STRESS RELAXATION IN WELDING JOINTS OF 5052 ALUMINUM USING THE ULTRASONIC METHOD.

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Abstract. *This work presents the application of the ultrasonic technique to verify the stress relaxation in 5052 aluminum alloy plates. A special geometry was developed, so each plate to be welded had uniaxial stress in the measurement region Twenty-two plates were tested, eleven in the rolling direction and the remaining in the orthogonal direction. The plates were stress relief using a heat treatment to set an initial stress free reference state. After that, they were welded to create the stress field in the area of investigation. A final step was to cut each one of the samples in a different period from the time of welding. After each step, the stress was measured in the uniaxial stress region. A calendar of the process was established to record precisely the time of each step. The differences in the acoustoelastic constants related with rolling direction and the variation of the Young's Module were taken into account. The results showed a clear effect of relaxation in those samples. The magnitude was not so pronounced as in steel, but kept the same percentile relation with the ultimate strenght of material.*

Keywords*: ultrasonic stress evaluation, residual stress relaxation, aluminium alloy, non-destructive evaluation, ultrasonic waves.*

1. Introduction

The aluminium and its alloys are amongst the most versatile, economic and attractive metallic materials for a broad range of applications. Its use as structural metal is lower than the steel only. It is used in the manufacturing of components and mechanic systems that require materials with low specific gravity weight. Its high mechanic resistance makes it very useful for the construction of moving structures like vehicles and aircrafts. The aluminium is not ferromagnetic, is non-toxic and has high thermic and electric conductibility. A notable advantage of the aluminium is its high resistance to the progressive oxidation, once its surface atoms combine with the atmosphere oxygen creating an oxide-protecting shield that prevents the progression of its deterioration. When submitted to certain treatments or linking alloys, it becomes resistant to corrosion within more aggressive conditions.

Although many elements combine with aluminium to form alloys, there are few others that, alone or combined, provide desirable general properties. The main elements are: copper, silicon, manganese, magnesium and zinc. The magnesium is one of the most efficient elements and it is largely used in alloy creations, because it provides the highest resistance against corrosion. The aluminium-manganese alloys (Al-Mg) form an important group of aluminium alloys that are not thermically analyzed, or, they are not hardening by a thermo treatment of solubility and ageing, but by a solid solution and hardening (mechanic work). Besides this mechanic resistance gain, the manganese allows these alloys to keep a high level of ductility as well as an excellent resistance against corrosion and (weld ability). An example of this alloy is the 5052, which has 2.5% of magnesium in its composition.

Aluminium 5052 plates are used for the manufacturing of components for transportation and storage businesses particularly, for example, storage tanks, boats, buses and delivery van bodies. The manufacturing processes of its pieces could introduce residual tensions on the final products. In this case these pieces already have tensions from the original plates, their final tension values would be unknown and impossible to be estimated, which could provoke dramatic failures of the structural components, causing financial losses, and in extreme, deaths. The Science and Technology concern regarding these problems is old and huge, which encountered solutions indicating distinct actions, for example, the use of elevated safety levels, development of more tenacious materials able to attend better the existing requests, requirements for more rigid regulations on the control of manufacturing and assembling of structural components, use of the non-destructive rehearsals with rigid techniques to guarantee the location and dimensioning of fissures every day smaller on the components inspection, and through the knowledge of materials residual tensions, which associated to fissure dimensioning, allow a severe structure safety condition control.

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The introduction of residual stresses into the materials during the component manufacturing process can be done by operations like welding, blowpipe cuts, etc., which involve forging processes or drastic temperature modifications (Modonesi, 2002). The presence of residual stresses demands that stress heat treatments be done in the majority of the manufactured components. The control of the generated tension is not always possible: only with statistics approaches from destructive rehearsals that it is possible to evaluate the stress magnitude of the process. Destructive processes represent high costs in many cases and they do not provide absolute guarantee of manufacturing process control, once they are made over samples, usually with lower dimensions. The failure cost in materials used for manufacturing components can be high, as well as the pieces refuse cost that suffer any kind of distortion during the subsequent tooling process. The adequate control of residual stress magnitudes, using a non-destructive method, would permit a significant decrease of these costs. The same method could be used for the creation of new productive processes, with less tendencies of residual stress generation, optimizing the component manufacturing. This method should have a low cost as well as an adequate development stage, in order not to require a high specialization level from employers and professionals who will use it.

