New Approach on the Cold Welding of Metals: Application to Aluminium Bars

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Área Temática: Ingeniería de Fabricación

Resumen

La soldadura por frío por presión es un proceso de fabricación de empalme en estado sólido con varios usos importantes, pero carente en sus fundamentales. Este papel presenta un nuevo acercamiento de la investigación en el campo, trayendo contribuciones originales teóricas y prácticas al conocimiento del principio de la soldadura en frío y creando las bases para el desarrollo de los nuevos procesos que tratan los materiales modernos. El acercamiento se basa en un FEM capaz para predecir el comportamiento material durante la deformación, considerando varias condiciones introducidos por el código usado: análisis estático no linear, tensión grande y desviación grande, dislocaciones prescritas. La correlación entre las tensiones y la deformación del material ha sido tratada luego. Las dimensiones y las características de la zona afectada mecánica - MAZ (desarrollado en el material debido al proceso de deformación) están también alcanzados.

Palabras Clave: *modelo con elemento finito, soldadura por frío, deformación plástica, empalme de aluminio*

Abstract

Cold pressure welding is a solid state joining manufacturing process with several important applications, but with gaps in its fundamentals. This paper presents a new approach of the research in the field, bringing both theoretical and practical original contributions to the knowledge of the cold welding principle and creating the bases for the development of new processes addressing modern materials. The approach is based on a FEM capable to predict the material behaviour during the up-setting, considering several constrains introduced by the used FEA code: non-linear static analysis, large strain and large deflection, prescribed displacements. Correlation between stresses and material deformation is further addressed. The dimensions and characteristics of the *Mechanical Affected Zone* – MAZ (developed in the material due to the up-setting process) are identified.

Keywords: *finite element modelling, butt cold welding, plastic deformation,* aluminium joints

1. Introduction

Cold welding process can be easily and comfortably achieved, being practically the result of the pressing force applied between two metal sheets appropriately and carefully cleaned. This process requires important materials deformation degrees (usually over 70%), obtained by using high pressing forces, able to generate upsetting pressures ten times greater than the maximum yield strength of the material. Cold pressure welding can be achieved mainly by two methods: spot welding and butt welding. In both cases, similar or heterogeneous welded joint can be obtained. Easy deformable metals as Aluminium or Copper can be cold-welded, but the process can be also achieved between dissimilar metals (Aluminium-Stainless Steel, Aluminium-Titan etc.), as well as between theirs alloys. Wires and bars can be joined using butt cold welding .

2. Principle of Pressure Butt Cold Welding

Butt cold pressure welding rises very interesting theoretical and practical problems regarding the minimum value of the squeezing force that ensures the joint achievement, the material flowing, the material cold hardening (increasing during the process), and the yield stress and cold hardening interdependency . A diagram that illustrates the main forces acting in butt cold pressure welding is presented in Fig. 1.

Comparing with hot pressure welding, when the parts extremities are heated by Joule effect and the pressure is approximately $p = (0.1 \ldots 0.2)\sigma_c$, in butt cold welding case the pressure is $p = (8 \ldots 10)\sigma_c$, meaning that, for the same material, a 100 times bigger pressing force is applied [2].

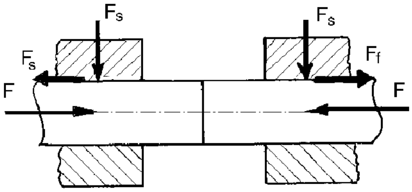

Fig. 1. Main forces acting in butt pressure welding process

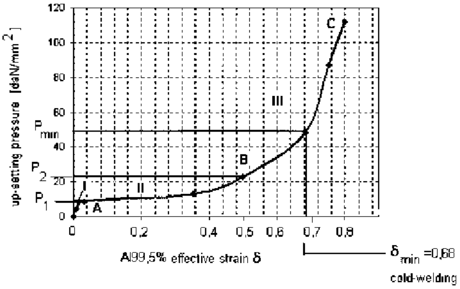

Fig. 2. Pressure - deformation curve in butt cold welding case

The explanation is that the specific compression pressure depends on the deformation needed value, δ. Fig. 2 presents the correspondence between the material deformations and the applied pressure , illustrating the practical behaviour of the material during the deformation process. The *b-c section* of the curve represents the material cold hardening area, where a high deformation is obtained only if using pressure values bigger than the material yield strength. This is the area where the cold welding is achieved at a minimum deformation rate of 70% for aluminium, or 80% for copper.

Due to recent developments in engineering software, which made possible the modelling of the physical processes and their mechanisms easier than ever, a FEA for aluminium butt cold welding was developed by the authors considering the material elasto-plastic constitutive law.

3. Deformation process modelling of the bars on butt-cold welding

The constitutive elasto-plastic model has involved the Von Mises criterion, which was used to define the effective stress.

As *time curve* (specific for the COSMOS - *NSTAR* code), the material constitutive law (stress-strain curve) was used for introducing the isotropic non-linear material.

The material used to simulate the butt cold welding process was *99.5% Al* with different description: the linear-elastic part was introduced by the Young modulus $E = 6.9\ 10^{+10}$ $[N/m^2]$ and the Poisson ratio $\nu = 0.33$, whilst the plastic behaviour was described by the strain-stress relation illustrated in Fig. 3 .

