

FINITE ELEMENT ANALYSIS OF STRESSES AND DEFORMATIONS IN COLD PRESSURE WELDING ASSEMBLY

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***Abstract:** The non-detachable joining of materials with different nature under cold pressure, which we will refer to as "welding," is a form of solid-state diffusion that is unique because it is performed at normal working temperatures. Other forms of solid-state welding are performed at high temperatures, but even though these temperatures are high, the material is not melted, only more ductile. Although cold pressure welding has many important applications, it also presents aspects that are still uncontrolled in its fundamentals. The paper presents research in this field, bringing some original theoretical and practical contributions to the understanding of the principle of cold pressure welding and laying the foundations for the development of new processes that address modern materials. The approach is based on the "Advanced Meshing Tools" and "Generative Structural Analysis" modules of the CATIA software, which allow the simulation of the mechanical behavior of assembled structures, both by analyzing individual elements and as assemblies with connections modeled by idealized elements implemented in these modules. The paper will thus analyze the correlation between stresses and material deformations in the mechanically affected zone (MAZ).*

Key-words: cold pressure, welding, diffusion, simulation

1. Introduction

The cold pressure welding process can be easily and conveniently carried out, practically resulting from pressure applied between two previously processed and carefully cleaned metal parts. This process requires materials with a high degree of deformability (usually above 70%), achieved by using high pressing forces capable of generating deformation pressures ten times higher than the material's maximum yield strength. Cold pressure welding can be mainly carried out through two methods: spot welding and butt welding. In both cases, welded joints can be made between identical or different materials, resulting in homogeneous or heterogeneous assemblies. Easily deformable metallic materials such as aluminum or copper can be cold pressure welded, but the process can also be carried out between different metallic materials such as aluminum-steel, aluminum-titanium, etc.

2. The determination of the thermic field equations

Cold pressure welding has both interesting theoretical and practical aspects related to the minimum clamping force required to achieve the joint. Compared to hot pressure welding, where the edges of the parts are heated through Joule effect and the pressure is around $(0.1 \dots 0.2)\sigma_c$, in the case of cold pressure welding with end-to-end joining, the pressure is $p = (8 \dots 10)\sigma_c$, which means that for the same material, the pressure can be up to 200 times higher.

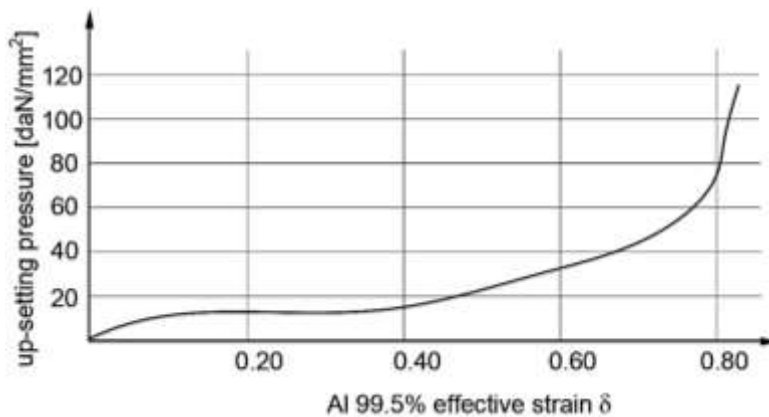


Fig.1. Pressure - deformation curve cold welding case

3. Materials and methods

3.1. Materials

For the experimental determinations of cold pressure welding, cylindrical specimens with a diameter of $\Phi = 30$ mm and a length of 35 mm were used, made of S235 steel and aluminum. The specimens were obtained by cutting from a bar (for steel) and sheet (for aluminum) using a band saw produced by Einhell (TC-SB 200/1). The chemical composition of the materials used for the specimens is presented in Table 1 (for S235 steel) and Table 2 (for aluminum) [1].

