AN OVERVIEW OF WELDING ON COGGED SURFACES

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Abstract: *Welding by cold pressing on cogged surfaces, produces the joint of a component made from an easy deformable metal by pressing on the cogged surface of a harder metal component. Different welds between aluminium (the easy deformable component) and copper, brass, steel, stainless steel (harder component, cogged on the contact surface) can be obtained. The weld is obtained only by deforming the aluminium component at a deformation rate of 20…30%. The weld tensile strength is up to 10% of aluminium ultimate tensile strength, better results being obtained for the shearing strength. The weld contact electric resistance is negligible, recommending the process for producing dissimilar elements used in electrotechnics.*

Key words: *Cold Pressure Welding, Aluminium Joints.*

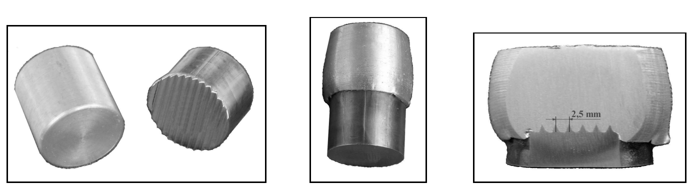
1. Introduction

Cold welding on cogged surfaces is a technology developed by researchers from Robotics and Welding Department, *Dunărea de Jos* University of Galați [9]. Easy deformable samples, having plane surfaces, are pressed on cogged surfaces of harder samples (Figure 1). Of importance for joint achievement is the deformation rate of the easy deformable material.

The practical advantage of the cold welding on cogged surfaces is due to the fact that the joint is obtained only by deforming the easy deformable sample, at lower deformation rates than in the case of classical cold welding. This aspect is illustrated in Figure 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 [7].

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

- direct, between two samples with different plasticity;
- indirect, between two samples with the same plasticity, using an intermediate easy deformable material.



a) b) c)

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

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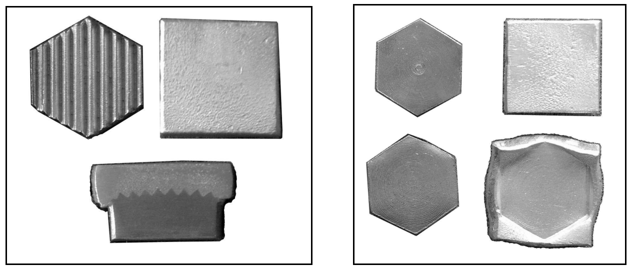


a) b)

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

2. Direct Welding

Through direct welding by cold pressing on cogged surfaces an easy deformable material is joined with the cogged surfaces of a harder metal. Were used cylindrical samples with 30 mm diameter and highs of 20...40 mm. The contact surfaces were firstly mechanically cleaned with a rotating steel-wire brush, at a rotating speed of 2800 rot/min. Immediate after the samples' cleaning, a hydraulic press was used for samples up-setting [6].

Different welded joints were achieved between aluminium (easy deformable sample) and copper, brass, steel and stainless steel (harder, cogged sample). Based on the mechanical test results, several conclusions about the characteristics of the cold welded on cogged surfaces joints were drawn.

Through direct welding by cold pressing on cogged surfaces an easy deformable material is joined with the cogged surfaces of a harder metal. The contact surfaces were firstly mechanically cleaned with a rotating steel-wire brush, at a rotating speed of 2800 rot/min. Immediate after the samples' cleaning, a hydraulic press was used for samples up-setting. Different welded joints were achieved between aluminium (easy deformable sample) and copper, brass, steel and stainless steel (harder, cogged sample). The macroscopic images of these joints are presented in Figure 3.

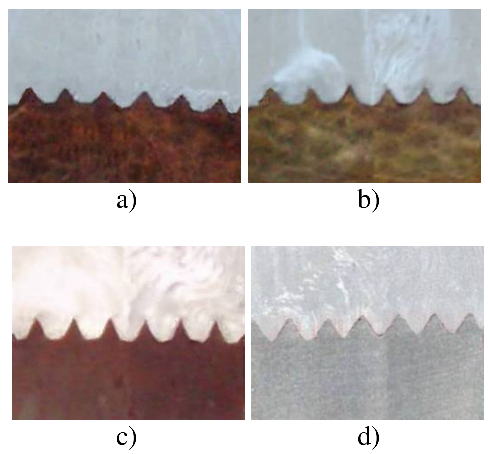


Fig. 3. *Direct welded joints on cogged surfaces*: *a*) *Al-Cu*; *b*) *Al-brass*; *c*) *Al-steel*; *d*) *Al-stainless steel*

Deformation rate. The weld was achieved only by deforming the aluminium sample, at a deformation rate of 20-30%. Higher deformation rates aren't recommended [1].

