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THE MODEL OF ALUMINIUM DEFORMATION COLD-WELDED ON COGGED SURFACES

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ABSTRACT

Cold-welding on cogged surfaces can be performed by pressing a piece of aluminium on a cogged surface of a component made up of a more rigid, hardly mouldable material. There have been made welded joints between aluminium (the soft, easily mouldable component) and copper, brass, carbon steel, stainless steel (the rigid component, cogged). Welding has been performed by deforming only the aluminium component with a rate of deformation of 20…30%. The finite element modelling of the system aluminium-brass has allowed to analyse the stress and local strains distribution in the welded joint. Thus, the correct technological parameters have been established in order to avoid problems such as cracks or insufficient joints/ weak joints.

KEYWORDS: finite element modelling, cold welding, aluminium joints.

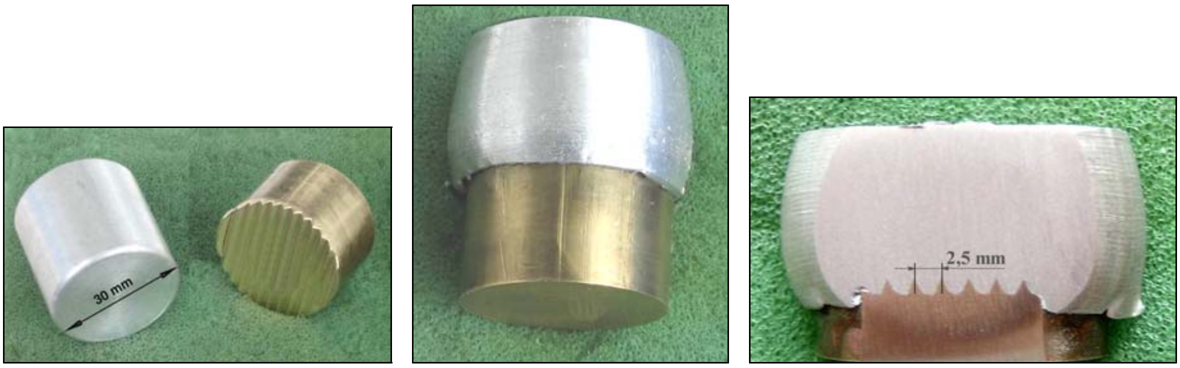
1. INTRODUCTION

Cold welding by pressing on cogged-surface is a new technological option for welding aluminium with different ferrous and nonferrous metals. The process was developed [1] and patented [2] within Robotics and Welding Department from Dunarea de Jos University of Galati, Romania.

The components of the easily-mouldable metals (aluminium, lead, tin, etc.) having plane surfaces are to be pressed on cogged components made up of more rigid materials (copper, brass, carbon steel, stainless steel, etc.), see Fig. 1 a. The purpose is to obtain the deformation with 20…30% of the plastic component only (Fig. 1 b) [4].

During pressing, aluminium occupies the whole space between the cogs (Fig. 1 c). The welding is done by means of isolated gripping points binding, during the relative slipping of the perfectly clean surfaces brought into contact.

The mechanical resistance of the joints is low, but it can be increased by means of thermal treatment. The contact electrical resistance is insignificant, aspect which recommends the use of such joints in the field of electronics [5].



a) b) c)

Fig. 1. Specimens’ components: a) before up-setting; b) welded specimen;
c) the brass cogs imprint the aluminium.

The practical advantage of the cold welding on cogged surfaces is due to the fact that the joint is obtained only by deformation of the easy deformable sample, at lower deformation rates than in the case of classical cold welding. This aspect is illustrated in Fig. 2. At the same deformation rate, the weld was achieved only in case of pressed samples on cogged surfaces, the pressed plane samples couldn’t be joined [1].

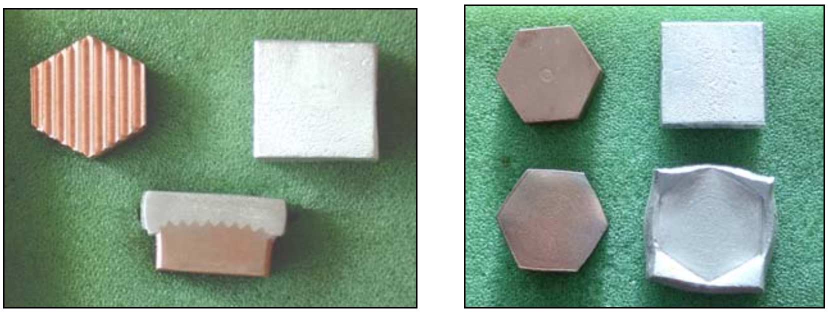

a) b)

Fig. 2. Al-Cu pressed samples at the same deformation rate:
a) weld on cogged surface; b) un-weld samples on plane surfaces.