Although there are several methods for residual stress measurements, like the well developed and largely used hole drilling techniques, X-ray diffraction and neutron diffraction method, all of them with well established and precise methodologies, they present limitations because some methods are destructive while others have a difficult instrumentation to be transported, some of them due to the need of trained and authorized technicians make them possible to happen or by the restricted application on the material surface layer. Due to this fact, the interest in the development of new methods to supplant these limitations increases, allowing investigations about the tensions on mechanic components. With these criteria, the acoustoelastic method becomes the most suitable alternative. Ultrasonic waves are the base for the acoustoelastic method. The ultrasound one can be used for stress analysis through the measurement of the ultrasonic wave speed variation that occurs when it diffuses through a material in two different tension conditions. The main ultrasonic method used for stress evaluation is based on the route time variation of shear waves – acoustic birefringence method. However, critically refracted longitudinal waves, that is, diffusing parallel to the surface, have been used since they are more sensitive to stress variation (Santos & Bray, 2000).

One of the generating processes of manufacture of residual stresses is the welding. An important related phenomenon to this process is the stress relaxation, that is, the reduction of the residual stresses with the time after the welding. Works effected in steel (Chance, 2000, Andrino, 2003) proved that residual stresses that appeared due to welding had diminished with the time, without the necessity of heat treatment. To know the phenomenon of stress relaxation in welded structures is basic for the definition of the involved factor of security in the project of metallic structures and component mechanics. To know how to quantify this relaxation correctly can mean a great economy in terms of materials and processes. The relaxation effect can be observed in the case of components that do not fail, exactly after being requested with loads theoretically enough to fail them. This occurs because the existing real internal stress in the element can be 30% minor than the foreseen ones in the project. This phenomenon defies the common sense of the current researchers and is the base for the described study in this work.

This work proposes the use of the ultrasonic technique through the generation of critically refracted longitudinal waves (L_{cr}), for the verification of the stress relaxation in 5052 aluminum plates. Twenty-two plates were assayed. Initially, the plates were taken for heat treatment for stress relief and after that they were welded to create the stress field in the inquiry area. A daily pay-definitive time was established for each body of testing with the intention to verify the existence or not of the relaxation phenomenon. Plates in the longitudinal and transversal rolling direction were investigated. The variation of the elasticity modulus in relation to the rolling direction was also taken into account in this work.

2. Literature Review

The observation that the ultrasonic wave speed when passing in the interior of an elastic solid under stress was different of that measured in a free isotropic solid of stress, motivated the beginning of the acoustoelastic theory, decades behind. Experiences have shown that the variation of the ultrasonic wave speed depended, beyond the state of stress of the material, on the direction of propagation of the ultrasonic wave in relation to the crystalline plans and on the direction of the movement of particles of the way for the ticket of the wave (polarization). This phenomenon of the variation of the speed of the ultrasonic wave when passing through an elastic material under stress, passed to be called acoustoelastic effect, for the similarity with the already known photoelastic effect of the light (Lamy, 2002). When a homogeneous half is anisotropic, a light beam that crosses suffers a double refraction, generating waves that present different angles of polarization. Materials that present this property are called doubly refractors or birefringences. The greatest analogy between the photoelasticity and the acoustoelasticity occurs when a shear ultrasonic wave perpendicularly happens to the surface of a isotropic solid submitted to a plain state of stress. Under stress, the solid becomes acoustic anisotropic and the incident shear waves are refracted in two directions with different angles of polarization. The material is said to be then acoustic birefringence (Lu, J. et al, 1996).

From the study of the acoustoelasticity, the development of works was possible aiming at the use of the ultrasound for measuring the stress in materials. The physical base of the theory is to find the microscopic level, therefore a stress is applied to a solid cause variations in the distances, whose consequence is the alteration in the ultrasonic wave speed. This is also function of the density of the way and its elasticity modulus. The variation of these interatomic distances is function of the elastic constants of the material (Biittencourt, M. S. Q. et al, 2000). The linear theory (small deformations) of the elasticity in general is adjusted to describe the elastic behavior of the materials. Through it, the elastic constants of the second order is reached, Lame´s constants, λ e μ, for an isotropic material, however this theory is limited for infinitesimal perfect elastic solid deformations, or either, for solids where the deformations are functions only of the stress and temperature. There are two causes that can explain the non-applicability of the linear theory of the elasticity. First, the solid can be anelastic or plastic. Second, the deformations can be so large that the infinitesimal theory is not accurate.

