# A SYNTHETIC APPROACH TO COLD PRESURE WELDING ON COGGED SURFACES

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## ABSTRACT

*Pressure welding on cogged surfaces represents a new technological variant of the cold welding. The components that are made from a material with higher plasticity (aluminium, lead etc.), having flat surfaces, are pressed on or between the harder material components (copper, brass, carbon/stainless steel, titanium, etc.) that have cogged surfaces. The main particularity of this technique is to achieve an appropriate joint by deforming only the component with higher plasticity. Due to the low degree of deformation needed, reduced pressure forces are applied in comparison with the classical cold pressure welding. The welding in isolated catching nodes is achieved by gripping, while the aluminium is gliding on the flanks of the teeth. The tensile strength of the joint is relatively low reaching up to 10% of the aluminium part, but can be improved by applying a heat treatment. Welded joints were made in various combinations, resulting in bimetallic or multilayered workpieces. Due to the negligible contact resistance, these joints can be appropriately used for applications in the electrotechnical field.*

**KEYWORDS:** Cold pressure welding, cogged surfaces**,** aluminium joining

## 1. INTRODUCTION

The welding of aluminium alloys presents some difficulties due to the formation of an oxide layer on their surfaces. They can be assembled in different mechanical methods like gluing, welding (hot or cold welding), and hybrid methods (mixed) [1]. Cold welding consists of joining similar or dissimilar metals at temperatures below the melting point and without the use of filler material [2–7]. Among the processes used for cold welding are friction stir welding [8–11], rotary friction welding [12–15], diffusion bonding [16–19], explosive welding [20–23], or ultrasonic welding [24–27], each of them having their own advantages or disadvantages.

The principle of pressure welding consists of bringing the peripheral atoms of the components at the distance comparable with the lattice constant, so that a good connection is achieved. In order to obtain quality joints, cold pressure welding has the following particularities [28]:

- thorough cleaning of the surfaces to be welded, before the moment the pressing force is applied;
- plastic deformations must reach values above 70% in the case of aluminium alloys and above 90% in the case of copper;
- the use of elevated discharge pressures due to the occurrence of strong strain hardening of the material during deformation; for example, the necessary pressure in the case of soft aluminium (annealed) is 800-1000 MPa, 8-10 times higher than its tensile strength.
- Cold welding is applicable in end-to-end variants, in points, or by cold rolling.

*Butt cold welding* is used for welding wires, bars (having a diameter between 0.05-13 mm), or profiles of reduced transversal sections, made from easily deformable materials like aluminium, copper, gold, platinum, silver, lead, tin, cadmium, etc. This procedure produces quality joints with good mechanical resistance, with the fracture occurring in the base metal as can be seen in figure 1 [29**]**. One of the most important applications is welding aluminium or copper wires that are in the process of trellising.

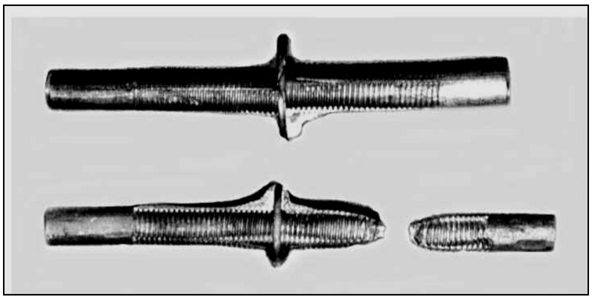

**Fig. 1.** Aluminium bars butt cold welded [29]


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*Cold welding in points* is applied to sheets with 0.2-15 mm thickness stacked and pressed locally with the help of piercers, usually having a circular form. Local deformation can be achieved bilaterally (Fig. 2a) with two pins for obtaining a symmetrical deformation of both components and unilaterally with one piercer when an aesthetic joining is desired (Fig. 2b). Two or more sheets of the same or of different thickness can be welded (Fig. 2c). A specific application is the welding of aluminium couplings from the power supply stations of trans-siberian railways. This has important economic effects by eliminating the use of copper completely [30]. Thus, sections between 5x60mm and 10x100mm were welded in 4-5 points and were used for conducting electric currents of up to 18.000 A.

