Cold welding on cogged surfaces

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Resumen

La soldadura por frío entre superficies dentadas es lograda presionando una chapa de aluminio deformable fácilmente por una superficie dentada de un componente más duro. El proceso requiere la limpieza exacta de las chapas en el área de contacto. El empalme se logra solamente por grande deformación plástica del componente del aluminio, que entra entre los dientes del más duro, hecha de cobre, o de acero carbón o inoxidable. El papel presenta el modelo 2D por elemento finito del proceso: Los resultados como tensión elemental y las tensiones en el área de contacto en el componente de aluminio fueron discutidos y comparados con experimentos. Se presentan también la deformación y/o las grietas del aluminio que fluye durante presionar entre los dientes del material más duro, a diversas grados de deformación. El uso industrial más importante del proceso es en electrotécnica, para los empalmes disímiles de aluminio-cobre.

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

Abstract

Cold welding on cogged surfaces is achieved by pressing an easy deformable sheet of aluminium on a cogged surface of a harder component. The process requires sheets accurate cleaning in the contact area, where the cold welding is expected to occur. The joint was obtained only by large plastic deformation of the aluminium component on the harder one, made from copper, or carbon/stainless steel. The paper presents the 2D Finite Element Method Model of the process; results as aluminium component elementary strain and stresses in the contact area were discussed and compared with experiments. The aluminium flowing during pressing into the harder material cogs at different deformations, its deformation or cracking are presented, as too. The process industrial application in electrotechnics, to obtaining dissimilar joints of aluminium-copper, is of high importance due to the coupled materials electric properties.

Key words: finite element modelling, cold welding, cogged surfaces, plastic deformation, aluminium joints

1. Introduction

Cold welding by pressing on cogged-surface is a new technological option for welding aluminium with different ferrous and nonferrous metals. The cogging main advantage is the achievement of the cold welding only by deforming the easy mouldable component at lower deformation rates, than the classical butt cold welding process requires. As Fig.1 presents, the components of the easily-mouldable metals (aluminium, lead, tin, etc.) having plane contact surfaces are pressed on cogged components of the harder materials (copper, brass, carbon steel, stainless steel, etc.). The welding is ensured only by the aluminium plastic deformation. During pressing, aluminium fills in the whole space between the cogs. The welding is achieved in isolated points, after the aluminium gripping into the cogs, during pressing and its relative slipping on the carefully cleaned contact surfaces [1-4].

a) b)

Figura 1. *a) Cu and Al samples to be welded; b) cold welded joint on cogged surface*

Finite element model of the aluminium component deformation was used to determine optimum process parameters by studying the strains and stresses in the contact/joining area, avoiding excessive pressing and cracks forming.

2. Modelling Conditions

The 2D finite element model cold welding on cogged surfaces considers, due to the symmetry, only a half of the aluminium-brass joint. MARC Mentat 3.1 code was used for the process analysis. Fig. 2 presents the sketch of the model, where:

- the active part 1, is modelled as being rigid and non-deformable with time-dependent prescribed displacement elements on y axis, allowing the up-setting process control;

- the aluminium part 2 (99.5%Al, 30 mm diameter, 40 mm length), is largely plastically deformed during pressing; The mesh contains 1440 of 4-noded PLANE2D elements. Gap elements are used to model the contact between the aluminium and the active part 1 (the pressing device) and also for the brass cogs (part 3), where cold-welding occurs. The material elasto-plastic behaviour is described by Young modulus E, (E = 72 000

N/mm^2), Poisson ratio, (ν = 0.32) and a strain-stresses curve (experimentally obtained) introduced by a Swift law:

$$\sigma = A\left(\varepsilon_0 + \varepsilon_p\right)^m , \qquad (1)$$

where: A = 492.37 and m = 0.242.

- the brass part 3 is considered rigid and hardly mouldable; the contact/joining line simulates the cogs shape.

The influence of different cogs pitches on cold-welding obtaining was also analyzed. (Fig. 3).