Table 1. Chemical composition of steel materials used in experiment

Chemical composition [%]	Fe	C	Mn	P	S	Cr	Ni	Cu	Other
S235	97.72	0.20	1.40	0.04	0.04	0.003	0.01	0.55	0.10

Table 2. Chemical composition of aluminium materials used in experiment

Chemical composition [%]	Al	Fe	Cu	Si	Mg	Zn	Mn	Cr	Ti	Sn	Pb	Ni	Sb
Aluminium	95.47	1.34	1.12	0.47	0.43	0.92	0.11	0.02	0.02	0.001	0.04	0.01	0.01

The aluminum used is a low-alloy aluminum. It is known that the solubility of some alloying materials in aluminum is low. However, some alloying elements that are still present in aluminum, even in low concentrations, improve its mechanical properties as well as its technological properties.

The aluminum and its alloys do not undergo solid-state transformations, so they do not have the possibility of annealing or normalizing heat treatments. Heating aluminum alloys above 200°C leads to a decrease in hardness and strength.

Different materials were chosen for the workpieces because in cold welding, bonds between atoms of different nature are formed, which are much more stable and stronger than bonds between atoms of the same kind. It is anticipated that this will increase the possibility of intermetallic compounds in the joint [2].

3.2.Methods

The experimental method consisted of butt joining the steel and aluminum samples. In order to increase the diffusion surface, the joining surfaces of the steel samples were only processed by facing, resulting in a roughness $Ra = 12.5 \mu\text{m}$.

To achieve cold welded joints, a CP 86150 hydraulic press was used with the following specifications: pressing force of 250 daN, piston displacement of 200 mm, pressing speed of 10-100 mm/s. The pressing speed was an important parameter in achieving the joint.

Once the workpieces were prepared, they were pressed to achieve cold pressure welding. Successive joints were made, first on pieces placed freely on the hydraulic press, then on pieces using additional positioning and guiding devices. The work method without auxiliary devices is shown in Figure 2, while the method that used additional devices is shown in Figure 3 [2].

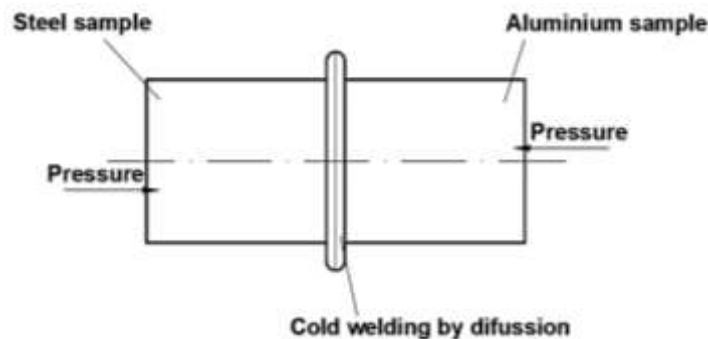


Fig.2. Pressing parts without additional device

After pressing, it was found that the cold-welded parts by pressing without additional devices in the joint area deformed non-uniformly and uncontrollably, without precise flow directions, suffering from undulating and barrel-shaped deformations (fig.4). To control and eliminate these unwanted deformations of the parts, additional devices were used to work with, with the help of which both the positioning and orientation of the parts were achieved during pressing in the form of two guide bushings in which the assembly parts were inserted.

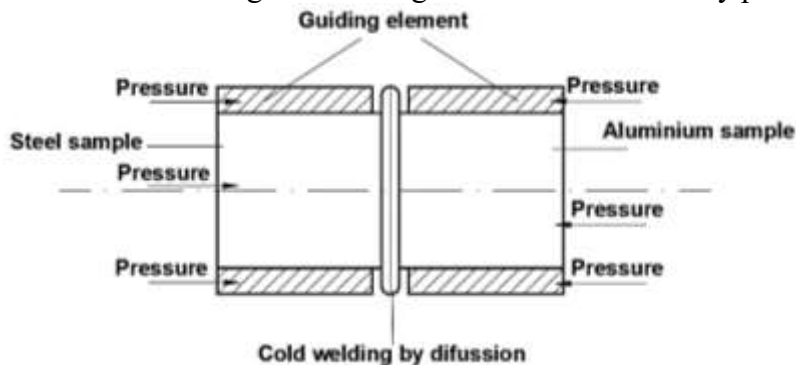


Fig.3. Pressing parts with additional device

The length of these bushings was made to be 5 mm smaller than the length of the assembly parts, and the material that was extruded during pressing was intended to fill the space between the ends towards the outside (fig.5).