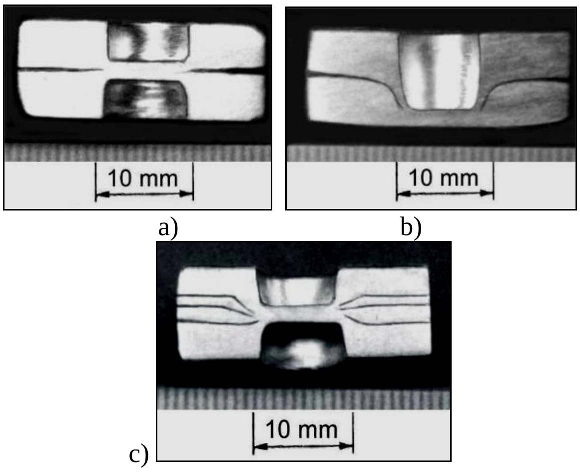



**Fig. 2.** Aluminium plates joined by cold welding [28]

*Cold roll welding*. This process is applied for obtaining bilayered or multilayer joints. The strips of different materials that are about to be cold rolled welded together are passed through straightening, smoothing, and cleaning machines. Usually, the joining is not done on the entire surface of the strip but on numerous centers (nodes) of the metal links. These are enough to accomplish the joint, and allow bending of the multilayer strips into rolls without breaking those bonds [31].

This paper presents an approach of a new cold pressure welding technique that was developed within the Centre for Advanced Research in Welding (SUDAV) from "Dunarea de Jos" University of Galati. Cold pressure welding on cogged surfaces is especially suitable for joining dissimilar metals. It is well known that welding heterogeneous materials raises certain challenges [32]–[35], and this new procedure can offer solutions for some of them.

## 2. PROCESS DESCRIPTION

The process consists of pressing plastic material components, having flat surfaces, on harder material ones that have cogged surfaces. It is intended to deform only the plastic component. This method is destined mainly for the welding of aluminium alloys with other metals.

The cogged surfaces preparation can be theoretically justified by the following aspects:

- the tilted or zigzag welded surface is larger than the area of the normal section of the components to be welded. For this reason, it offers good mechanical strength, even if the strength per unit area of the weld is low due to punctiform grips or inclusions;
- the existence of tangential stresses in addition to the normal ones favourably influences the clamping and cold welding processes;
- the low-speed movement of metals in the welding area helps to eliminate the oxide films resulting in cold welding by sliding (gripping).

In the practice of pressure welding, there are various situations that support the statements above and can be considered a starting point for welding on cogged surfaces.

*Tilted butt welding* has been applied since ancient times to forge welding in which the preparation of the ends is done in the form of a feather or in the shape of a "wolf's mouth" (welding in a "V" shape). It is still applied today to butt welding of wires. Figure 3a shows the microstructure of a cold-welded joint, inclined, end to end, with multiple discharges [36].

*Welding of bimetallic passages* is used in aerospace construction and oxygen production plants. Aluminium + titanium and aluminium + stainless steel tubular bimetallic elements were made. The longitudinal section of the joint has a characteristic appearance, as in figure 3b [28], where it can be observed the processing of some circular channels in the hard component.

*Explosion welding* is used for plating large surfaces, intended for military armour or chemical industry containers, in various combinations of materials. Due to the strong impact, the materials behave as if they were plasticized. They intertwine, forming characteristic waves, as in figure 3c.

The main practical advantage of serrating the surfaces is the possibility of cold welding by deforming only the more malleable metal component, with a much lower degree than in the case of classical welding by pressure. This aspect is presented in figure 4. The samples pressed on cogged surfaces were properly welded, while at the same degree of deformation, the flat surfaces could not be joined [4].