Cold welding on cogged surfaces can be achieved in the following variants:

- direct, between two samples with different plasticity (Fig. 1);
- indirect, between two samples with the same plasticity, using an intermediate material.

Indirect welding with an intermediate easy deformable layer of aluminium or lead was used for dissimilar hard metals (having cogged contact surfaces) joints as copper+Al+stainless steel, brass+Al+steel etc (Fig. 3a).

Indirect welding with hard metal intermediate layer, use easy deformable samples with plane contact surfaces, welded through a cogged intermediate layer made of a hard metal (Fig. 3b). The intermediate sample, adapted to the easy deformable samples shape, can be obtained by chipping, forming, drawing or bending (Fig. 3c).

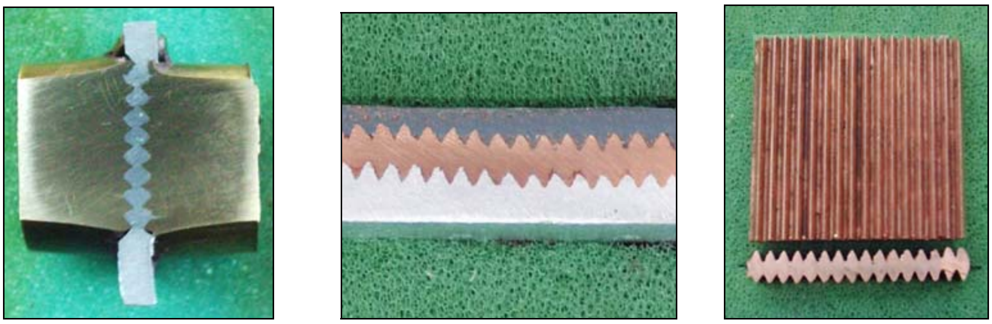

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Fig. 3. Indirect cold welding samples:
a) brass+Al+brass; b) lead+copper+aluminium; c) intermediary element.

The numeric modelling of the aluminium component deformation is necessary in the study of the tensions and local deformations of the welded joint, in order that the previously mentioned defects to be avoided and correct technological parameters to be established. Finite element modelling of the temperatures field, stresses and strains developed during the welding process are the research themes of the Robotics and Welding department [6], [8], [9].

2. FINITE ELEMENT ANALYSIS

The components of the numerical model used for finite element analysis are (Fig. 4):

1 – the active body which apply the pressure necessary for the welding; it has been considered as the rigid, non-deformable body and its kinematics has been described by means of its movement variation along the y axis;

2 – the aluminium sample has been considered as the deformable body;

3 – the brass sample is hardly deformable in comparison with aluminium sample and has been considered the second rigid body.

Mention should be made that only half of the axial section of this system has been considered, given its symmetry (Fig. 5). In this case, the boundary conditions applied on the left side nodes of the meshed deformable sample consist in u_x, u_z displacements blocked: $u_x = u_z = 0$ [7].

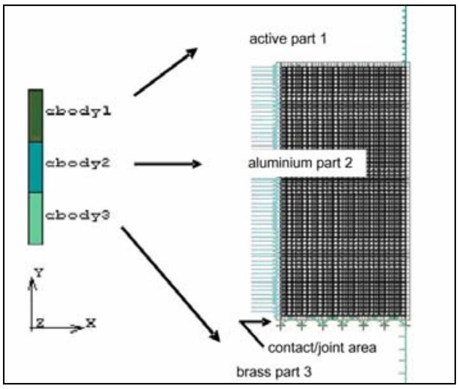


Fig. 4. Elements of the numerical model.

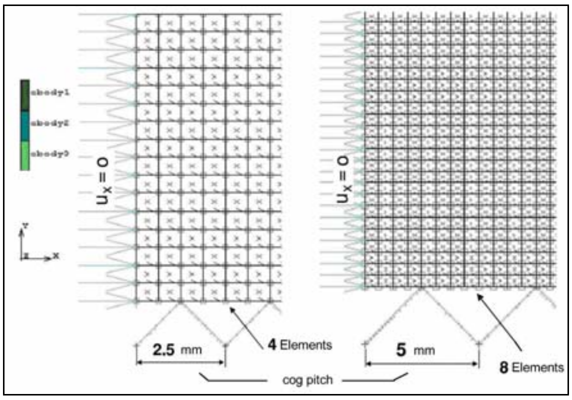


Fig. 5. Mesh of the deformable body.

