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Fatigue FEM analysis in the case of brazed aluminium alloy 3L59 used in aeronautical industry

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Abstract. The use, on a larger scale, of brazed aluminum alloys in the aerospace industry led to the need for a detailed study of the assemblies behavior. These are built from 6061 aluminum aloy (3L59) brazed with aluminum aloy A103. Therefore, a finit element simulation (FEM) of durability is necessary, that consists in the observation of gradual deterioration until failure. These studies are required and are previous to the stage of the producing the assembly and test it by traditional methods.

1. Introduction

Brazing is a joining process wherein metals are bonded together using a filler metal with a melting (liquidus) temperature greater than 450°C (840°F), but lower than the melting temperature of the base metal. Filler metals are generally alloys of silver (Ag), aluminum (Al), gold (Au), copper (Cu), cobalt (Co) or nickel (Ni).

The brazing procedure has following steps, figure 1.

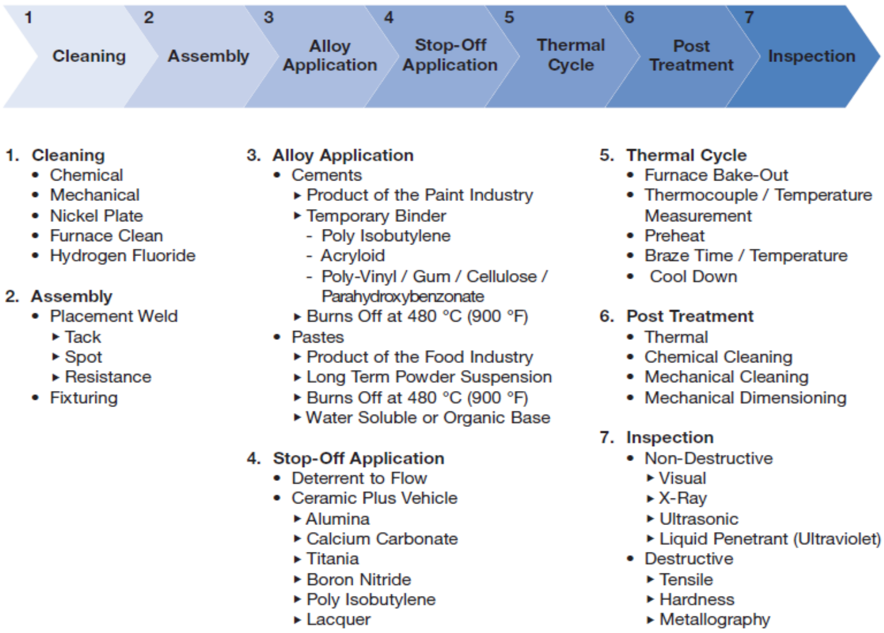


Figure 1. Braze procedure [11].

There are many situations where the manufacturer may be put in a position to choose between several technological processes to produce components / products. Also, within each set technological process can be done an optimization regarding the technological parameters required to achieve the product [10].

2. Materials and methods

Experimentally, were analyzed several possible technologies for producing brazed aluminum assemblies. [1] The variables that were considered for the experimental plan will be noted as A, B etc. and the parameters of these variables will be noted as a1, b1, etc. table 1.

Table 1. Experimental plan with variables and parameters.

No.	Parameters	
1	A - surface preparation process to brazing:	
2	a_1	degreasing with acetone of both surfaces that will be in contact; [2]
3	a_2	First thechnological process of surface preparation: [2] - Degrease surface with acetone; - Pickling in DEOXIDIZER 30 min; - Wash in hot water bath; - Wash in cold water bath; - Rinsing 5 min in nitric acid; - Wash in hot water bath; - Wash in cold water bath;
4	a_3	Second technological process of surface preparation: - Degrease surfaces with acetone; - Chemical alkaline degreasing (soda) 30 min; - Wash in hot water bath; - Wash in cold water bath; - Pickling 12 min in ALOCLENE 100; - Wash in hot water bath; - Wash in cold water bath; - Rinsing 5 min in nitric acid; - Wash in hot water bath; - Wash in cold water bath.
5	B – the aplication way of filler material on base material:[6]	
6	b_1	deposition of filler material on the edges of the base material surfaces;
7	b_2	deposition of filler material on a surface of the base material;
8	b_3	deposition of the filler material on both surfaces of the base material.
9	C – the type of acetylene used:	
10	c_1	usual acetylene 2.0;
11	c_2	high purity acetylene 2.6.
12	D – the type of flame used:[5]	
13	d_1	oxidizing flame;
14	d_2	carbide flame;
15	d_3	redusing flame (neutral).

