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THE INFLUENCE OF THE VOIDS ON AN ADHESIVE LAP JOINT: EXPERIMENTAL AND NUMERICAL ANALYSIS.

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Abstract

The aim of this paper is to present an experimental and numerical characterization, which is a typical adhesive for aerospace applications. This was done with two kinds of structures, with and without voids, and comparing their structural performance. Additionally, the X-RAY NONOTOM CT SCAN (computed tomography) has been used to determinate the distribution of the voids in the adhesive. Subsequently, numerical models, which represent experimental trials, were developed by modelling adhesives using the finite element technique. A shear test has been performed on the specimens in order to confirm the resistance of the bonded joint taking into account that the materials have the same mechanical characteristics. Then, the numerical simulation has been developed using the software ANSYS in order to analyze the adhesive lap joint model. The finite element displacement analysis of the single lap joint was examined for the cases with and without voids. The stress of the adhesive single-lap joints is mainly generated during the cooling process. The results between the experimental tests and the numerical model are in good agreement. In fact, it is noted that the numerical models have been shown to be very representative of experimental trials with reasonable maximum errors. Additionally, we have noted that the absence of the voids increase the stiffness of the lap joints with a reasonable percentage of the loads charges. In the absence of the voids, the load failure of the joint has been increased. However, the increase rate in the failure load changes depending on the structural features of the adhesive and the type of the adhesive.

Keywords: *Adhesive; lap joints; voids; deformation; load; adhesively bonded.*

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I. INTRODUCTION

Adhesively bonded assemblies are increasingly used in the transport industries, such as automotive or aeronautics because of their numerous advantages: low-weight structure, high mechanical performance and relatively uniform repartition of stresses along the bonded area [1]. The fuselage of Boeing's 787 passenger aircraft is the large structures where composites are adhesively bonded with metals [2]. The first who develop an analytical model to determine the shear stress distribution in a single lap joint is Volkersen [5]. A modern technique developed in the product of the lap joint for the application [1, 2, 3, 4, 6] all of this modern technique is important for many engineering parts but it deferent to depending of the utilization, [2, 7, 11]. The airline industry has been marked by numerous incidents, in case of durable joints fibber reinforced composite materials widely used carp present extent strength and stiffness. For the aerospace application precisely the bonded joints, one of the main issues failure are the voids inside of the adhesive, we assumed that the voids are the original failure of the bonded joints under the big charges. These voids can be result from volatile impurities that evaporate when we assembling the lap joints during the curing process, another source of voids are the entrapment of the air between the adherend and the adhesive during manufacturing of joints [9].

The increasing of the shear stress at the end of the adhesive can be results of the presence of the voids [9, 8, 10]. Chadegani and Batra demonstrated that the effect of a void on the energy release rate of an interface crack [9, 11]. Ahmed Sengab and Ramesh Talreja reviewed a numerical study of failure of an adhesive joint influenced by a void in the adhesive [9]. All of these studies are recently proving.

The aim of this study is to use the following steps which are the loud characterization using Shear Test, X-RAY CT scan NANOTOM machine to determinate the existence and the distribution of the voids, and the software ANSYS numerical part resumes a simplified creating and control of the voids, like the precedents researches proving and confirming the existence of the voids, however, our hypotheses supposed that the original of the cracks results of the voids.

As consequence, the static analysis of a bonded joint is considered a non-linear analysis where the non-linearity is due to the presence of contacts and to different materials. This non-linearity of geometric type and material type is translated as the inability to solve the problem with a single step, therefore, arises the need to discretize the application of the displacement, by performing the simulation as a succession of simulations, each of which sees the final result of the previous simulation as the start condition.

2. REALIZATION OF THE SAMPLES:

Six samples are investigated these made of 56 mm thickness and 101.6 mm long, 25.4 mm wide composite plates. The overlap zone is 25, 4 mm^2 of surface us know in figure (1). The structural of the adhesive is epoxy DGEBA/EPONE/ F28, CAT/IPDA Isophrine Diamin. Used for assembling the two composite plates, the composite plates layer with 0, 02 mm of thickness.