## 3. WELDING TECHNIQUES

Cold pressure welding on cogged surfaces can be classified in two groups of joints made by *Direct Welding* (DW) and *Indirect Welding* (IW), respectively:

a) with soft intermediary metal;
b) with hard intermediary metal.

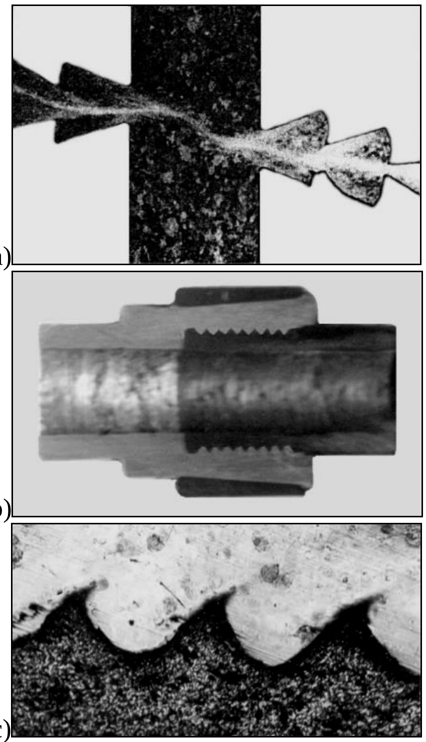

a) b) c)

**Fig. 3.** Welded joints performed by pressure welding on cogged surfaces.

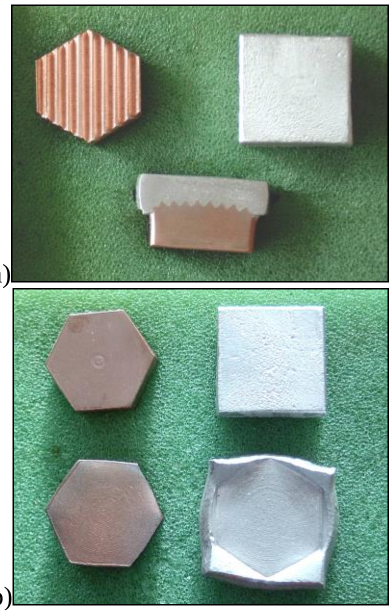

a) b)

**Fig. 4.** Aluminium and copper samples pressed with the same deformation rate: a) cogged surfaces joint; b) lack of joint on flat surfaces

Welding can be done directly, between two components with different plasticity, or indirectly, between two components with the same plasticity using a different intermediate material. The use of an intermediate layer allows to weld materials that:

- are difficult to be deform, which would require the use of very high pressures;
- have different mechanical characteristics, without mutual solubility in the solid state;
- are difficult or impossible to hot weld, as in the case of materials with very different coefficients of expansion.
- the main element in the indirect welding is the intermediate layer which must be weldable with each component separately. Depending on its plasticity related to the materials to be welded, we can distinguish the following situations:
- cold welding on cogged surfaces with a soft intermediate layer;
- cold welding on cogged surfaces with a hard intermediate layer.

It is noted that this characterization of plasticity is relative, not absolute. For example, copper is more easily deformable (softer) than steel but harder (harder to deform) than aluminium or lead.

### 3.1. Direct Welding

Cold direct welding on cogged surfaces is performed by pressing an easily deformable metal on the serrated surface of a harder material (Fig. 5).