Many attempts have been made to develop the theory of finite deformations. Brillouin (1925) formulated the elastic theory in a tensorial notation and derived some from the basic equations for finite deformations. Later, he extended his work and gave a complete formulation of the basic theory. Murnaghan (1937) developed the theory in a general tensorial notation. Biot (1940) developed the theory particularly for the solid elasticity daily pre-stressed and considered the stress effect on the wave propagation. Cauchy (1948) derived some of the basic equations. Murnaghan (1951) rewrote his work of 1937 in a matricial notation (Andrino, 2003). To analyze the problem of finite deformations, it is necessary to define different states that the material will have before reaching the final state. These states are called: natural state, initial state and final state, shown in figure 1 (Leon-Slamanca, 1998).

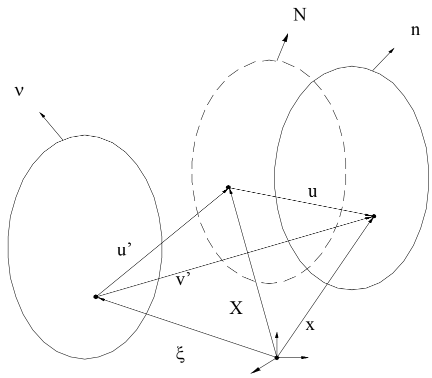


Figure 1: Coordinates for a material in the natural, initial and final state.

The natural state of the body mentions the free initial state of stress and deformations to it, and is defined by ξ in Fig.1. The initial state (X) mentions the body to it that was deformed or is on the action of some applied load. Finally the final state of the body (x) occurs when the movement of the wave or elastic deformations is superposed on the body in the beginning or the deformed state previously.

Based on the cited studies above, Hughes & Kelly developed the acoustoelastic theory in 1953. They described the change in the ultrasonic speeds as a function of the elastic deformation for isotropic solids. From deriving these functions, they obtained the relation between the stress and the wave speed, measured by the time of flight, using the properties of the material. Equation (1) indicates the speed of the waves longitudinal plain, traveling parallel to the applied load. This type of wave is the one that presents the most significant variation of the time of flight with deformation (Egle & Bray, 1976). The first index in the speed (v) represents the direction of wave propagation and the second represents the direction of the particle movement. This indicated that the speed can be related to the deformation (α_1), in the direction of the stress application (Bray and Stanley, 1997).

$$\rho_0.V_{11}^2 = \lambda + 2\mu + (2l + \lambda).\theta + (4m + 4\lambda + 10\mu)\alpha_1 \tag{1}$$

In this equation ρ is the initial density; λ and μ are the elastic constants of Lamé´s second order and l, m and n are the elastic constants of the third order of Murnaghan's. For a uniaxial state of stress, $\alpha_1 = \varepsilon$, $\alpha_2 = \alpha_3 = -\nu\varepsilon$, where ε is the deformation in direction 1 and ν is the coefficient of Poisson. Based on these relations equation 1 is:

$$\rho_0.V_{11}^2 = \lambda + 2\mu + \left[4(\lambda + 2\mu) + 2(\mu + 2m) + \nu\mu\left(1 + \frac{2l}{\lambda}\right)\right]\varepsilon \tag{2}$$

Relative sensitivity for longitudinal waves is the variation of the speed with the deformation and can be calculated deriving from it Eq. (2) and dividing the derivative for the original equation, as Eq.(3).

$$\frac{dV_{11}/V_{11}^{0}}{d\varepsilon} = 2 + \frac{\mu + 2m + \nu\mu(1 + 2l/\lambda)}{\lambda + 2\mu} = L_{11} \tag{3}$$

In Equation (3), L_{11} is the constant (or coefficient) acoustoelastic for critically refracted longitudinal waves (L_{cr}). Superscript 0 indicates the wave speeds at null strain in direction 1.

Unidimensional stress can be calculated by the application of the relation stress strain in elastic solids (law of Hooke). Equation (3) can be rearranged to give the stress variation in terms of the relative time of flight (dt/to), as shown in Eq.4. In this, t_0 is the time of flight that the wave leads to cross a free passage of stress of the material that is being investigated.