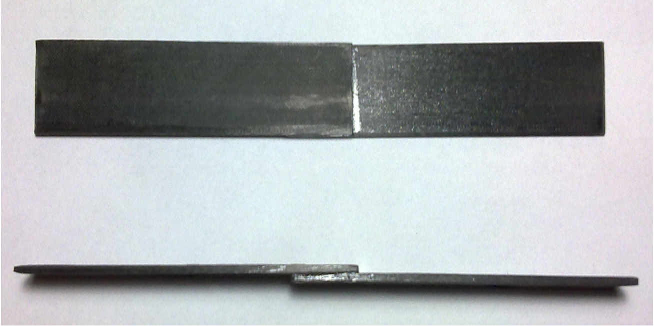

Figure 1: images of the samples

3. THE TEST OF THE SINGLE LAP SHEAR:

For the tests it was, first of all, estimated a maximum load value in order to choose a machine that will ensure the secure rupture of the specimens. Assuming that the average maximum shear stress was 40 MPA3, considering a contact surface of 645 mm2, we get a load of about 26 KN. Therefore we have chosen a machine of brand INSTRON Series 59804 with a floor (Figure 2) with load cell of 50 KN.

The clamping was entrusted to pneumatic jaws of 5 KN with flat grips in symbiosis with the typical normative geometries of the specimens for the mechanical testing of composite and elastomeric materials. In Figure 2 is shown a grabbed and ready for the test specimen.

The software for the acquisition of the data used to set various values, for both the output and the input, in order to generate a series of files that represent at the best the characterization of the mechanical properties regarding the experimental investigation. In general the most important parameters are:

* Load in N (ordinates)

The files generated by the software are:

* A report in pdf format representing the graph

* The machine management software files for further elaborations of data

* File.csv for Excel where there are the parameters ranked by columns.

However, for logistical reasons it was preferred to convert the data in file.txt and process them with Matlab. The tests were carried out by setting the most important parameters at the following values:

* Speed of the slide 2mm / min

* Sampling frequency of 10 hz.

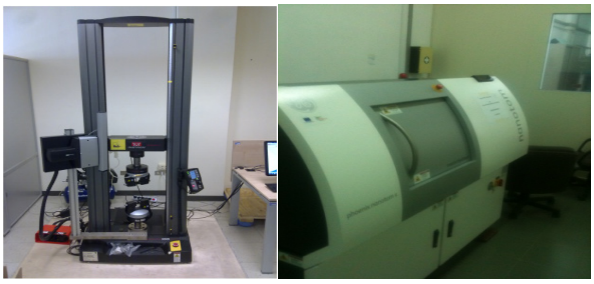

Figure 2: view of a X-ray nanotom machine and an INSTRON machine

4. THE EXPERIMENTAL RESULTS

At this point it is passed to the phase of execution of the tests carried out in two groups of 5 tests each. In figures 3 and 4 are the graphs of the load according to the displacement for each sample. the average values and the standard deviations of the most representative magnitudes of the mechanical properties of the bonded joint and that will be used later for the numerical model.

Using x-ray NANOTOM CT scan machine to analyzed the two samples. 3D view of the structure from the CT SCAN machine obtained (figure 5 And 6). A clear view of voids distribution, we can see a deferent distribution of voids apart from these manufacturing defects can also be identified using the x-ray CT scan. The study is almost half way through and some useful results have been obtained. Interesting numbers of micro voids are observed in addition some millimeters scan; according these results we can say that this subject has been further Clearfield.