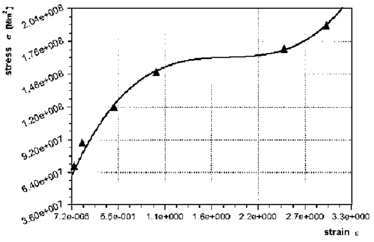

Fig. 3. *Strain-stress characteristic curve of 99,5% Aluminium*

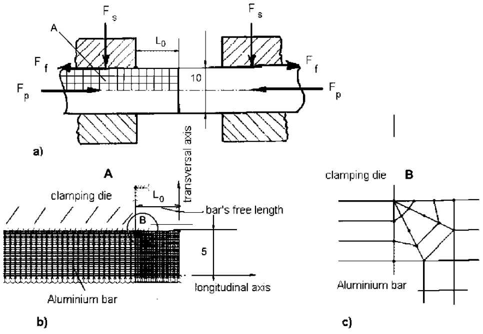

Fig. 4. Butt-cold welding model: a) sketch of the butt cold welding; b) finite element model; c) adapted mesh for the critical area

Fig. 4 presents the sketch of butt cold welding of aluminium bars and the finite element model used for analyzing and interpreting this process, described by:

- *The geometry*: two bars (99,5% Al, 10 mm diameter, 40 mm length each of them) were isothermal upset. The symmetry reasons allowed that only a quarter of bars joint to be modelled. The clamping dies were modelled as being rigid, with sticking friction acting to prevent the bars sliding.

- *The mesh defined geometry*: the main part of the finite element mesh contains 4-noded PLANE2D axis-symmetric displacement pressure elements. Near the die corner, where the rollover was expected to occur, the elements have triangular shape, accommodating the deformation mode. Gap elements were used to model the contact between the bar and the clamping die, using an additional line surface (Fig.4,b).
- *The constraints applied* on the finite element model were: non-linear static analysis, elasto-plastic material model, large strain and large deflection, prescribed displacements.
- *The loads* of the model: pressure-displacement elements of the bars.
- *The Newton-Raphson iterative method* was used to ensure at any time step the stiffness matrix convergence of the model.

4. Mechanical Affected Zone, MAZ - FEA & Experiments

After completing the finite element model analysis of the butt cold welding process, the results related to the equivalent stress distribution on two main directions, along x and y-axis in the Aluminium bars were analyzed.

The maximum values of the equivalent stresses are recorded in the joint area, indicating that the initial structure of the base material has changed due to the plastic deformation process. The stress values in the bar, in the clamps proximity are decreasing with the distance from the cold welded joint to minimum values around 6.5 10^7 N/m^2 (at 0,02 m), corresponding to the starting point of the base material plastic deformation and cold hardening of it.

The pressure influence was studied by analysing the image of the MAZ on the x-axis, at different distances from the joint, on B1-B5 lines (Fig. 5,a). The results are presented in Fig. 5,b, indicating that the stress distribution decreases from the B1 line (bar cold weld) to the B5 line (situated at 0,02 m from the cold weld). The maximum values of the equivalent stresses are recorded in the joint area, outside the clamps, indicating that the base material initial structure has changed due to the plastic deformation process. As general conclusion regarding the B1-B5 lines, the stress values are decreasing on radial direction, from the bar contact points with the clamps.

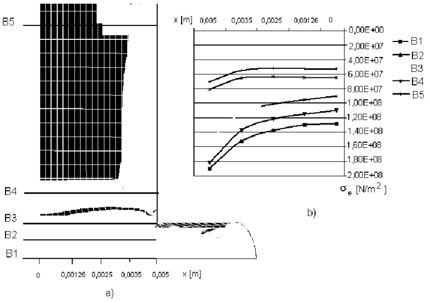

Fig. 5. Von Mises stress distribution: a) in the mechanical affected zone along x-axis; b) stress distribution chart along x-axis

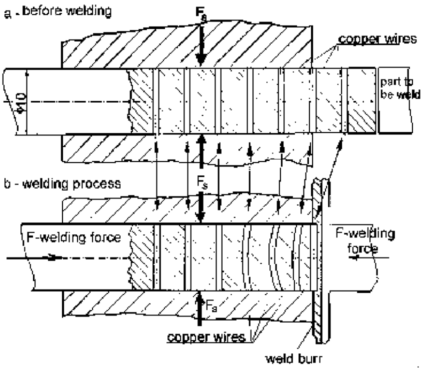

Fig. 6. Sketch of the test assessing the material flow

Cold pressure welding experiments were performed by using a 200 kN hydraulic press. The pressed material displaces *inside* and *outside* the clamping area and the bars material becomes harder, finally producing the cold welded joint. As Fig. 6,a, shows, several small diameter copper wires were introduced in the bars before welding . After cold welding achievement (Fig. 6,b), due to the copper wires deformation, the image of the deformation process inside the bars is obtained, the slope of the strains and stresses curves being practically illustrated by the shapes of these deformed wires.

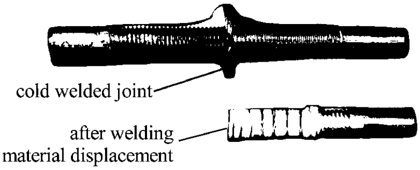

Fig. 7. Images of butt-cold welded bars and of the deformed copper wires

Fig. 7 presents the macroscopic image of a cold welded joint obtained at room temperature, after applying the necessary up-setting force and the image of the deformed copper wires.

5. Conclusions

Several general conclusions must be underlined:

- The finite element model developed for the butt cold welding process for aluminium bars, 10 mm diameter is capable to describe the material deformation during upsetting. This model can be used as starting point for future research on the achievement of dissimilar cold welded joints.

- Theoretical and experimental results confirm that the material flows inside of the clamping area, producing the cold hardening phenomenon, whose intensity decreases when the distance from the weld increases.

- The material flowing inside the aluminium bars is more evident and rapid along the y-axis, due to the material mechanical anchoring phenomenon on clamps contact line and to the quicker surface cold hardening.

6. References

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