Insufficient pressings with reduced degrees of deformation have resulted in an incomplete filling of the space between the cogs, and consequently, in a reduced mechanical resistance. This inconvenience may easily be eye-noticed. The smaller discrete unfilled spaces may be seen with the microscope or by means of penetrating liquids.

Moreover, exaggerated pressings result in the deformation of cogs or in cracks. The practice has proved that the peripheral cog frequently modifies its position towards the exterior as a result of the influence of the deformed aluminium on it. Exaggerated pressing is signaled by the flaring of the components.

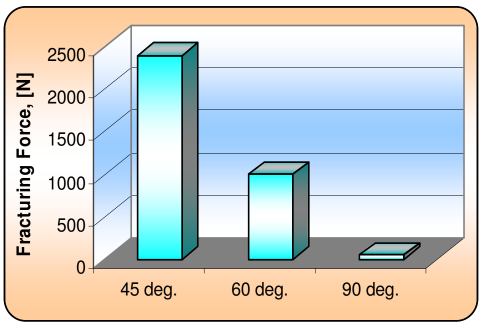


Fig. 4. *The ultimate strength by the stretching of cogs with different angles*

Minimum deformation rate in cold welding on cogged surfaces. The further contact surfaces of the two components were mechanical cleaned after the bolts mounting, using a rotating wire brush at a speed of 2800 rot/min. The up-setting process of the specimens was made immediately after cleaning, using a 200 kN hydraulic press. For the same deformation rate (computed only for the aluminium component), 3 tensile tests were made, to balance the experimental results. These average values were used to plot the diagram in Figure 4.

Figure 5 presents the tensile strength - deformation rate dependency in case of cold welding on cogged surfaces of the aluminium with different materials. Analyzing these curves plotted in case of pressing the aluminium component on copper, steel, respectively stainless steel, small differences regarding the joint resistance can be noticed, which allow grouping these materials in two categories:

- 1st group: copper and brass; the joint maximum resistance is obtained at 20% deformation rate (computed only for the aluminium component);
- 2nd group: steel and stainless steel; the joint maximum resistance is lower than in copper and brass case and is registered at 30% deformation rate (computed only for the aluminium component).

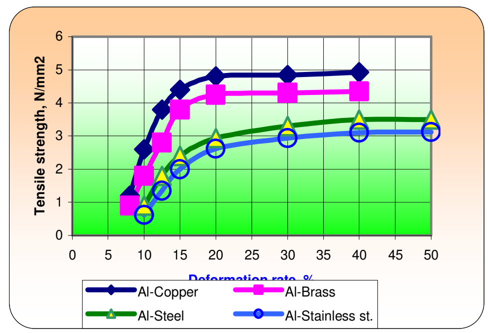


Fig. 5. *The tensile strength-deformation rate dependency in case of cold welding on cogged surfaces of the aluminium with different materials*

This behavior can be explained, on one hand, by the natural tendency of the aluminium-copper couple to form cold welded joints by up-setting. On the other hand, these different behaviors are due to the different friction forces initiated on the contact surface at pressing, which are responsible for the aluminium slip over the second material cogs and the gaps filling-in.

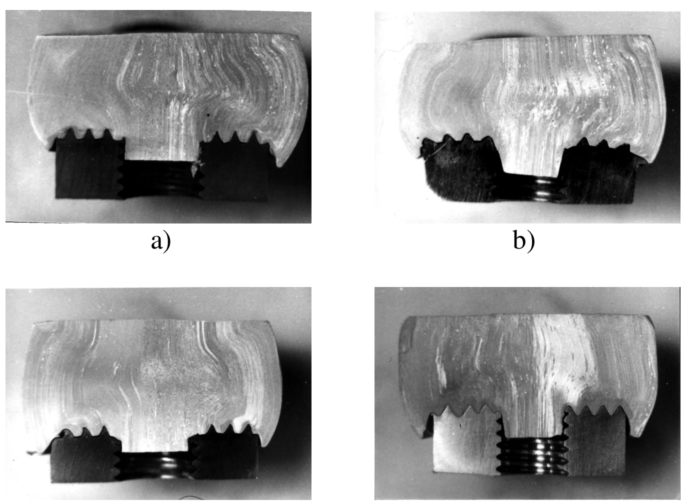
The metallographic analysis showed, for the same 20% deformation rate, that the gaps were completely filled only in the copper and brass cases. In the steel case, the gaps were completely filled only at the 30% deformation rate. The initial shape of the cogs of the harder material wasn't modified during the pressing process.

From the Figure 5 we can conclude that the joint maximum strength is obtained at 20% deformation rate, although the cold welding process starts at lower deformation rates. The joint tensile strength is up to 5 MPa. This small value is due to the achieving of the welding in just a few isolated points, because the aluminium slips and stocks in the harder materials' cogs.