Fig.4. Pressing parts without additional device



Fig.5. Pressing parts with additional device

3.3. Finite element analysis method

The "Advanced Meshing Tools" and "Generative Structural Analysis" program modules in CATIA allow for simulating the mechanical behavior of assembled structures, both through the analysis of individual elements and as assemblies with connections modeled by idealized elements implemented in these modules. The analysis was performed taking into account both the case of the free pressing of the two parts, as well as the case of using additional devices to prevent uncontrolled flow of material [3], [4], [5].

Figure 6 shows the simulation of the behavior of the parts without an additional device, with frontal distribution of the pressing force. In the upper part, with a higher degree of deformation, is the aluminum part, showing the "barrel" shape. The pressing force was kept the same as in reality, at 150 daN. The maximum values of stress, represented graphically by colors close to red, were $9.87 \cdot 10^8 \text{ N/m}^2$, but distributed separately. The minimum values of stress, represented by blue colors, had values of $1.56 \cdot 10^8 \text{ N/m}^2$. To visualize the material flow on the entire contact surface, Figure 7 shows a section through the welded parts. A circular distribution of stress is observed on the contact surface between the parts, towards the outside. Inside the surface, the material was very lightly stressed. Increasing the value of the pressing force to 170 daN and subsequently to 200 daN did not result in significant material flow values, maintaining the geometry of the deformation.

The following simulation was made by applying the pressing force from the cylindrical surface of the parts, in axial directions, oriented from the ends towards the contact surface. Figure 8 shows the simulation of the behavior of the parts without an additional device, with the distribution of the pressing force from the cylindrical surface of the parts and at the same magnitude of 150 daN. As expected, the aluminum part deformed more than the steel one. One difference between the two simulations is that, when applying the force from the cylindrical surface, the flow of material was more pronounced towards the joint surface, and also the stresses were concentrated towards that area, which became prominently colored red, with a maximum value of $8.44 \times 10^8 \text{ N/m}^2$. A section through the assembly is shown in Figure 9, where an extension of the deformed contact surface can be observed, indicating a more pronounced material diffusion.

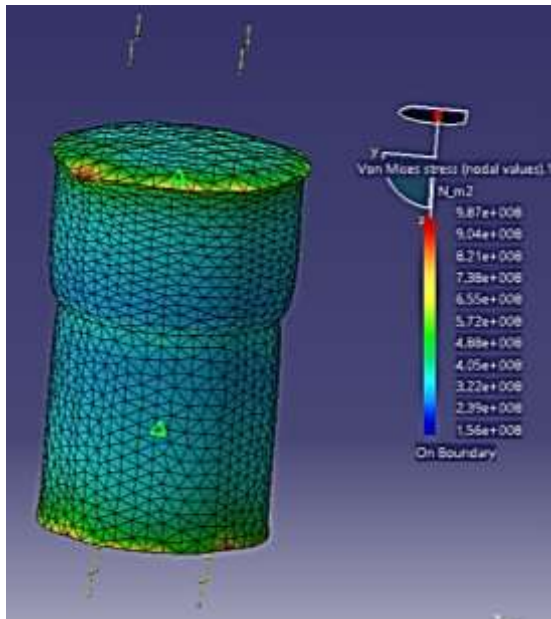


Fig.6. Analysis of deformations and stresses with the application of force on the frontal surface