3. Experimental researches

Assemblies on which were performed destructive and non-destructive testings have the dimensions shown in figure 2.

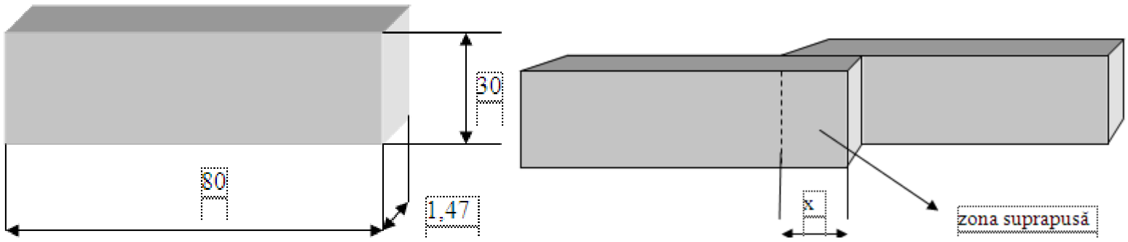


Figure 2. Assembly plate-plate.

For each technology type were performed several specimens as can be seen from figure 3.

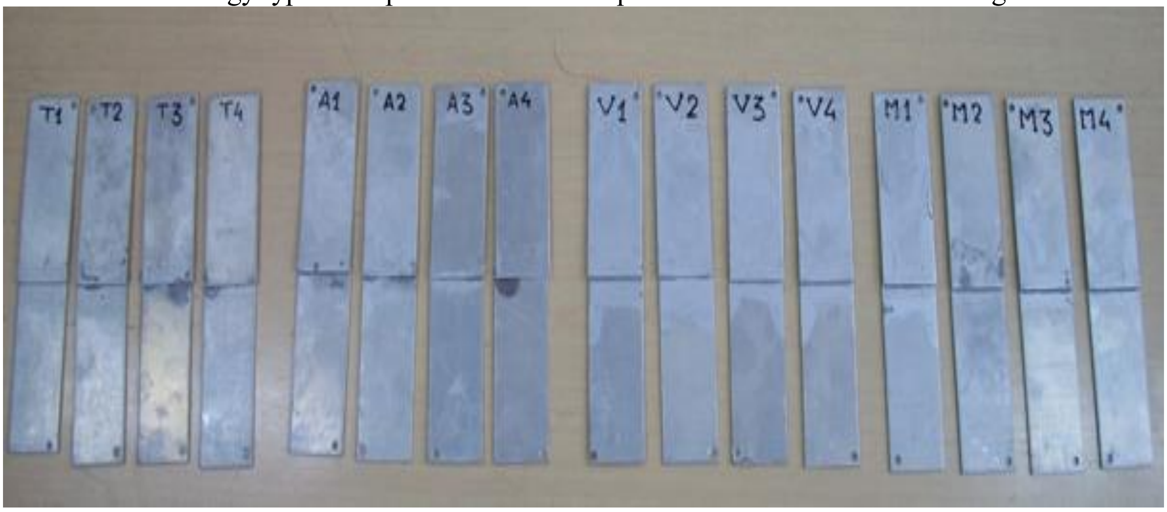


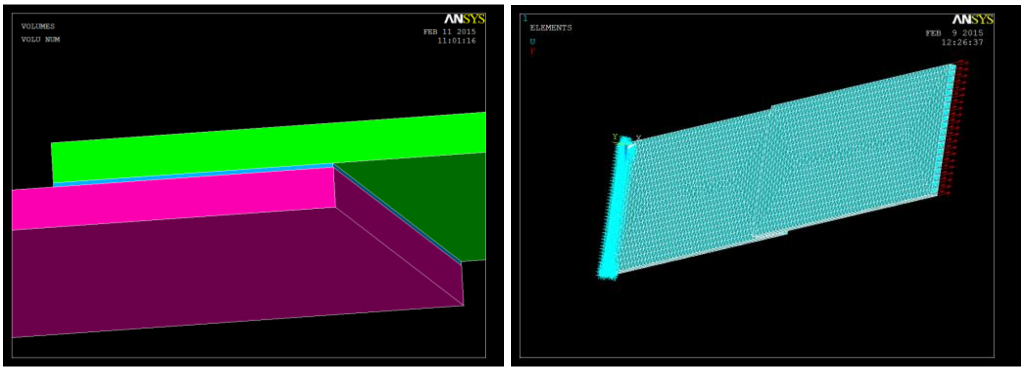
Figure 3. Sets of specimens.

As follows, this work aims to analyze the fatigue behavior by simulation of the obtained samples by representative technologies.

Using finite element analysis, can be determined theoretically the number of cycles that the brazed assembly type plate-plate makes until fracture. Finite element analysis (FEA) is achieved through subdivision of a piece in a number of finite elements or numerical integration point network, being interconnected to their external nodes. Interconnected nodes are called mesh. This mesh is planned to contain the material and structural properties that will define the way how the structure will react to certain loading conditions. Nodes are distributed to a specific density throughout the material depending on the anticipated load levels of a certain area. The areas which will receive larger amounts of load usually have a nodes density greater than those less or not at all loaded.