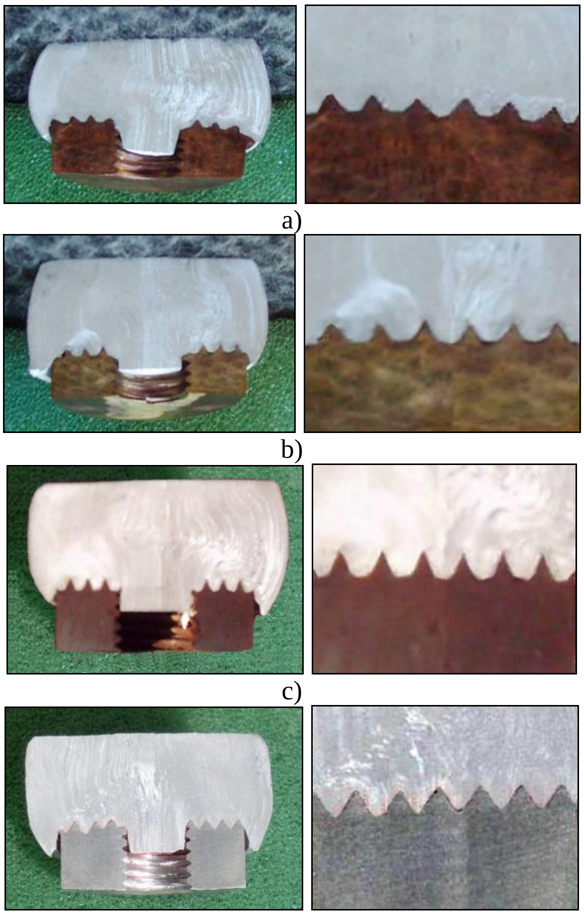

a) b) c) d)

**Fig. 5.** Welded joints achieved by pressure on cogged surfaces: a) Al+Cu; b) Al+Brass; c) Al+Steel; d) Al+Stainles steel

The surfaces to be welded were mechanically cleaned with a rotating stainless steel wire brush at a speed of 2800 rpm. Immediately after cleaning, free pressing (without limiting the deformation of the aluminium) on a hydraulic press was performed. Welded joints were made between aluminium (soft, easily deformable component) and copper, brass, carbon steel, and stainless steel (harder, cogged component). A 200N/mm$^2$ pressing force is necessary to obtain quality joints. The macroscopic analyses of the joints made from 30mm diameter components are presented in Figure 5. It can be observed that the joints show no visible defects and the penetration of the softer material into the harder one is complete.

Tensile and shear tests were performed on the welded joints, using specially designed equipment, as presented in Figures 6 and 7.

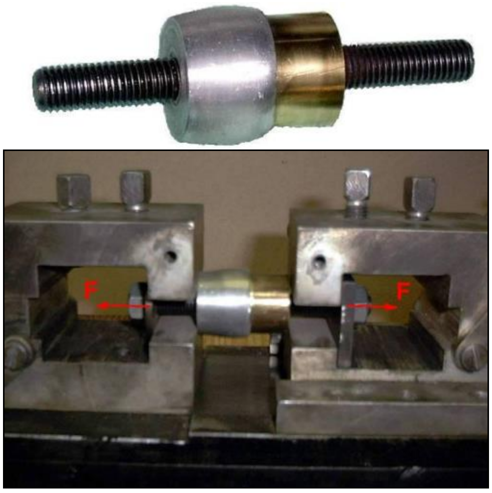



**Fig. 6.** Equipment used for tensile testing

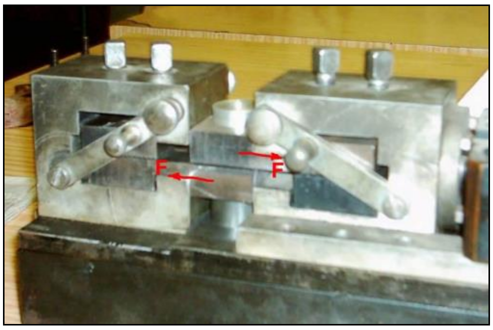



**Fig. 7.** Equipment used for shear testing

Based on the results of the tests performed, the following characteristics of the joints welded on cogged surfaces can be stated:

A. *The geometry of the teeth* must be chosen according to the dimensions of the parts to be welded.

From theoretical point of view, it can be used any geometric shape for threading the section of the teeth: triangular, trapezoidal, square, or semicircular. The triangular shape is recommended due to its simpler shape that is easy to machine.