$$d\sigma = \frac{E(dV_{11}/V_{11})}{L_{11}} = \frac{E}{L_{11}.t_o}dt \tag{4}$$

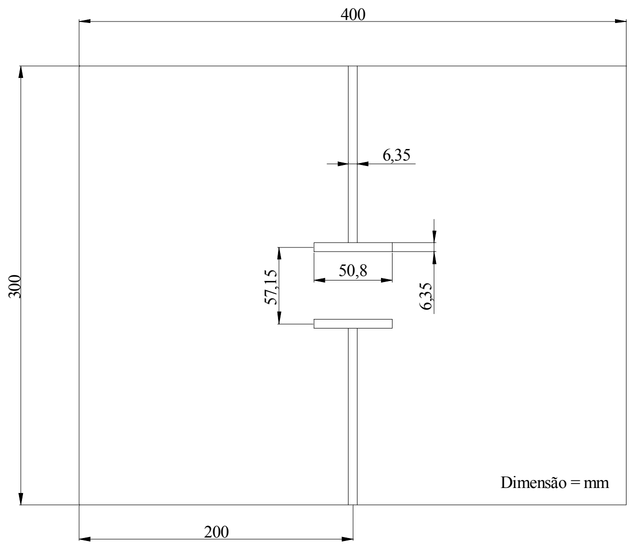
3. Experimental Procedures

To examine the effect of the stress relaxation in welded joints, a special geometry was developed. This geometry was based on the study by Mofat (1951) in his master of science of analysis of the relaxation in welded steel plates. Elaborated geometry and the preparation steps were executed to cause a compression effect in the area to be inspected.

3.1. Geometry and plate preparation.

The dimension of the plate is 400 x 300 x 9 (mm). In the two sides of the sample were machine rips in form of "T", under camber line relative to the biggest side of the plate. The width of these rips in the top of the T is of approximately 50,8 mm (2 pol) and the distance between rips of 57,15 mm (2 ¼ pol). The perpendicular rips are of 6,35 mm (1/4 pol), placed where bevels in double "V" of 60° were made for the posterior application of the welded one. The figures 2a and 2b respectively, show the plate used in the experiment and the plate with its dimensions.

(a)



(b)

Figure 2: a) 5052 Aluminium plate; b) Final dimensions

The process of cutting the plates was effected by regular metallic saw to reach the desired dimensions. The plates were faced with a miller so that the specified final dimensions in the project were reached. Then the bevel was machined with a milling machine. After the tooling process was carried out a heat treatment for stress relief, aiming to remove any resident stress in the material caused by tooling. The heat treatment consisted of heating the parts at 170ºC for 8 hours, followed by cooling in the interior of the open oven.

3.2. Plate welding preparation.

The process used for the plate welding was the MIG. The metal addition used was the 4043 with diameter of 0,89 mm. Cylinders of argon with Helium with pressure and outflow controllers were used in the welding. The welding chain and tension was regulated through source SYNCROWAVE 300, a programming and chain pulsation device. All the meltings were produced with top weld and the weldings carried out in a plain position with an automatized system. It was done one weld pass; the parameters of welding shown in table 1 remained unchanged during all the experiments. Before the welding execution, all the test bodies suffered abrasive spraying for cleanness. After that, the surfaces were cleaned with exempt compressed water air.

Table 1: Welding Parameters (Plate relaxation).

	Current (A)	Tension (V)	Weld. speed (mm/min)	Stick-out (mm)	Outflow gas (l/min)
Pass	240	20	180	4	10

3.3. Equipments

For the longitudinal wave generation and reception, two transducers, Harisonic - 2,25 MHz, mounted in a support were used, (detail 1, Fig. (3)), with two Plexiglas, that allow the waves to reach and catch the surface of the material in an angle of about 26°. The linking between the shoes is made by an aluminum plate, that serves to apply the necessary pressure for the attainment of the adjusted contact enters of the interested surfaces and to keep fixes in the distance between the shoes. For the generation and reception of ultrasonic pulses, a pulser-receiver, model 5073 PR - Panametrics was used, (detail 2, Fig. (3)). This pulser is on to a data acquisition device for the reading of the time of flight and for the data processing for the stress determination. The data acquisition program used was L-Stress v. 1,0 (detail 3, Fig. (3)), developed especially to calculate stress in mechanical components, through the time measurement of flight of superficial longitudinal waves ("L_{cr} waves"), using the acoustoelastic theory. The complete equipment can be seen in the following figure.