Sample 2 has been meshed in finite quadratic four-nodded elements considering 24 elements on the x axis and 60 elements on the y axis, so as that the uniformity degree of the mesh to be ensured. The number of elements on the x axis has been established so as to ensure an initial contact between the nodes of the meshed body 2 and the points of the grooves on the surface of sample 3.

The behaviour of the body 2 material (technical aluminium Al 99,5) has been described in relation to the total elastic deformation and to the achieved plastic deformation by means of a Swift law in the form:

$$\sigma = A\left(\varepsilon_0 + \varepsilon_p\right)^m \tag{1}$$

with the following values of the parameters: A = 492,37 and m = 0,242.

The elastic deformation area of this material has been described with the Young module and the Poisson coefficient as follows: E = 72 000 N/mm^2 and $\nu = 0{,}32$.

The modelling has been made by using the MARC Mentat 3.1 programme. Moreover, different degrees of deformation of the aluminium component and different notching pitches have been used in order to perform the modelling [3].

3. THE RESULTS OF THE MODELLING

The analysis with finite elements may provide global or specific elements, on certain desired directions. Figure 6 illustrate the distribution of the equivalent Cauchy tension for the 2,5 mm notching pitch and for a 20% degree of deformation [3].

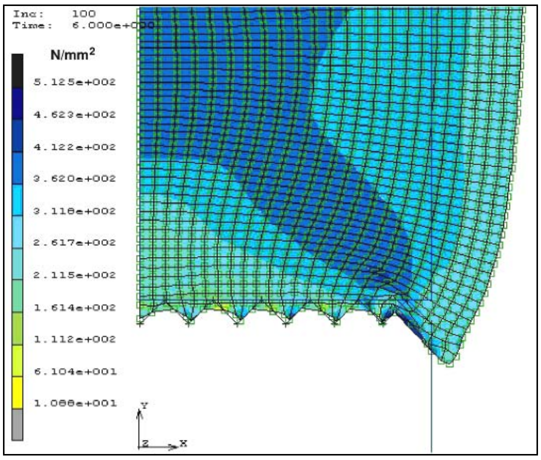


Fig. 6. The distribution of the equivalent Cauchy stress (2,5 mm pitch).

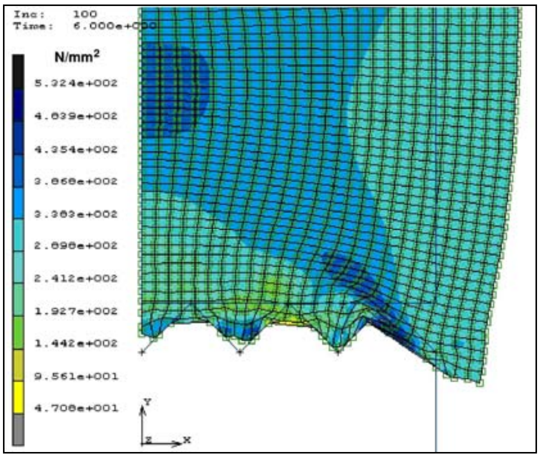


Fig. 7. The distribution of the equivalent Cauchy stress (5 mm pitch).

The images illustrating the modelling process point out the following aspects:

- The external general shape of the deformation is specific to the classical free upsetting;

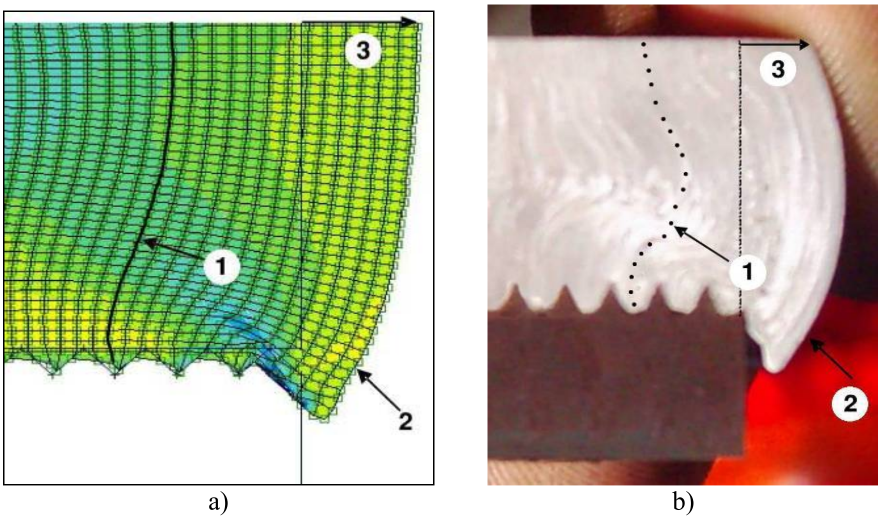
- The central part of the mesh like a "S" due to the staying of the aluminium in the space between the cogs (Fig. 8);
- Strains and stress reach maximum values on the diagonal of the meshed deformable body, along the general slipping line of the material;
- High local stresses are traceable at the bottom of the cogs and on the edge of the welded area;
- The top of the cogs seems slightly flat or round. This aspect may be explained by the parameters of the contact points calculus imposed between the meshed deformable body and the rigid brass body.