It is important to note that it is not necessary a validation of the experimental data, due to ANSYS simulation program which has in its data base the nature of base material 3L59 (asimilated with 6061) and filler material A103.

Modeling fatigue behavior of brazed joints should contain first static test simulation followed by fatigue test simulating of the structure. The results of the first simulation will be used on the fatigue test in selecting relevant nodes which are expected to give up after a specific number of cycles. Its geometry is shown in figure 4a, in figure 4b there are data for the analyzed structure load and namely the embedding and forces that act on tensile. It should be noted that the chosen force to simulate the test is the force mentioned in the literature [3], the force specific of the base material. Please note that the selected force is F = 4200 N and is applied to the upper plate 2, while embedding is performed on the bottom plate 1, [7] .



a. b.

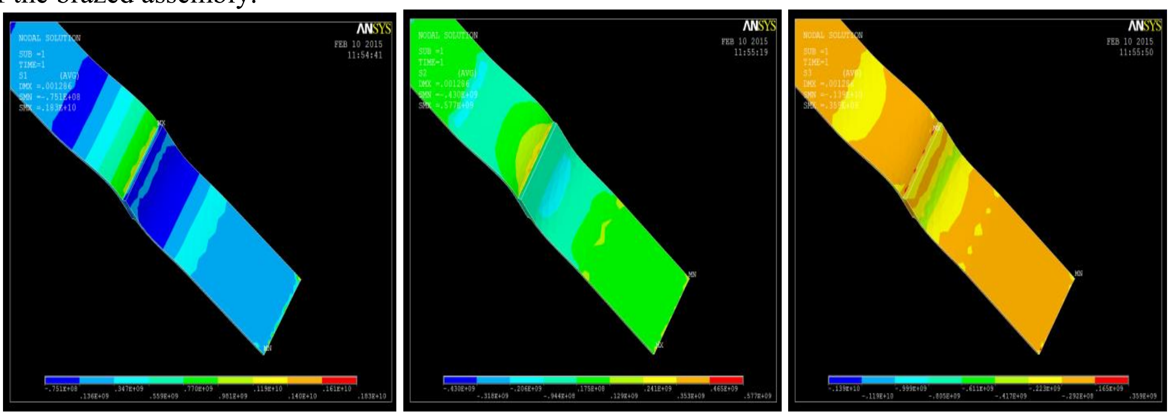
Figure 4. Geometrical description of the load status of the structure: a. – brazed join geometry; b. – embedding and forces that act on the structure in tensile test.