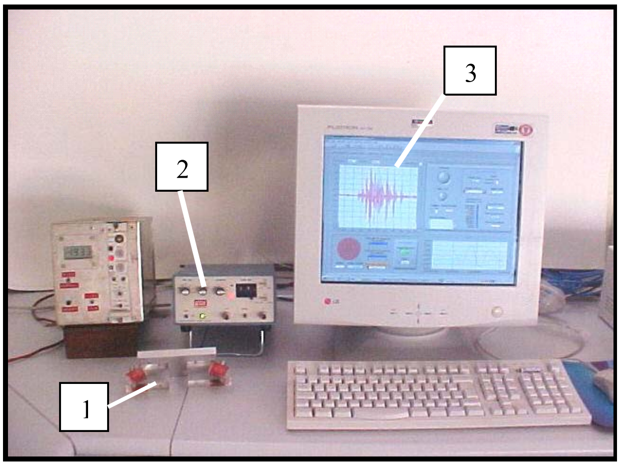


Figure 3: Equipment for determination of the time of flight.

3.3. Stress determination in plates.

For estimating the stress, first the times of flight with the ultrasonic transducer were measured. The procedure for measuring this time of flight consists of placing the ultrasonic probe a daily pay-definitive number of times, in each position. For each measurement, the sensor is removed, the area of contact between the part and the clean transducer, a new couplant is applied and the sensor must be placed again in the measurement position. For each measurement, the force adjusted between the transducer and the bar must be always the same one, preventing the effect of rigidity in the tranducer.

From the measured times of flight, the stress determination is carried out using Eq. (4). It is necessary to calculate the times of flight before the welding (reference time), and after the welding (plates with residual stresses from the welding). Analyzing the equation, there is the necessity of the previous knowledge of the acoustoelastic constant for the correct determination of the residual stresses. These constants were determined initially for each rolling direction, using for both directions the following value of the modulus of elasticity: E = 72000 MPa. A correction was effected in the value of these modules. Using the speed values of longitudinal and transversal ultrasonic waves through the method pulse-echo (GE PANAMETRICS, 2003), new values for the moduli of elasticity for each rolling direction were calculated. For plates with longitudinal rolling direction the joined value was: E = 68736 MPa and for the orthogonal direction the value was: E=67824,5 MPa. With these values, the acoustoelastic constants were calculated again. The acoustoelastic constant for plates in the longitudinal rolling direction was of 2,34, and for the orthogonal direction of lamination was of 2,46.

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3.4. Procedure for determining the relaxation in welded plates.

Twenty-two plates with the dimensions and characteristics shown in section 3.1 were used. Eleven of these plates were cut in the longitudinal rolling direction, or either, greater parallel length to the rolling direction, and the other eleven ones in the orthogonal direction, or either, greater perpendicular length to the rolling direction. The longitudinal plates were assigned as: CR2-1, CR2-2... CR2-11 and the transversal plates as: CR1-1, CR1-2... CR1-11. All the plates, before being welded, were taken to furnace for heat treatment of stress relief, to eliminate any type of stress that could have been introduced during the tooling process. After this treatment, the parts came back to the laboratory for measuring the time of flight for the free state of stress. The plates were sandpapered in the measurement place. The temperature of the laboratory was controlled at about 22° C. The ultrasonic transducer was placed in the center of the plates, parallel to the camber line of the lesser length of plates and enters the two rips in form of "T" (Fig. (4)). The times of flight were measured in the two sides of plates and an average for the final result was carried out.

After the measurement of the times of flight for the free state of stress, the plates were taken to the welding laboratory of the IAE (Institute of Aeronautics and Space), located in the Aerospatial Technology Center, CTA, in São Jose dos Campos, for the welding of the vertical rips of plates. After the welding, they were taken again to the laboratory. For each plate, after the welding, was written down the respective hour, and determined time for the cut of the welded rips, as table 2. The cut is necessary to remove the original stress generated by the welding. It was necessary to sandpaper the inspection area and wait until the plates reached 22°C. Each plate, after the necessary measurements, was taken to the Laboratory of Agricultural Machines, of the College of Agricultural Engineering of the Unicamp, for cutting the rips welded through a regular metallic saw. After each cut the plates came back to the laboratory. One more time they were sandpapered and rested until reaching the temperature of 22 °C, and the times of flight were measured. For each plate, four measurements between welding and cut and other four measurements after the cut of the same ones were made.

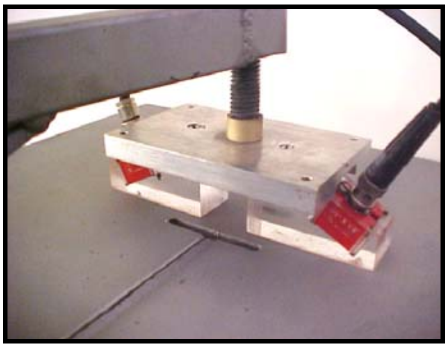

Figure 4: Positioning of the probe for measuring the time of flight.