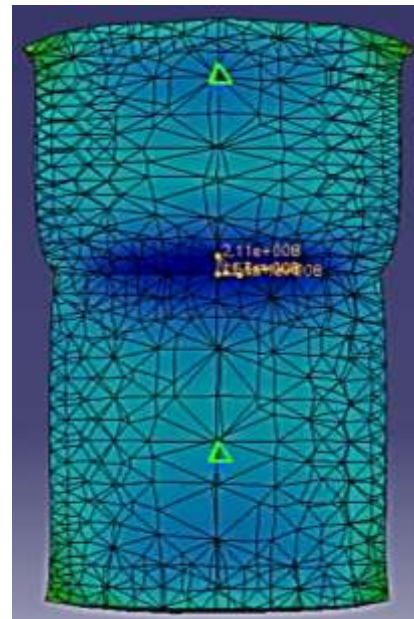


Fig.7. Material flow inside parts when force is applied to the front surface

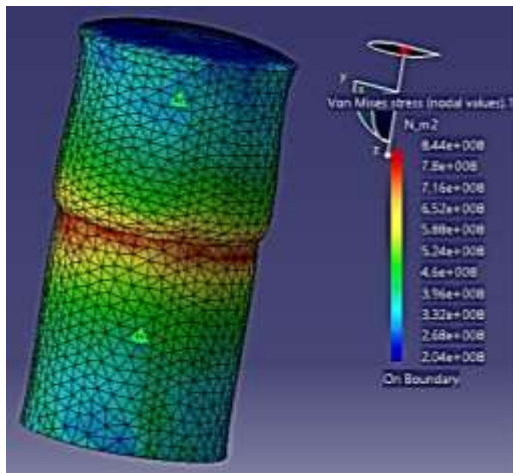


Fig.8. Analysis of deformations and stresses with the application of force on the cylindrical surface

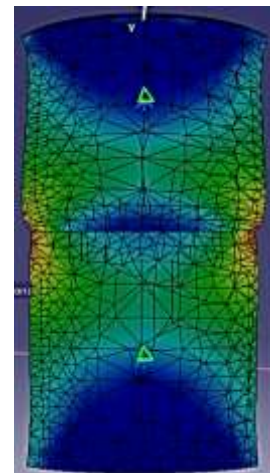


Fig.9. Material flow inside the parts when force is applied to the cylindrical surface

Further simulations of cold pressure welding were carried out with an additional device. By using the material uncontrolled flow retention device, a significantly smaller deformation was observed, especially for the aluminum part. Analyzing the stresses in the material, a value of $1.79 \cdot 10^9 \text{ N/m}^2$ was found, which is higher than in the case of pressing without the device. This shows that the energy consumed during pressing was used much more efficiently and concentrated towards the diffusion surface (fig. 10). By analyzing the stress distribution in a section through the assembled parts (fig. 11), an increase in the diffusion surface was observed, confirming that when using the device, the pressing force is distributed towards the joining surface.

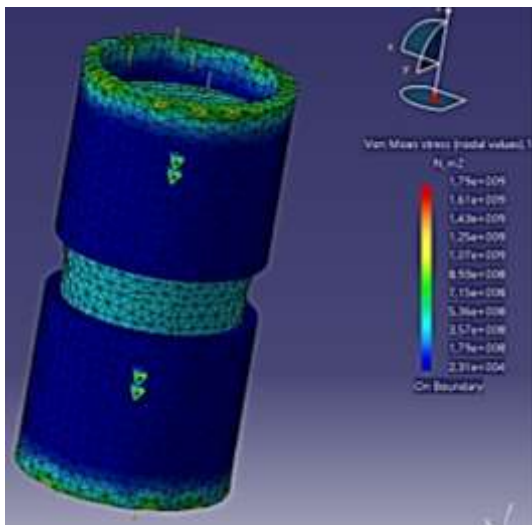


Fig.10. Analysis of deformations and stresses when pressing with an additional device (F = 150 daN)

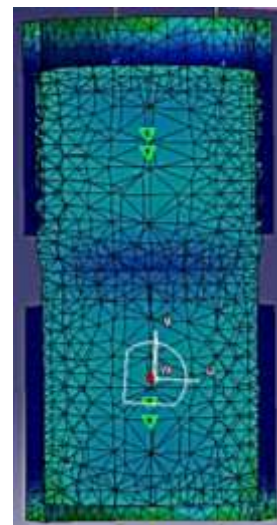


Fig.11. Material flow inside parts when pressing with additional device (F = 150 daN)

Increasing the pressing force to 300 daN resulted in a deformation of the aluminum part and uncontrolled material flow towards the top, as shown in figures 12 and 13 with a penetration of the device. In this penetration zone, stresses reached a value of $8.12 \cdot 10^9 \text{ N/m}^2$.

The next simulation consisted of applying a pressing force (150 daN) on the cylindrical surface of the parts, in axial directions oriented from the ends towards the contact surface. Figure 14 shows a well-controlled material flow, oriented towards the contact surface, and good material extrusion in the joining zone. Additionally, in figure 15, a very good distribution of material inside the parts can be observed, with the entire joining surface being subjected to the diffusion process [6].