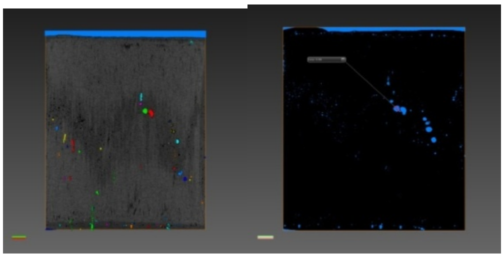

Figure 4: Joint Section Binary Image Slice CZM

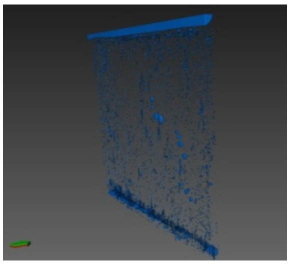

Figure 5: Joint Section Binary Image

The X-ray NANOTOM give us a deferent image when we could observed the voids in the adhesive, it can be of different shapes. It can be shown with a circular and in star forma. In the manufacturing process of adhesive joints, After the excel results by AVISO software with the image analysis we obtained in the section of CZM, when it was observed an interesting nembers of voids disturbed in the surface of 490.3216 mm^3 under a big charge. These results make us doubting in the failures in the shear test.

Where is indicated with Fmed the maximum load, with δFmed the displacement corresponding to the maximum load, with τmed the average tangential tension at maximum load and with Etmed the total energy valued as area subtended by the load / displacement curve. The values were calculated excluding the experimental data that were mostly departed from their average values, and this, in order to evaluate the average properties avoiding the values characterized by great loss due to specific abnormalities which are not found on almost all of the samples.

The experimental data indicate the absolute improvement brought by the voids in terms of mechanical strength or for what concerns the toughness of the adhesive meatus (energy and maximum displacement). During the course of the test the gradual advance of the announced cracks was noted aurally by subsequent crackles. The final break instead happened with a dramatic crash and a cloud of smoke at the joint.

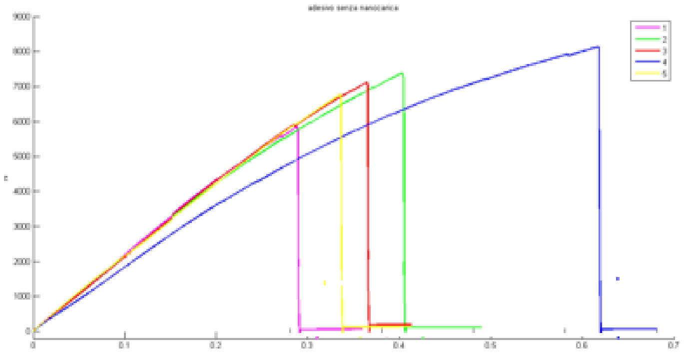

Figure 3: Results of the shear tests.

5. NUMERICAL SIMULATIONS

For the simulations we used the ANSYS WORKBENCH 15 software which constitutes a multi-physical simulation environment. It is an integrated platform, since the application packages that operate on simulations and other support software, are integrated with each other, that is, they have the ability to interact interchangeably; in practice it can easily pass, within the same working environment, from an application to another by transferring the database generated from a block to another, helped in this by a very versatile and advanced graphical interface typical of a structure of blocks

Here, has been used the Static Structural block for the static structural analysis while was used the ANSYS Composite PRE-POST packages for modelling of the adherents and the Mechanical Model environment for modelling of the adhesive film. It has been observed during the various iterations that by acting on the resin module of the bonding, it is acted also on the overall stiffness of the joint. With only the parameters of the models CZM it's not possible to set the stiffness of the adhesive film that affects the deformation at the break of the bonded joint. While the values of τ_{max} and critical ERR (ENERGY RELEASE RATE) govern the value of the breaking load. By iterating several times have been reached the values in Table 1 and which, remember, are related to a given configuration of the mesh and of the number of the total steps. With these parameters, were obtained the force-displacement features reposted in Figure 7a and 7b and Table 2 shows the main parameters and the errors compared to the experimental values of the joint. Note that increasing the displacement, the crack front, advances towards the central zone. This front is comparable to the area that goes from the blue areas to the red areas. However, for the evaluation of the crack front ANSYS WORKBENCH provides an output parameter defined as status, which is part of the contact Tool, whose purpose is precisely to plot the status of CZM contact.