Table 2: Welding end cutting timetable

	Welding time		Cutting time	
Plate	*Day*	*Time*	*Day*	*Time*
CR 11	*11/26/2003*	*10:30*	*11/26/2003*	*16:30*
CR 12	*11/26/2003*	*10:00*	*11/26/2003*	*16:30*
CR 13	*11/25/2003*	*16:00*	*11/27/2003*	*11:00*
CR 14	*11/25/2003*	*16:30*	*11/27/2003*	*11:00*
CR 15	*11/25/2003*	*10:00*	*11/28/2003*	*12:00*
CR 16	*11/24/2003*	*11:30*	*12/02/2003*	*14:00*
CR 17	*11/24/2003*	*11:00*	*12/02/2003*	*14:00*
CR 18	*11/25/2003*	*11:30*	*12/05/2003*	*09:00*
CR 19	*11/24/2003*	*09:30*	*12/09/2003*	*15:00*
CR 110	*11/24/2003*	*09:00*	*12/09/2003*	*15:00*
CR 111	*11/19/2003*	*16:40*	*12/12/2003*	*13:00*
CR 21	*11/26/2003*	*11:30*	*11/26/2003*	*16:30*
CR 22	*11/26/2003*	*11:00*	*11/26/2003*	*16:30*
CR 23	*11/25/2003*	*15:00*	*11/27/2003*	*11:00*
CR 24	*11/25/2003*	*15:30*	*11/27/2003*	*11:00*
CR 25	*11/25/2003*	*10:30*	*11/28/2003*	*12:00*
CR 26	*11/24/2003*	*16:30*	*12/02/2003*	*14:00*
CR 27	*11/24/2003*	*15:00*	*12/02/2003*	*14:00*
CR 28	*11/25/2003*	*14:30*	*12/05/2003*	*09:00*
CR 29	*11/24/2003*	*14:30*	*12/09/2003*	*15:00*
CR 210	*11/24/2003*	*14:00*	*12/09/2003*	*15:00*
CR 211	*11/21/2003*	*11:30*	*12/12/2003*	*13:00*

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4. Results and discussion.

As described, the times of flight for the residual stress calculation were obtained for all plates in four situations. In the first of them, the time of flight was measured after the plates were led for stress relief. There were problems in relation to the setting of these plates in the device used for welding, they had to be faced to reach the value of 9 mm of thickness. After this tooling, new measures were made for the calculation of the time of flight. Then the plates were taken for welding and after a daily pay-definitive time as shown in table 2, they were cut. Also for these two situations the times of flight were measured. Table 3 shows the obtained values:

Table 3: Time of flight for determining stress operation in plates.

Plates	CR 1-1	CR 1-2	CR 1-3	CR 1-4	CR 1-5	CR 1-6	CR 1-7	CR 1-8	CR 1-9	CR 1-10	CR 1-11
Pre-tooling	26485.9	26495.8	26518.8	26522.6	26487.3	26480.0	26497.7	26494.0	26507.1	26496.0	26472.5
Post-tooling	26424.5	26402.4	26428.4	26411.9	26413.6	26398.3	26414.8	26416.1	26412.5	26398.	26389.8
Post-weld	26397.0	26418.3	26387.6	26344.5	26377.8	26381.5	26523.4	26364.4	26353.6	26348.7	26371.4
Post- cut	26416.3	26439.4	26469.0	26415.1	26436.0	26415.9	26569.3	26399.1	26405.4	26400.6	26382.1
Plates	CR 2-1	CR 2-2	CR 2-3	CR 2-4	CR 2-5	CR 2-6	CR 2-7	CR 2-8	CR 2-9	CR 2-10	CR 2-11
Pre-tooling	26494.9	26492.3	26515.0	26501.1	26526.5	26471.5	26531.4	26482.5	26486.9	26500.8	26511.4
Post-tooling	26404.6	26404.4	26389.5	26412.3	26414.1	26408.4	26403.4	26420.6	26401.4	26427.3	26403.2
Post-weld	26443.6	26436.1	26340.8	26398.7	26322.8	26402.	26419.7	26390.7	26402.7	26390.2	26384.8
Post-cut	26442.0	26472.4	26425.0	26452.3	26383.6	26475.9	26473.3	26427.2	26435.7	26434.7	26384.8

With the results of table 3 and with the use of Eq. (4), the stress value can be calculated. For a better visualization, the referring data to longitudinal plates are shown in figure 5. The line in blue shows the stress caused by the plate tooling the green line and the red line show the remaining stresses after the plates were welded and cut, respectively.