Materials deformation. In classical butt cold pressure welding case both materials are deformed. This joint's strength depends on the number of the cold welded points (of the contact surface) initiated as a result of the material flowing at deformation rates over 70%.

As it was already mentioned, in the case of the contact on cogged surface only the aluminium component is plastically deformed by up-setting. The increase of the aluminium deformation rate over 20-30% doesn't improve the joint strength. When pressing, the aluminium component slips and fills-in the gaps between the cogs. The harder component's cogs stop the aluminium flowing on the contact surface. The increase of the deformation rate moves the material plastic deformation to a weaker, milder area, situated on the middle of the aluminium component, without any influence on improving the dissimilar joint's strength. This explanation was theoretically and practically confirmed by FEA, respectively by the metallographic analysis.

The model of the materials deformation process corresponds to the macroscopic images of different dissimilar joints presented in Figure 6.



a) b) c) d)

Fig. 6. *Macroscopic images of different samples of cold welding on cogged surfaces at 50% aluminium deformation rate: a) Al-steel; b) Al-Cu; c) Al-brass; d) Al-stainless steel*

The aluminium flowing lines were visible on the macroscopic images realized on different cold-welded samples on cogged surfaces at 50% deformation rate. The mesh deformed shape corresponds with the real material deformation process.

The increased value of the aluminium deformation rate used for joints achievement doesn't affect the shape of the steel cogs. Small influences were recorded on the brass case (Figure 4c). The copper cogs were visible deformed at 50% the deformation rate.

The cogs geometry must be correlated with the dimensions of the welding samples. In small samples case, the cog angle must be up to 45^0 for a pitch over 2.5 mm (Figure 7). The double cogged joints resisted better of the simple cogged joints (Figure 8).

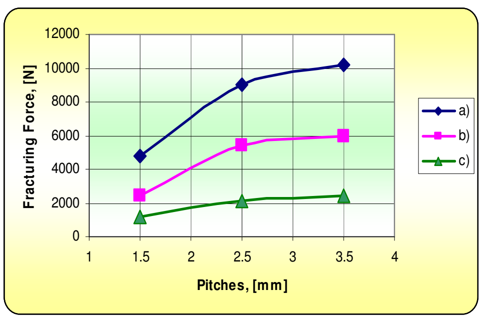


Fig. 7. *The ultimate strength at different pitches: a) by cross shearing; b) by longitudinal shearing; c) by stretching*

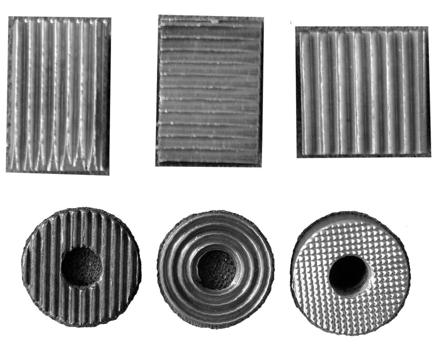


Fig. 8. *Different cogging*

The joint mechanical characteristics are: the tensile strength is up to 10% of aluminium ultimate tensile strength (50…80 MPa), double values were registered in case of the shearing strength (Figure 9).

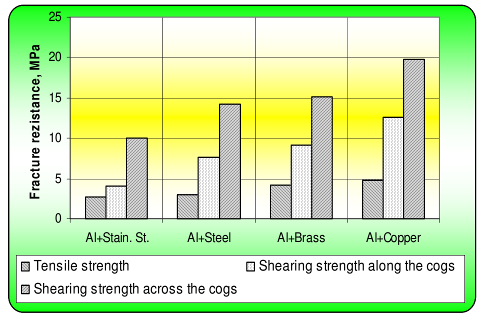


Fig. 9. *The fracture resistance for different cold-welded samples on cogged surfaces* [4]

Thermal treatments. Components of aluminium and copper, on the one hand, and of aluminium and carbon steel, on the other, were welded by using a degree of deformation of 30% applicable to the aluminium component only.

The lack of homogeneity in the joints (made up of materials with very different dilatation - contraction coefficients) may result in the shearing of the joint during the warming-cooling of the samples. In order to avoid such situations, a pre-compression device has been used (see Figure 10).

It is represented by a U 120 profile with plane-parallel processed internal facets and holes, which allow the free passing of the screws threaded in the samples.

The pre-compressing is obtained by means of the screwed nut. The dimensions of the support have been chosen so as to allow its placing in the thermal-treatment furnace. The heating was performed in an electrical laboratory furnace.

The mechanical characteristics can be improved through thermal treatments; up to a 3 times increase can be obtained by joints' 30 minutes heating at 500 ^{0}C, at normal atmosphere [5].