Regarding the direction and shape of the teeth in the plane of the welding surface, based on the experimental tests it is recommended that:

- in the case of rectangular surfaces, the serration can be longitudinal (figure 8a) or transversal (figure 8b), this is preferable because it facilitates the flow of the metal, on a shorter path, along the indentations;
- in the case of double symmetrical surfaces (square, circle, etc.), the direction of the serration has no influence (figure 9 c, d, and e);
- the shape of the teeth in the plane of the surface to be welded can be linear, circular (figure 9e), square, hexagonal, etc. following the peripheral shape of the surface. The complex (double) serration in figure 8f provides superior mechanical resistance.

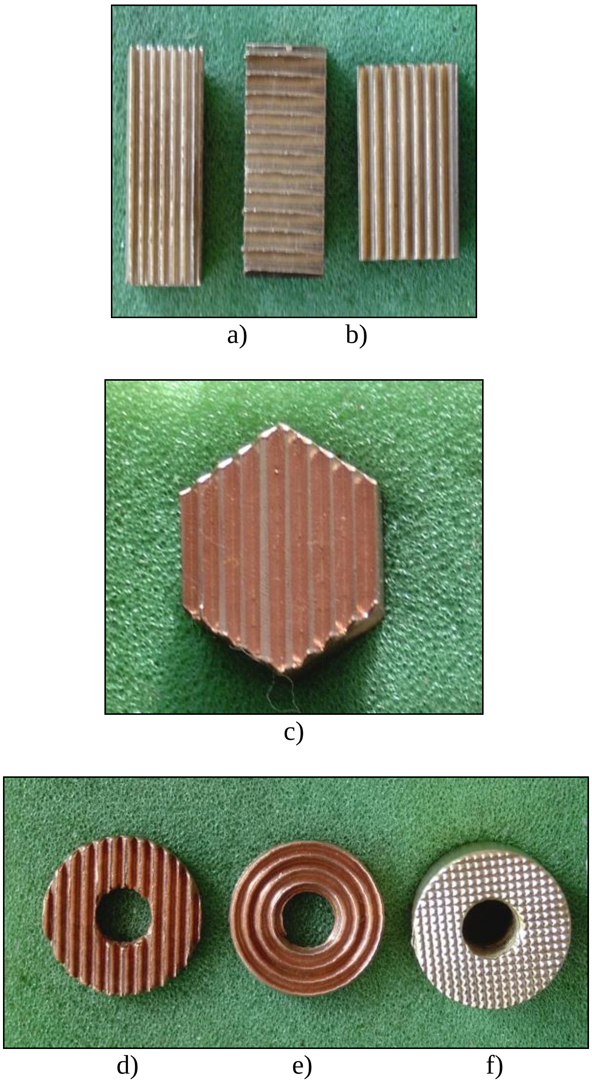



**Fig. 8.** Teeth pattern

The experimental tests also revealed that the ideal angle at the tip of the teeth is below 60 degrees due to the fact that, with its decrease the tensile strength of the joint increases (Fig. 9) [37].

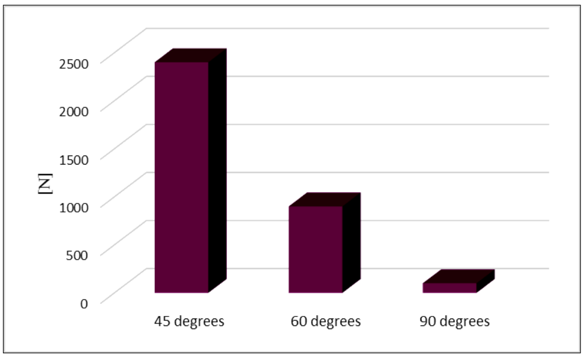



**Fig. 9.** Force determined for different teeth angles

The size of the tooth step must be chosen according to the size of the parts to be welded. The force at which the welded joint beaks is higher as the step size increases (Fig. 10-11). A modification in step size from 1.5 to 3.5 mm leads to an increase of necessary force to break the joint of approximately 200% in the case of transversal shearing, 300% for longitudinal shearing, and 200% for tensile. This can be explained by the increase in the length of the sliding path (gripping). In the case of welding small parts, it is recommended a step of 2.5 mm.