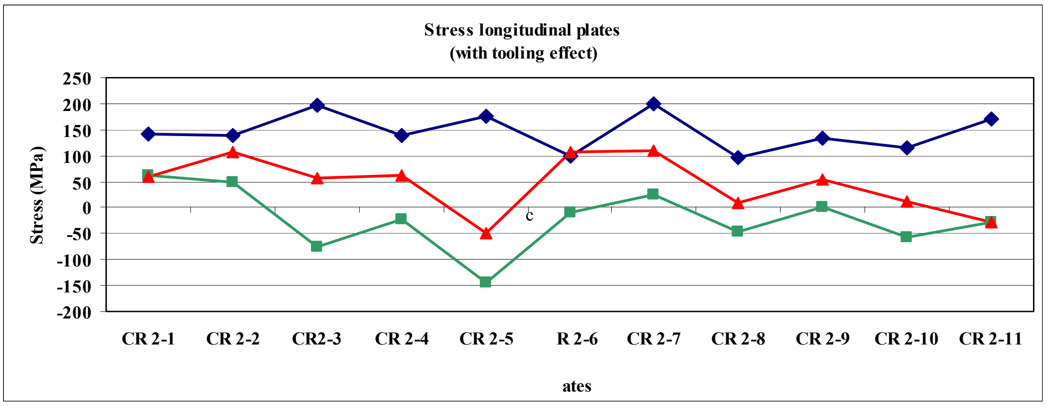

Figure 5: Stress in longitudinal plates. Blue line - Stress due to tooling; Red line – Stress after cutting; Green line – Stress after welding.

For a better understanding of how the residual stresses caused by the welding affected the results after the welding and cutting. It is interesting to observe that the effect of the tooling caused in plates should be removed from the results. That is made subtracting the value from the stress caused for this tooling of the stress values that appeared due to the plate cutting and the welding. Figure 6 shows the graphic for longitudinal plates, again the red line shows the stress after plates were cut and the green line when they were later welded.

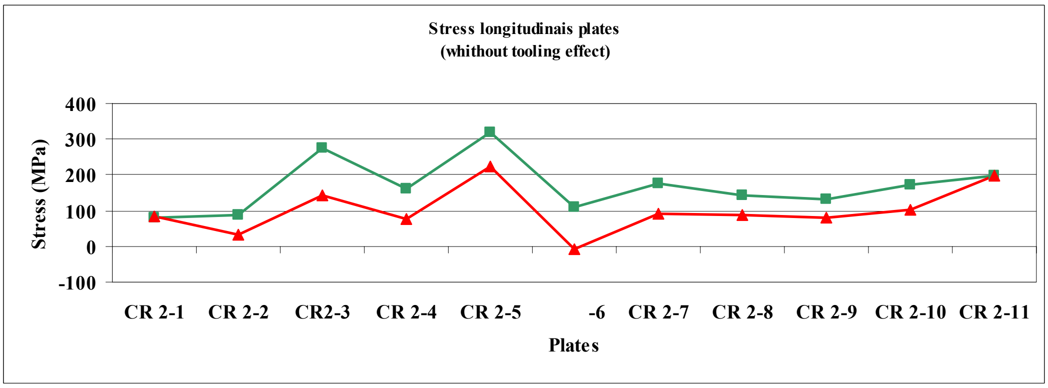

Figure 6: Stress in transversal welded plates without the tooling effect.
Red line – Stress after cutting; green line – Stress after welding.

This figure clearly shows that for all the plates, the stress suffered a reduction, but it is still not clear if the effect of the relaxation in this set of plates really occured. Table 4 shows an extract of the absolute values of stress of the graphic, deducting the values from the stress due to welding and cutting. The stress values are related with the time between plate welding and cutting. It also shows the transversal plate values.

Table 4: Values of stress for welded plates after cutting.