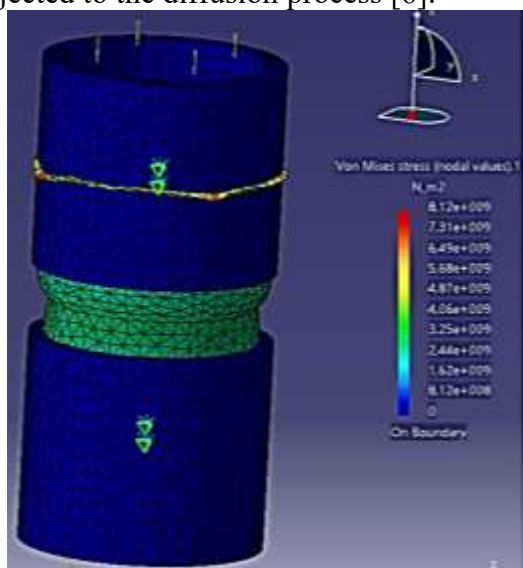


Fig.12. Analysis of deformations and stresses when pressing with an additional device (F = 300 daN)

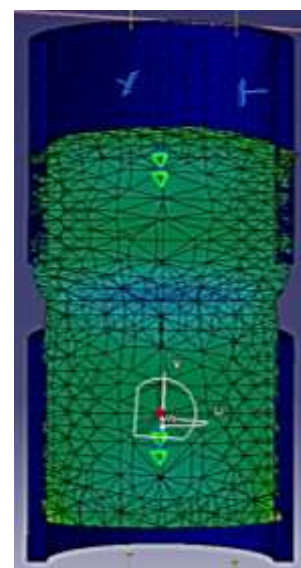


Fig.13. Material flow inside parts when pressing with additional device (F = 300 daN)

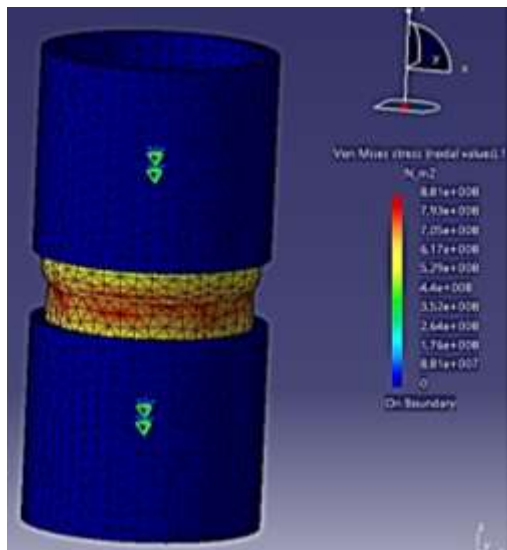


Fig.14. Analysis of deformations and stresses when pressing with an additional device with the application of force on the cylindrical surface

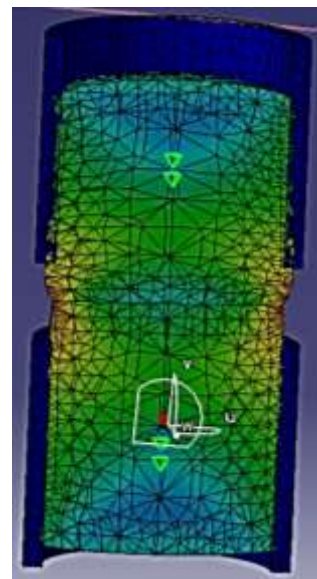


Fig.15. Material flow inside parts when pressing with additional device with application of force on the cylindrical surface

4. Conclusion

Finite element analysis using the CATIA software represents a modern method for studying various contacts, allowing the determination of important parameters for studying different contacts. Research has shown that cold welding can be achieved between samples made of different materials, due to cold diffusion mechanisms. The determinations made have shown that at the interface between steel and aluminum samples, a diffusion layer with variable thickness is formed, depending on the welding process parameters.

Depending on the applied technology, variations in the size of the diffusion surface have been observed (through the formation of hard intermetallic compounds such as $FeAl_3$), decreasing slightly towards the edges. Further research will investigate the influence of post-welding heat treatments on the adhesion force between parts, as well as on the metallographic structure.

References

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