**Fig. 10.** Preparation patterns of surfaces

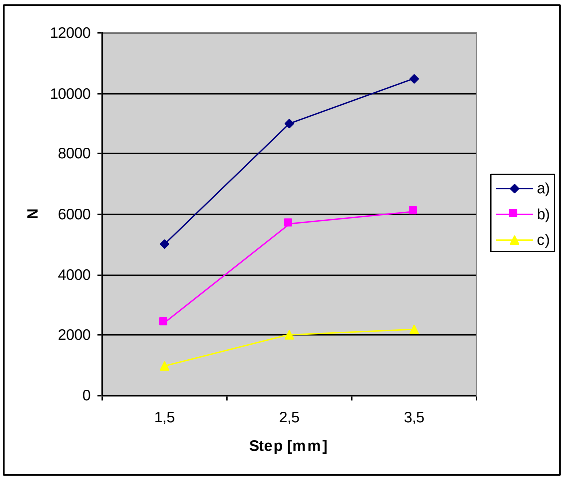
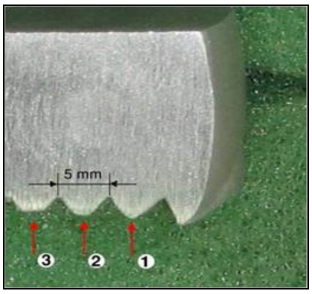



**Fig. 11.** Fracture force at different pitch sizes: a) by transversal shearing; b) by longitudinal shearing; c) by tensile testing

B. *Degree of deformation.* Welding takes place at a 20-30% deformation degree, by deforming only the aluminium component [38]. Lower deformation rates lead to an incomplete fill-inn of the serrated area as was observed both during experimental tests (Fig.12a) and numerical analysis (Fig.12b). The use of an exaggerated degree of deformation is inopportune and even harmful due to the development of cracks at the teeth's base (Fig. 13).

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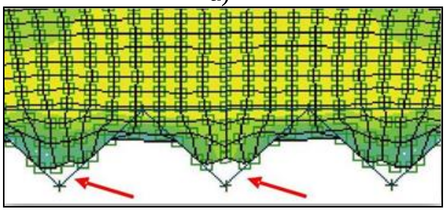


b)

**Fig. 12.** Incomplete penetration when applying insufficient deformation rate: a) experimental tests; b) numerical analysis

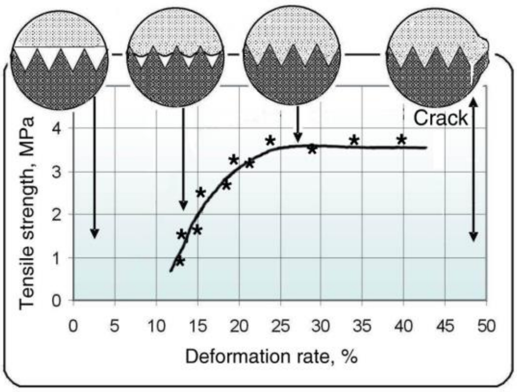



**Fig. 13.** Crack development in cold pressure welding on cogged surfaces

Due to the low deformation rate, the pressure required for welding is lower than in the case of the classical cold welding, reaching values of approximately 200 MPa

C. *Mechanical characteristics.* The tensile strength of cogged surface welded joints is up to 10% of the strength of soft aluminium (50… 80 MPa). The shear resistance has higher values, going up to more than twice as much as tensile strength (table 1).

Mechanical properties can be improved by heat treatment [39]. An increase in resistance of approximately 300% is obtained by heating the welded joints at 500°C for 30 minutes, in normal atmospheric conditions [40].

