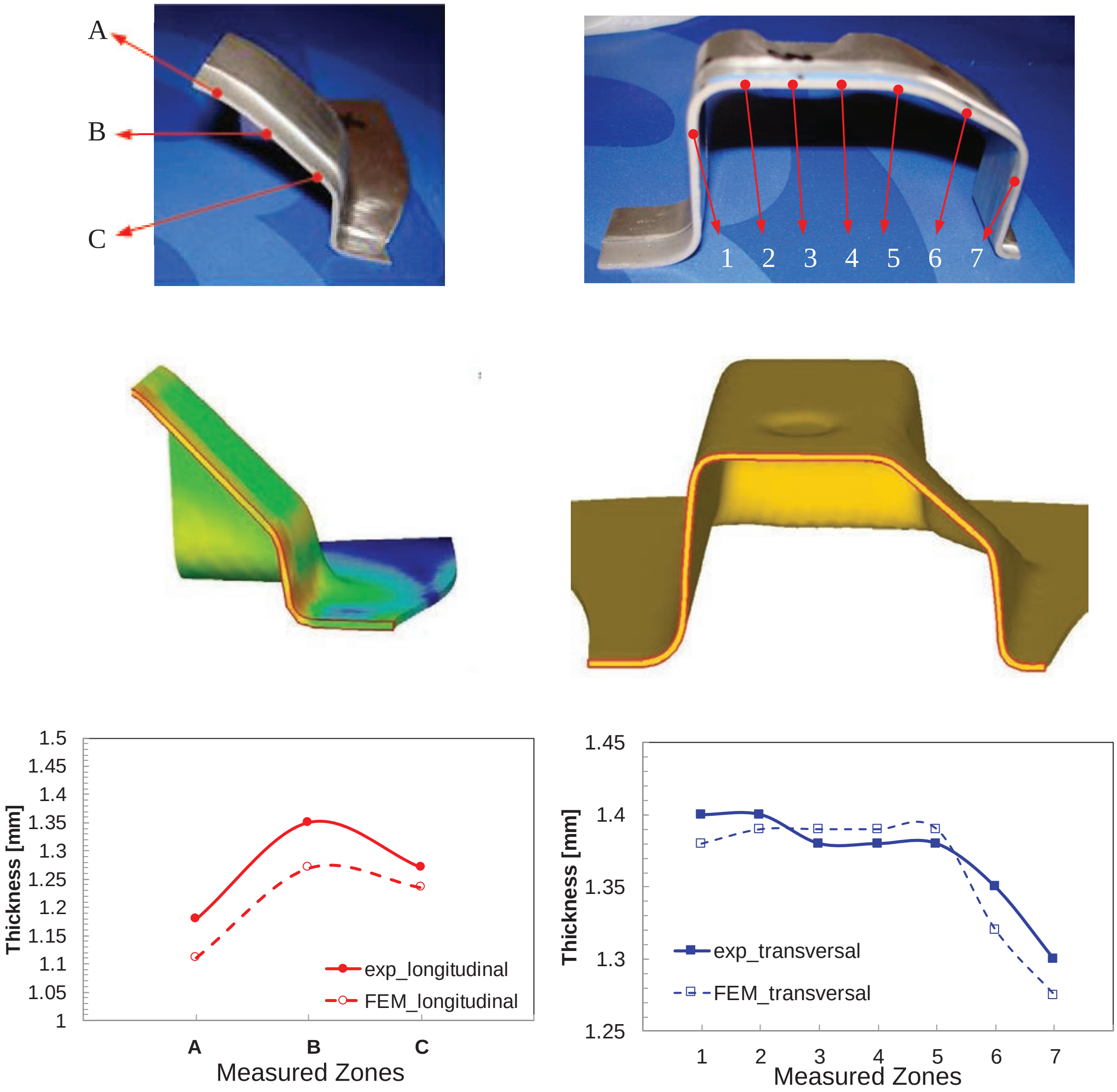


(a)

Hollomon's equation constants	**K [MPa]**	**n**
Parent material	132	0.280
FSWed joint	134	0.138

(b)

Fig. 4. (a) Typical true stress vs. true strain curves and (b) the Hollomon's equation constants of the parent material and FSWed samples in AA1050-O.



(a) (b)

Fig. 5. Comparison between predicted and measured sheet thickness in different regions of the stamped part: (a) longitudinal and (b) transversal sections.

Finally, Fig. 6 shows the post welding formability of the FSWed AA1050 blanks taken from a previous work [3]. The forming limit curve (FLC) corresponds to the most severe strain state that is the one occurring on samples with the welding line parallel to the length side of the FSWed blank. The soundness of the stamped parts is confirmed by the analysis of the strain distribution, which shows that the major strain vs. minor strain data measured in the cold formed part and predicted by the FE simulations are located within the safe region of the forming limit diagram that is the area below the FLC of the FSWed blanks.

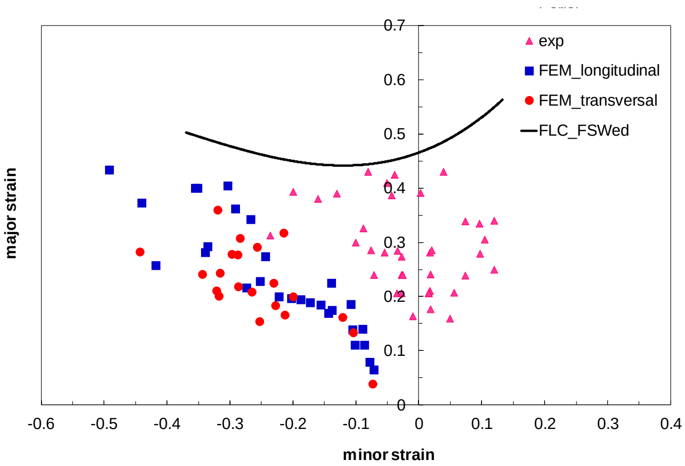


Fig. 6. Forming limit curve of the FSWed joint in AA1050 alloy and experimental and predicted values of major and minor strain

4. Conclusions

In the present work, the cold stamping of friction stir welded AA1050-O thin sheets was investigated. To this purpose, the plastic flow behavior of both parent material and FSWed blanks were characterized. Then, both experiments and FE simulations of the stamping process were performed. The main results obtained can be summarized as follows:

- the flow curve of the FSWed zone is characterized by stress values higher and ductility lower than those of parent material. Furthermore, the strain hardening coefficient of the FSWed blank is lower than that of the parent material;
- the constitutive equations of both parent material and FSWed zone were used as input data in the FE simulation of the cold stamping process of the friction stir welded blanks;
- the critical region of the welded assemblies, exhibiting the most severe strain state, was analyzed and the highest sheet thinning, equal to about 20% of the initial sheet thickness, was identified;
- the comparison between predicted and measured thicknesses, with the highest discrepancy equal to about 5%, shows the excellent capability of the FEM model to simulate the cold stamping of FSWed blanks;
- the soundness of the stamped parts is confirmed by the major strain vs. minor strain data, measured in the cold formed part and predicted by the FE simulations, that are located within the safe region of the forming limit diagram.

Acknowledgements

The authors wish to thank Dr. Massimiliano Pieralisi for his help in carrying out the experimental work.

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