In case of using cogged brass samples of 5 mm cogs pitch, the size of the finite elements, the degree of deformation, the angle of the cogs and the initial contact node-pitch have been preserved. In comparison with the previous case, the number of finite elements existing in the space between two pitches is double.

The distributions of the equivalent Cauchy stress for the 5 mm pitch are presented in Fig. 7. The stress distribution is similar only from the perspective of the general deformation of the aluminium. The local deformation of the material between the cogs, the flattening of the sharp points and the leaning of the peripheral tooth are better. The fact should be mentioned that the values of the strains and of the stress in the cogs' area are approximately four times higher.

4. EXPERIMENTAL RESULTS

The finite element analysis results were practically confirmed by welding tests. Slip lines, in the cold-welded joint sample, are visible on the macroscopic image presented in Fig. 8, *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.



a) b)

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

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 theoretically described at low deformation rates (Fig. 9). In practice, this type of flow is detected through optical microscopy or penetrating liquids tests (Fig. 10).

The non-uniform fill-in of the space between the brass cogs (Fig. 11) is also explained by the finite element model of the aluminium deformation process on y axis direction.

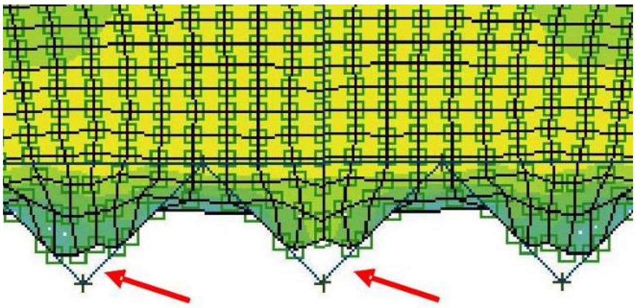


Fig. 9. Aluminium incomplete fill-in of the space between the cogs.

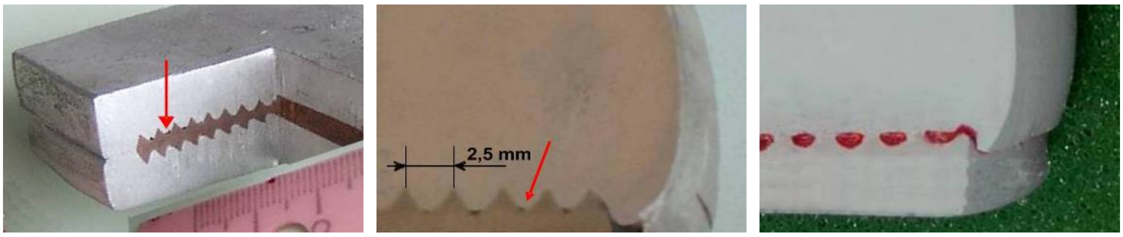


Fig. 10. Samples of aluminium incomplete fill-in of the space between the cogs.