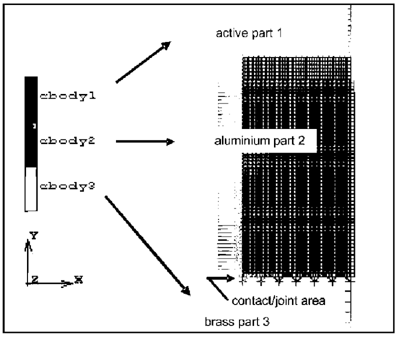


Fig. 2. Cold-welding on cogged surfaces 2d finite element model

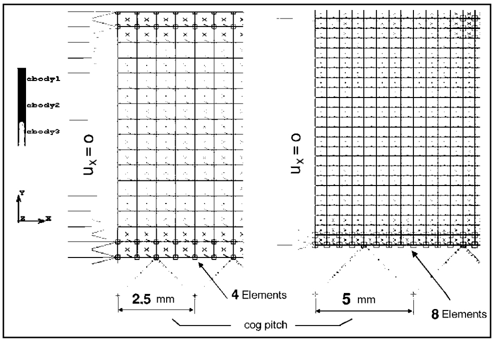


Fig. 3. Different cogs pitches and their influence on the process modelling

3. Finite Element Analysis and Experimental Results

Figures 4 and 5 illustrate the finite element analysis results concerning the equivalent plastic strain distribution and Cauchy equivalent stresses in case of using cogged brass samples of 2.5 mm cogs pitch. The aluminium part deformation rate was of 20% [3].

The images illustrating the aluminium part behaviour points out the following aspects:

- the general shape of the deformation is specific for the classical free upsetting;
- due to the aluminium upsetting and its anchoring into the brass cogs, the mesh longitudinal lines are deformed, becoming *S* shaped curves;
- strains and stresses reach maximum values on the general sliding line of the pressed material;
- the highest elementary stresses appears in the cogged/joining area, explaining the brass cogs smoothing and the cold welded joint formation.

Finite element analysis provides global and specific information concerning the strain-stresses couple in the aluminium component. The cogs are in fact stresses concentrators, which improves the dissimilar metals butt cold welding.

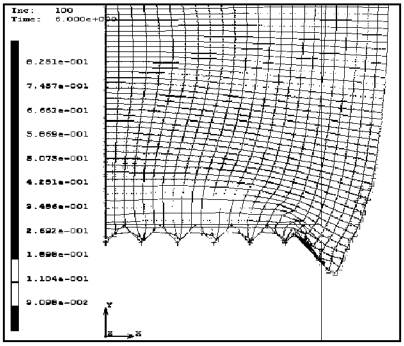


Fig. 4. *Equivalent plastic strain distribution, εt, (2.5 mm pitch)*

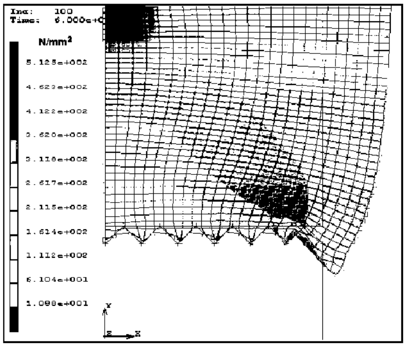


Fig. 5. Equivalent Cauchy stresses distribution, σ_t, (2.5 mm pitch)

In case of using cogged brass samples of 5 mm cogs pitch, the finite element model preserved the aluminium part meshing (the same number of finite elements was used), the cogs angle and their contact condition (Fig. 3). The differences come from the reduced number of brass component cogs, and their increased height, respectively. Although the aluminium part deformation rate was preserved at 20%, the increased cogs height and the doubled number of the finite elements between per cog pitch improved the material flowing.

Fig. 6 and 7 illustrate the finite element analysis results concerning the equivalent plastic strain distribution and Cauchy equivalent stresses in case of using cogged brass samples of 5 mm cogs pitch. Approximately 4 times bigger values of elementary strains and stresses were obtained into the joining/cold welded area.

The finite element analysis results were practically confirmed by welding tests. As Fig.8 presents, on the macroscopic image of the cold-welded joint are visible the deformed aluminium fibres *S* shaped. Moreover, a model correction is required: the friction coefficient value between the pressing device (active part) and the aluminium part must be increased.