Time	6	6,5	44	44,5	74	194,5	195	237,5	365,5	366	548
Plates	CR 1-1	CR 1-2	CR 1-3	CR 1-4	CR 1-5	CR 1-6	CR 1-7	CR 1-8	CR 1-9	CR 1-10	CR 1-11
Stress (MPa)	30.1	33.1	127.7	110.7	91.2	54.0	71.9	54.3	81.1	81.4	16.7
Time	5	5,5	43	43,5	73,5	189,5	191	234,5	360,5	361	505,5
Plates	CR 2-1	CR 2-2	CR 2-3	CR 2-4	CR 2-5	CR 2-6	CR 2-7	CR 2-8	CR 2-9	CR 2-10	CR 2-11
Stress (MPa)	-2.5	57.1	132.1	84.1	95.4	115.8	84.0	57.1	51.7	69.8	0.006

With these values, graphics can be constructed now to represent the stress values in the time between the welding and the cutting. The figures 7a and 7b show this effect. The existence of a tendency of stress reduction of the stress with time passing is clear. In this figure, the curves traced for squared minimums are only to show this tendency and they do not represent any shape to attempt the phenomenon.

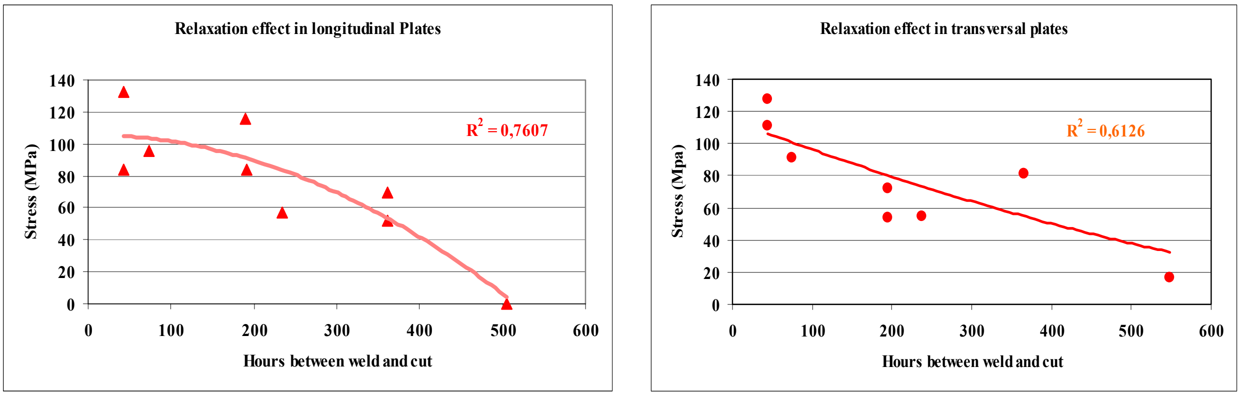

Figure 7: Relaxation effect in welded joints. a) Longitudinal. b) Transversal.

5. Conclusions.

A very known methodology in literature was used to verify the relaxation phenomenon in a material not investigated yet, the structural 5052 Aluminum. The inquiry confirmed the existence of the relaxation in 5052 aluminum plates when they were welded. Other authors (Chance 2000, Andrino 2003), also verified the existence of this phenomenon for welded steel plates. The measurements showed that, after 500 hours, the stress level varied in 140 MPa for longitudinal plates and of 126 MPa for transversal plates.

The ultrasonic method revealed efficiency in determining the relaxation effect. The method precision was the expected one: referring sensitivity to the rolling direction longitudinal and transversal that was of 1,65 MPa\ns and 1,55 MPa\ns, respectively. The maximum value of the standard deviation was 6 ns, what represents a value of 10 MPa for plates in rolling direction and 9,3 MPa for plates in the orthogonal direction. Considering that the majority of the ultrasonic techniques have a precision around 10-20 MPa, the employed system of data acquisition presented a high resolution.

An additional observation mentions the method stability: it did not have significant variation between the stress before the cut of the weld and in the following hours. It was verified that all the compression stress generated by the welding process was stored in the material until the cut was made and the stress alleviated. In the first cuts, minor open assembly time between weld and cut, it was observed that the difference of absolute stress was great, by contrast with that occurred when the cut was made in the biggest open assembly time. It was verified that this stress difference was small for bigger intervals, confirming that with the time passing and plates placed to the environment, the compression stress caused by welding was reduced. Considering that the initial stress in the region under analysis age of compression, what occurred was a clear relaxation of this compression, showing that the phenomenon really exists. The result is extremely motivating therefore it allows the verification that welded structures suffer some type of relaxation at room temperature, after the cut of weldings. This will allow the optimization of structural projects, since the factor time after welding must be also taken into account as an e influence factor.

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