A further advancement representation of the crack can be obtained observing the performance of the tangential tensions along the center line of the CZM contact, in function of the overlap abscissa and the load as a parameter. From Figure 7.a and 7.b it can be seen that increasing the load decreases the overlapping area after the de-cohesion of the contact. In particular in the transition from the represented status of tension, in the case without voids, from the purple curve to that of the red curve is shown the start of the structural crisis of the joint, and then the start of the path of the crack, which is characterized by the annulment of the shear stress at the ends of the overlapping area.

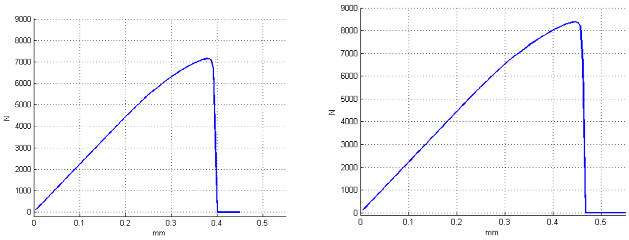

Figure 6.a: load-deformation

Adhesive-adhering relating to cohesive elements in the step in which the delaminating takes place of the joint. The increasing of the displacement, scrap towards the central zone. This resulted in comparable to the area that goes from blue to red areas. The advance of the front is not constant type straight line, along the width of the junction, but has a slight buckle. This is justified by noting that in the central area will have lower deformability of the joint related to further stress state that induce a more brittle behavior of the contact or an advance of breaking condition of CZM elements. Also note the increase of speed of crack propagation, with the advancement towards the central area of last cohesion. This is due to the intensification of tensions due to the increase of the load and decrease in the resistant surface. However, for the evaluation of the front crack in ANSYS Workbench provides an output parameter defined status, which is part of the Contact Tool, whose aim precisely to plot the status of CZM contact. In the figure 6.a and 6.d, and shows the status of the contact to the same step of the tensions, the interface adhering-adhesive, in the figure 7.c and 7.d

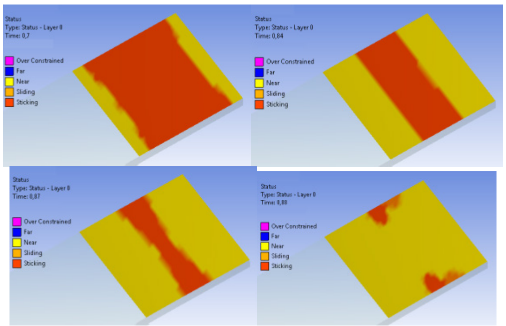

Figure 7.a: contact state by adhesive with voids

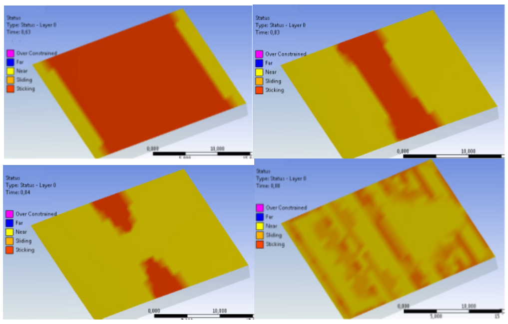

Figure 7.d: contact state by the adhesive without voids

DISCUSSION OF RESULTS:

This behavior is in line also with the slope of the force-displacement curve in which loses its linearity in correspondence with the above-mentioned load values. From the graphs of the τ of 8 a and 8 C figures, there is a certain similarity between the slopes of the curves of the first two lowest loads and the curves of the theoretical models (Figure 9) that help to validate the contact numerical model.

In 8.b and 8.d figures are plotted the curves τ (δ) obtained by APDL macro, where δ is the relative sliding between the Contact and Target surfaces chosen for creating the item CONTA174 used in the numerical model . These graphs while confirming the trend of the numerical theoretical models of debonding [3) allow to validate the simulations as it has been calculated, using always the same macro, the values of critical ERR comparing them with the values set in the cohesive model getting the results in table 4 Consider that the errors in the table are of computational type and discretization type.