**Table 1.** Tensile and shear resistance of welded samples [MPa]

| Joint | Transversal shearing | Longitudinal shearing | Tensile strength |
|---|---|---|---|
| Al+Stainles steel | 10,1 | 4,04 | 2,72 |
| Al+Steel | 14,15 | 7,58 | 3,03 |
| Al+Bras | 15,1 | 9,09 | 4,15 |
| Al+Cu | 19,7 | 12,63 | 4,8 |

D. *Electrical contact resistance*. Welded joints on cogged surfaces have a negligible electrical contact resistance, constant over time (Fig 14) without being influenced by clamping forces [41], [42].

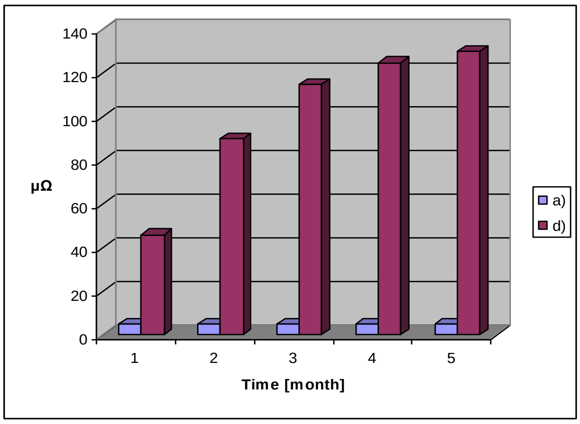



**Fig. 14.** ***Contact resistance vs. time*** of Cu-Al joint: a) joining by cold welded; b) assembling by screw

### 3.2. Indirect Welding

Experimental tests were carried out by cold pressure welding on cogged surfaces, using an intermediate layer in combinations of Brass + Al, Steel + Al, Stainless Steel + Al, Cu + Al, Cu + Al + Stainless Steel, Brass + Al + Steel types of joints**.**

#### 3.2.1. Soft Intermediate Layer

It is recommended to use a soft intermediate layer of a plastic metal that is easily deformable (with smooth surfaces) to weld components made of rigid materials, which are difficult to be formed (that have a previously machined serrated surface).

Experiments were performed using samples of copper, steel, or brass, and, as intermediate material, Aluminium 99.5% annealed (Fig 15) and lead (Fig 16). It was noticed a much easier flow of the lead to the exterior and along the teeth of the welded components.

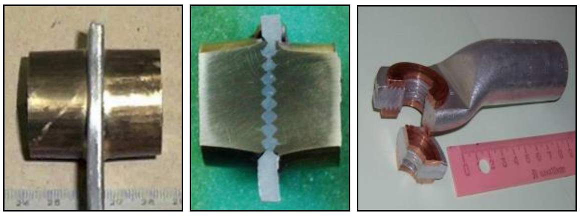


**Fig. 15.** Welded joints with intermediate Al layer

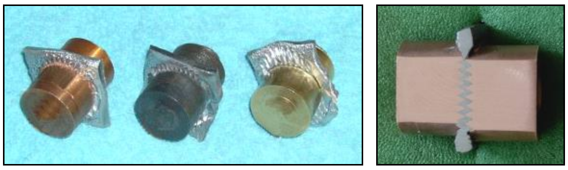


**Fig. 16.** Welded joints with intermediate Pb layer

In Figure 17 there are presented the results of the mechanical tests of the welded joints with aluminium and lead intermediary layers. It can be observed that the strength of the ones with lead intermediate material is lower than those with aluminium, which is normal due to the difference in tensile strength of these metals.