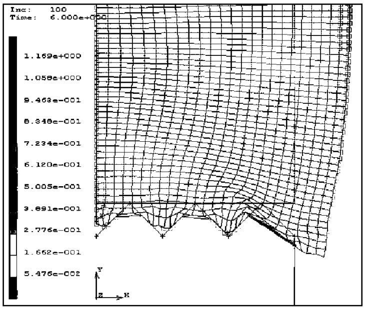


Fig. 6. *Equivalent plastic strain distribution, εt, (5 mm pitch)*

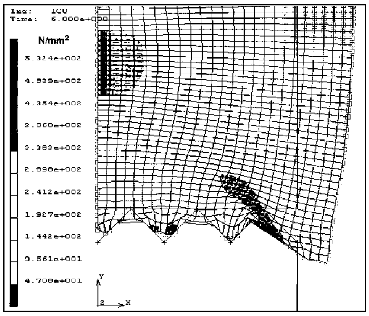
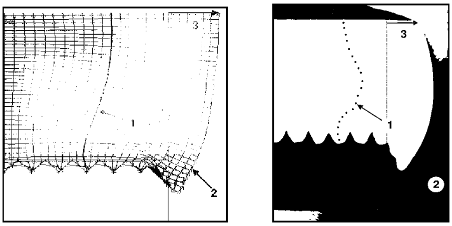


Fig. 7. *Equivalent Cauchy stresses distribution, σ_t, (5 mm pitch)*



a) **b)**

Fig. 8. *Aluminium part deformation: a) finite element analysis results; b) macroscopic image of aluminium-steel joint; 1- S-shaped fibres; 2-exterior flowing; 3-in clamps flowing*

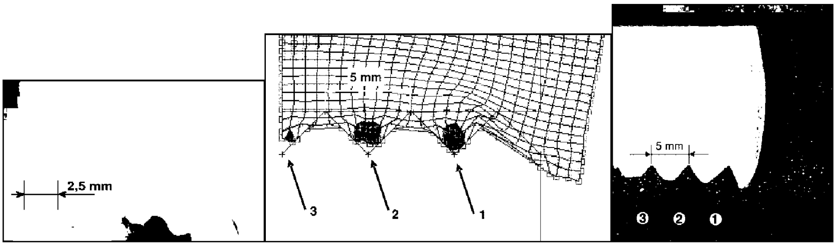


Fig. 9. *Samples of Aluminium incomplete fill-in of the space between the cogs*

The finite element model provides information about the material flowing into the cogged/joining area; incomplete fill-in of the space between the cogs is theoretical described at low deformation rates. The non-uniform fill-in of the space between the brass cogs (Fig. 9) is also explained by the finite element model of the aluminium deformation process on y axis direction.

In case of aluminium exaggerate pressing brass cogs peak flatting or even fractures occur (Fig. 10). This is due to the values of elementary strains-stresses couples recorded in the cogged/joining area during upsetting, which surpass the base materials ultimate strengths. Image of cracks forming into exaggerate pressed brass cold welded joints with an intermediate layer of aluminium is also presented in Fig. 10 [2-4]. The brass exaggerate enlargement that produces the brass cracking and the aluminium joint partial detachment can be detected by using penetrating liquids test.

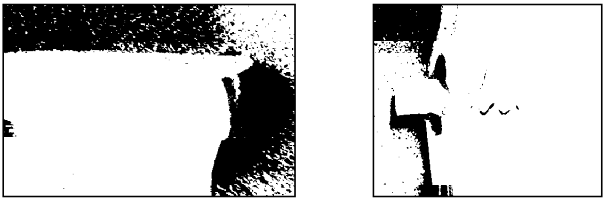


Fig. 10. *Brass cogs deformation and cracks forming in case of exaggerate pressing*

4. Conclusions

The finite element model of the aluminium deformation process during cold-welding on cogged surfaces gives in depth information about: the material flowing and blocking into the cogged/joining area, the strain-stresses couple; incomplete/non-uniform fill-in of the space between the cogs at low deformation rates; cracks forming at the brass cogs base in case of exaggerate pressing. Moreover, continuous pressing after the complete fill-in of the space between the cogs is useless for cold welding achievement.

The model can be used to determine the process optimum parameters by studying the strengths and stresses in the contact/joining area, avoiding insufficient/weak joints or cracks forming.

5. References

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