Following the above specified load condition, the most important results are related to stress conditions that are calculated by the program and provide a complex image of the stress that are developed during the tensile test. Thus, in figure 5a are shown the main stress S1 which show the maximum tensile stress on the interface of brazed area, while the maximum compressive stress occur in the lower plate 1, in the middle of it.

Type S2 main stresses are shown in figure 5b where the area from the close proximity of the brazed zone is seen as the area of the maximum tensile stress. In the middle of the inferior plate 1 can be seen a region (blue) in which there is a variation of the stress from the tensile ones to compression ones. In fatigue test, this area may be cracking on transverse direction, which can propagate, contributing to material tearing. Transverse direction is critical because it can cause cracking on the entire width of the material.

In figure 5c are presented stress type S3 which are formed in structure, with maximum tensile values also in the close proximity of brazing, while compressive stress (yellow) occur also in the middle of the inferior plate 1.

These types of stress S1, S2, S3, highlight dangerous zones which may produce the fatigue fracture of the brazed assembly.



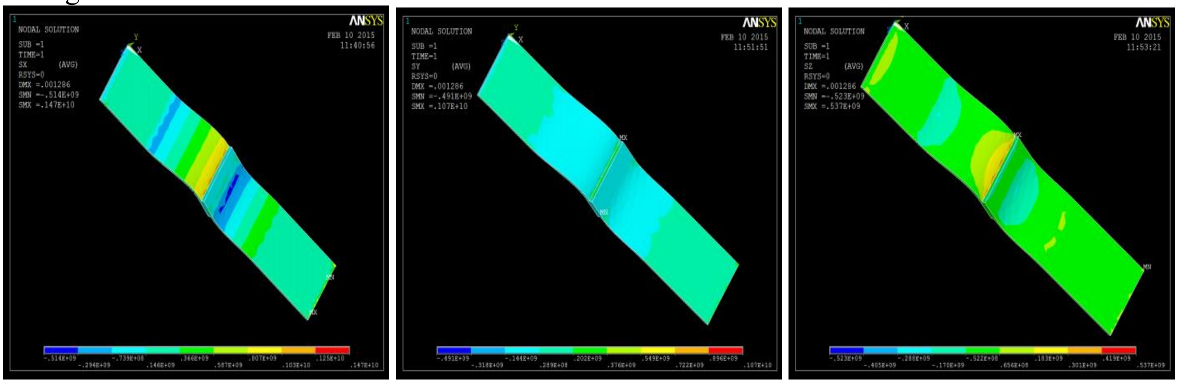
a. b c.

Figure 5. The presentation of stress’ conditions: a. – Stress type S1; b. – Stress type S2; c. – Stress type S3

In figure 6 it is shown the stress calculation corresponding to three axes OX, OY şi OZ. Thus, in figure 6a are shown stress on the OX axis, the axis on which tensile forces act. From image analysis may be seen how in the middle of the inferior plate 1 maximum compressive stress occur SX = -0.514 E9 N/m^2 and on the superior plate 2 appears jump from compressive stress to tensile stress, values ranged from SX = -0.739 E8 to SX = 0.587 E9 N/m^2. These areas will be analyzed in the fatigue simulation test.

In figure 6b it is shown the status of the stress on axis OY presenting a more uniform distribution of the stress, but marks a distinct boundary between the compression stress SY = -0.144 E9 N/m^2 and tensileing ones with values SY = 0.202 E9 N/m^2.

In figure 6c are presented corresponding stress to OZ axis, stress with a different distribution especially in the superior plate 2, where we can observe an insular area, relatively small, with tensileing stress SZ = 0.3 E9 N/m^2 located in an area with compressive stress values of SZ = -0.522 E8 N/m^2. This transition from compression to streching may cause appearance of fissures primers needed for fatigue fracture.



a. b. c.

Figure 6. Presenation of stress conditions: a. – Stress for axis OX; b. – Stress for axis OY; c. – Stress for axis OZ.

It is estimated that 50-90% of structural failure is due to fatigue, thus there is a need for quality fatigue design tools. However, at this time a fatigue tool is not available which provides both flexibility and usefulness comparable to other types of analysis tools. This is why many designers and analysts use "in-house" fatigue programs which cost much time and money to develop. It is hoped that these designers and analysts, given a proper library of fatigue tools could quickly and accurately conduct a fatigue analysis suited to their needs. The focus of fatigue in ANSYS is to provide useful information to the design engineer when fatigue failure may be a concern. Fatigue results can have a convergence attached. A stress-life approach has been adopted for conducting a fatigue analysis. Several options such as accounting for mean stress and loading conditions are available.