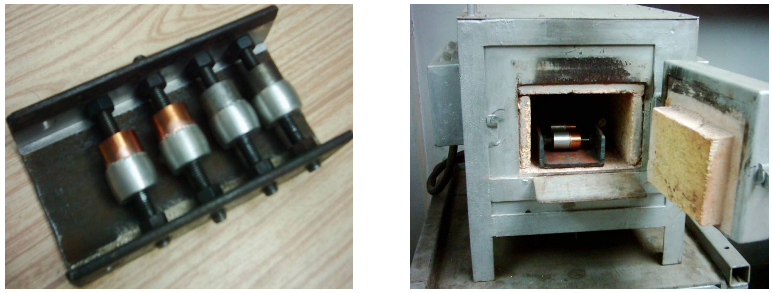


Fig. 10. *The compression device for the welded samples and the electrical furnace*

The heating by favoring the diffusion processes lead to a constant increase in the traction resistance of the joints welded on cogged surfaces, as it may be seen in the graph under Figure 11.

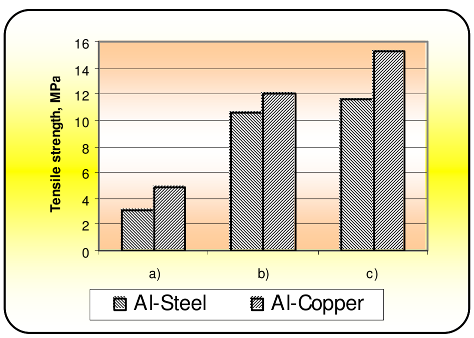


Fig. 11. *The influence of the thermal treatment on the resistance of the joint: a) without thermal treatment; b) with free thermal treatment; c) with pre-compressed thermal treatment*

The contact electric resistance measurements made with a CA 10 Microhmeter on the cold welded samples on cogged surfaces (Figure 12) indicates negligible values: 1 microhm for Al + Copper and 6 microhm for Al + Steel. These values are constant for different pressing force.

3. Indirect Welding

At indirect welding, the intermediate metal must be weld with each sample, according to their plasticity. Depending on their plasticity, it can be discussed about [2]:

- cold welding on cogged surfaces with an intermediate easy deformable layer;
- cold welding on cogged surfaces with an intermediate hard metal layer.

It must be underlined that the plasticity characteristic is relative, comparing with the steel, the copper is easy deformable and the steel is harder than the aluminium or lead [8].

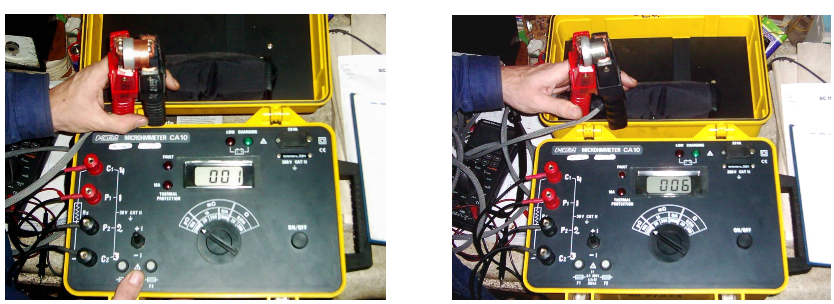


Fig. 12. *Contact electric resistance measurements*

Fig. 13. *Cold welding samples with Al and Pb intermediate layer*

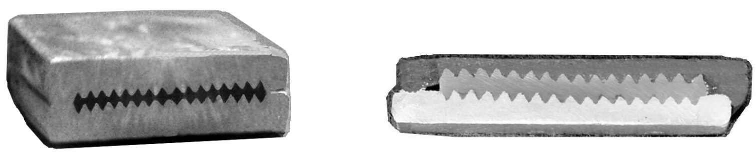


Fig. 14. *Cold welded samples with intermediate cogged layer*

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. Figure 13 presents the brass + Al + brass joint and the copper + lead + copper joint.

Indirect welding with hard metal intermediate layer. Easy deformable samples with plane contact surfaces are welded through a cogged intermediate layer of a hard metal. The intermediate sample, adapted to the easy deformable samples shape, can be obtained by chipping, forming, drawing or bending.

Figure 14 presents aluminium + copper + aluminium and lead + copper + aluminium cold welded samples.

4. Conclusions

• Cold pressed welding on cogged surfaces can be obtained at lower deformation rates of the aluminium component, up to 20…30%.

• Bi-metallic or multi-layer components can be produced by cold welding on cogged surfaces between materials with different plasticity properties [3].

• The joints' tensile strength can be improved by thermal treatment, with or without pressing, stimulating the diffusion process of the peripheral atoms of the two materials.

• The contact electric resistance of the cold welded samples on cogged surfaces is negligible, recommending this type of joints for the electrical engineering applications.

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