This value 336,6 Mpa/mm decreasing the Young's modulus of the resin constituting the adhesive film, from 230 MPa to 260 MPa, we obtain the constitutive relationship which is characterized by: Kt = 34,64 GPa /mm (contact stiffness) which is about one order of magnitude less. Therefore it can be inferred, also observing the force-displacement, that too rigid film anticipates and accelerates the damage of cohesive elements inducing a more rigid behavior, more fragile and less resilient. Finally in Figures 8.g and 8.k reported the comparison between the experimental characteristics and those obtained with the simulations from which you also rely on the quantitative validation of the numerical model.

In the figures 8E and 8F, is reported the comparison between the experimental curves and those obtained with the simulations which indicate the qualitative validation of the numerical model.

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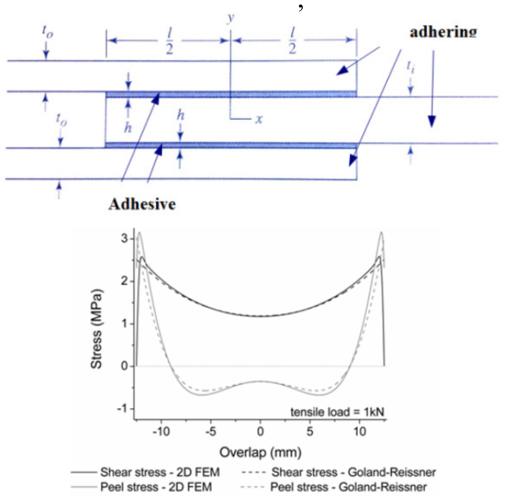

Figure 9: Comparison between the Goland Reissner theory and FEM

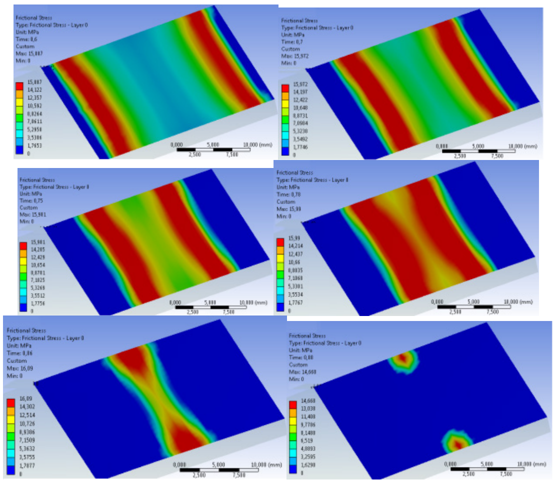

Figure 8.a: shear stress at the interface of the adhesive with voids

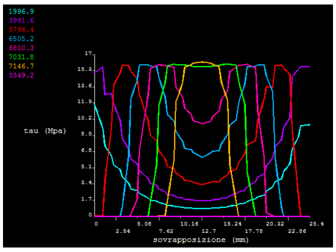

Figure 8.b: Shear stress at the centreline of the CZM contact at various values of the load (in N) for adhesive

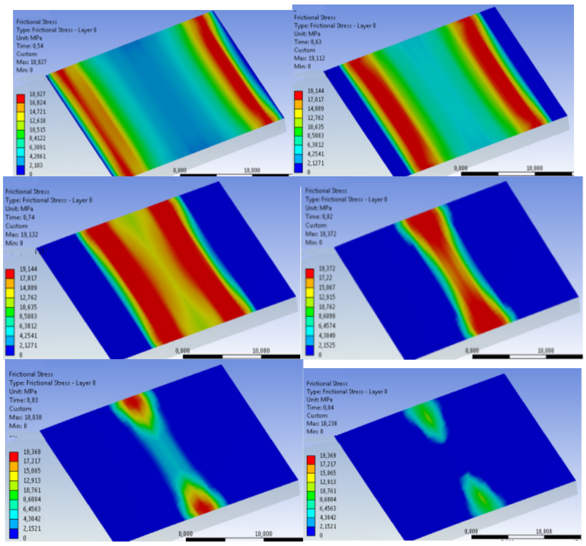

Figure 8.c: shear stress at the interface of the adhesive without

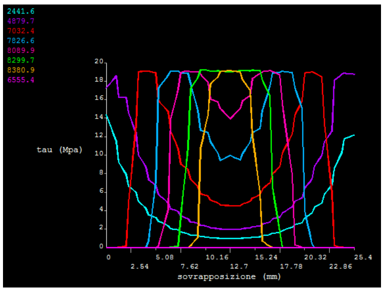

Figure 8.d: Shear stress at the centreline of the CZM contact at various values of the load (in N) for adhesiv