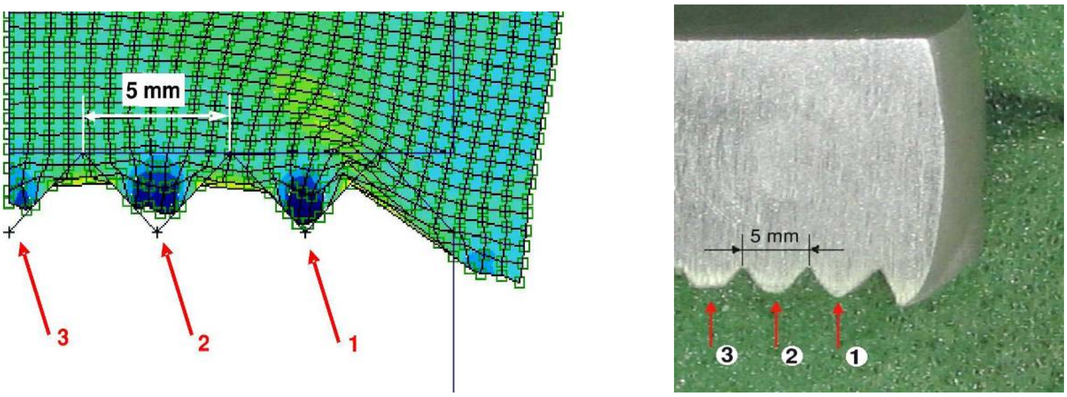


Fig. 11. Aluminium non-uniform fill-in of the space between the brass cogs.

In case of aluminium exaggerate pressing brass cogs peak flatting or even fractures occur (Fig. 12). This is due to the values of elementary strain-stress couples registered during upsetting into the cogged/joining area, which surpass the base materials ultimate strengths. As Fig. 12a presents, in practice, an important deformation of the last brass cog is encountered during cold-welding aluminium and copper.

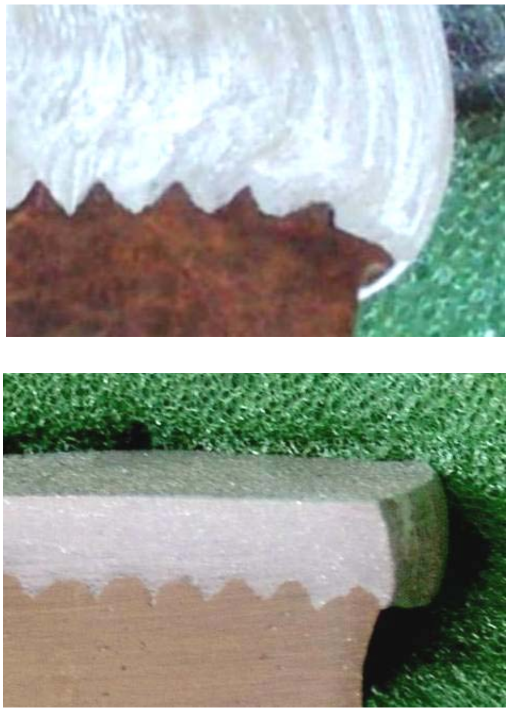

a)

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Fig. 12. Brass cogs deformations: a) aluminium-copper joint; b) aluminium-brass joint.

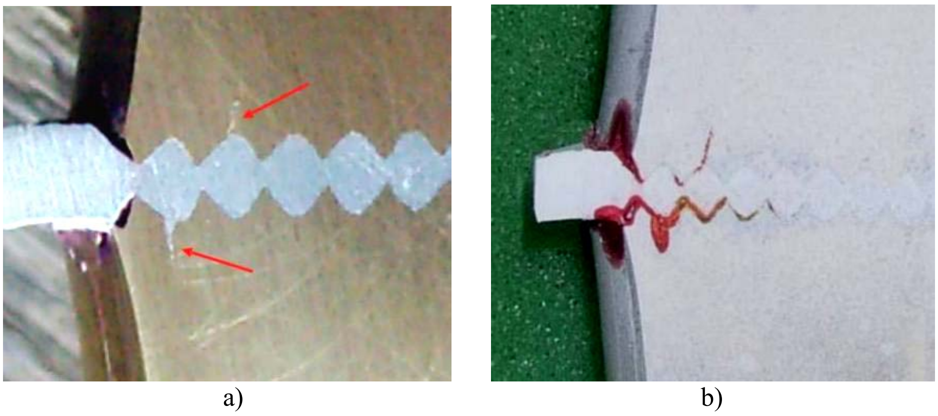
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Fig. 13. Cracks forming at the brass cogs base in case of exaggerate pressed cold-welded joint.

Cracks forming into exaggerate pressed brass cold-welded joints with an intermediate layer of aluminium is presented in Fig. 13. This is due to the stress values registered at the cogs base as results from the process finite element analysis. The brass excessive enlargement which produces the brass cracking and the aluminium joint partial detachment can be detected through penetrate liquids tests.

5. 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-stress couples evolution;
- 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, it must be underlined that 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 optimum process parameters by studying the strains and stress evolution in the contact/joining area, avoiding insufficient/weak joints or cracks forming.

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