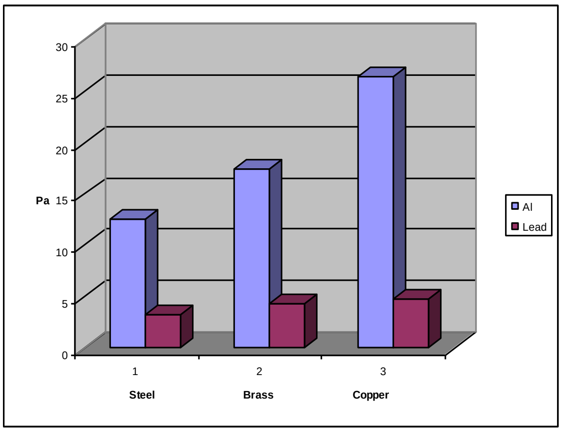



**Fig. 17.** Tensile strength of welded samples with different filler material

Compared to the tensile strength of the intermediate metal, the strength of the joint must be thought of differently. When using a soft aluminium layer, the resistance of the joint was less than 10% of the intermediary material. In the case of lead, the resistance of the joint equaled the one of the intermediary layers. The relative strength of the joint to the intermediary metal can be explained by the mechanism of joints' formation during sliding (gripping) in the case of welding on cogged surfaces. The medium deformable metal (aluminium) slides harder on the surfaces and will have fewer points of attachment, resulting in lower resistance. The easily deformable metal (lead) slides more easily on the surfaces and will have an increased number of attachment points and higher resistance.

### 3.2.2. Hard Intermediate Layer

This variant is used for welding two easily deformable metal components, with flat surfaces, on a cogged element made of harder deformable material. The intermediate element can have a shape similar to the components to be welded (polygonal, disc, shaft) and can be obtained by cutting, stamping, rolling, or bending (Fig 18).

Welding tests were performed with the harder intermediate element embedded inside the more easily deformable ones. Figure 19a presents a joint between two 10 mm aluminium plates with a 60x60 mm square intermediate element, and Figure 19b a joint between a 5 mm flat aluminium strip and a lead plate.

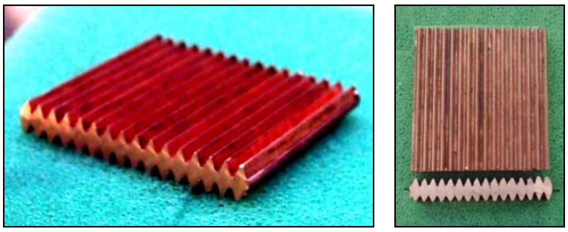
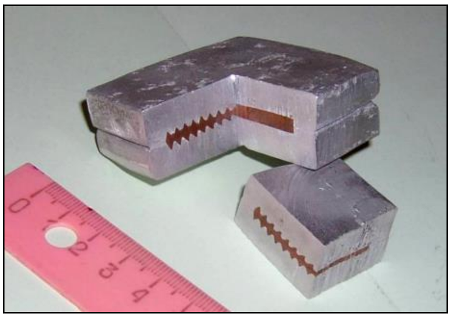


**Fig. 18.** Hard intermediate layer



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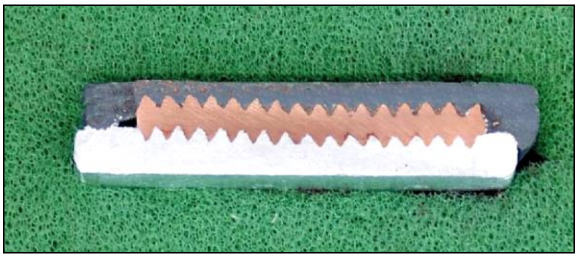

b)

**Fig. 19.** Joints made with hard cogged intermediate layer

## 4. CONCLUSIONS

Following the study done on cold pressure welding on cogged surfaces, it can be concluded that:

- cold welding on cogged surfaces is a simple method, easy to perform in any mechanical workshop.
- it requires the thorough cleaning of the welding surfaces before pressing the components, in the usual conditions of the environment, on any type of available press.
- it is recommended to machine the tip of the teeth at a below 60° angle for the serrated component.
- increasing the size of the tooth step leads to a higher resistance of the welded joint.
- welded joints on cogged surfaces have low mechanical strength and negligible electrical resistance, aspects which makes them suitable for use in the electrical field.

Further studies will be conducted to investigate by microscopy method the bond zone of the cold pressure joint.

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