Following the static analysis of the tensile behavior of brazed assembly were identified critical areas with the fracture possibility on the fatigue test. Afterwards, a "Transient" analysis in fatigue test was performed on the brazed aluminum assembly structure. For this were selected two nodes: N1 = 15367 in the inferior plate 1 located in the critical transition area from tensile to compression, in the middle of the plate and node N2 = 21739 in the superior plate 2 located in the tensile tension "island" with its values SZ = 0.301 E9 N/m^2.

For fatigue test analysis was considered that tensile force has value of F = 4200 N, and the frequency of vibration cycles is f = 5 Hz.[8]

As a result of the input data set and achieved fatigue analysis, figure 7 shows the results for the two nodes. In this respect, for the node N1 is calculated a maximum number of oscillations
n = 3 E5. For the node N2, the maximum number of oscillations is n = 7030 since in this area the maximum tension is S = 0.69 E8 N/m^2.

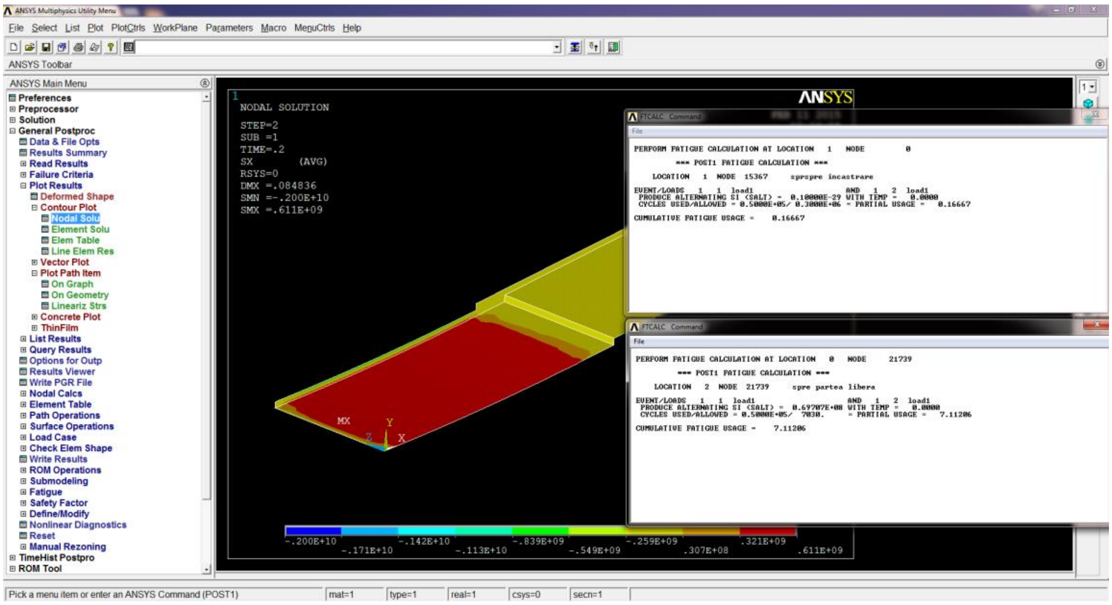


Figure 7. Presentation of the results of the fatigue test.

4. Conclusion

After simulation of the brazed assembly with static test to tensile, two distinct zones resulted where the transition from tension to compression occur.

Areas that make the transition from tensile stress to compression stress are considered primer fissuring occurrence areas.

Fissure propagation direction is transverse, which is the critical area of the brazed assembly.

After simulation of the tensile tests, it is observed that critical areas are in the close proximity of brazing and in basic material. For the simulation of the fatigue tests, these areas are only in the basic material, respectively in inferior plate 1 and superior plate 2.

After simulation of the fatigue tests, in the nodes corresponding to critical areas it is found a maximum number of cycles until fracture.

5. References

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