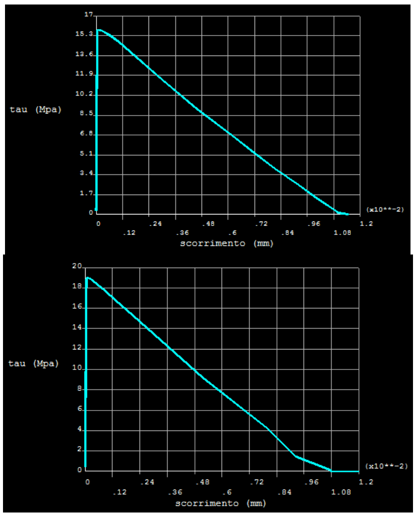

Figure 8.e and 8.f: constitutive relation the CZM model in the case of adhesive with and without voids

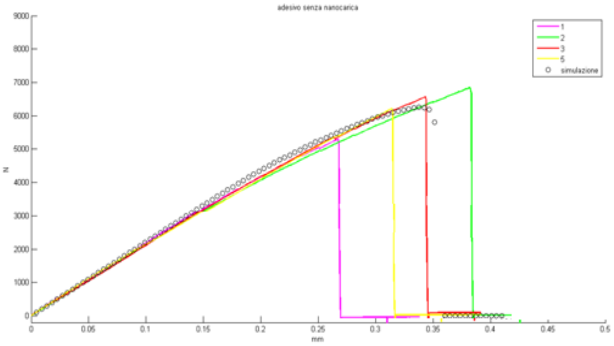

Figure 8.g: comparison between experimental and numerical data in the case with voids

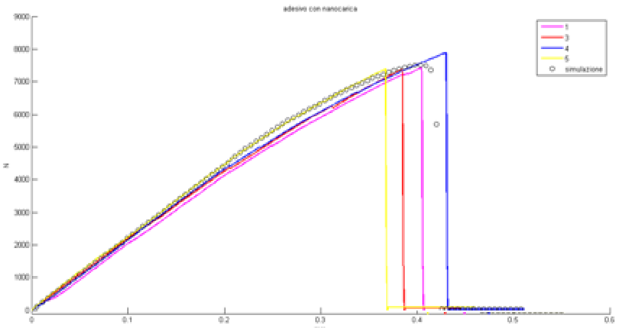

Figure 8.k: comparison between experimental and numerical data in the case without voids

6. CONCLUSIONS

In this study, the effects of voids on the adhesives, flexible and toughened adhesives at different tests on tensile failure load in single lap-joint geometry was investigated with an experimental and numerical analysis, the purpose of this, to improve and increase the mechanical performance and relatively uniform repartition of stresses along the bonded area, and decrease the weight structures, typical for adhesive aerospace applications, the results obtained were as follows:

- to improve and increase the mechanical performance and
- to distribute in a relatively uniform manner the stresses along the bonded area, and
- to decrease the weight structures, typical for adhesive aerospace applications, For the structural performance. Subsequently representative numerical models have been developed for modelling tests both the adherents that the adhesive using the technique of finite element. The main conclusions being reached and are as follows: Numerical models have shown well representative of the experimental tests with reasonable maximum errors. And after validation of the results the virtual cracks and the increasing of the shear stress cause the voids, considering the size of the voids because play a large role for the beginning of the expansion cracks in the adhesive, we couldn't confirm it experimentally, we must use another high technology machine under the control of the X-ray rayon, this technology simplified a direct view of the transformation of the voids, and the increasing of this cracks in the adhesive

with a 3D view of the deformation under big charge using the *3D metrology with high-resolution CT*.

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