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MECHANICAL CHARACTERIZATION OF BONDED JOINTS IN COMPOSITE MATERIALS

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Abstract: The aim of this work is to evaluate a series of glass fiber composite joints in order to determinate the minimum overlap length for them. The composite sheets are made of three layers: MAT + ROVING + MAT laminated with a polyester orthophthalic resin. The sheets are then joined with methacrylate adhesive "ITW PLEXUS MA 550", used in the Volvo Ocean Race to join the keel to the hull.
In order to accomplish this goal, adhesive strength of the composite sheets and the adhesive sheet joint were separately tested. From this tests were obtained the tensile strength, the Young modulus and the Poisson coefficient for the sheets and the adhesive shear strength for the joints. Next a FEM analysis was carried about obtaining the mean and the shear stress distribution.

1. INTRODUCTION.

The company sponsoring this research needed to investigate the possibilities of using adhesives to join different structural elements present in the ship's hull [1, 2], in order to improve its manufacturing process.
Nowadays several structural joints are made by manual laminated overlapping[3, 4], between them must be outstand the following:

a) Hull – Deck.
b) Deck – Bridge.
c) Deck – Engine room.
d) Deck – Winch.

The substitution of the lamination process an adhesive is expected to improve the following disadvantages:

a) The manual laminate needs a lot of operations, is slow and expensive ought to the required manpower.
b) The joint composite material is usually carbon fiber and so it is expensive.
c) It is difficult to join structures with different materials.

Figure 1. Example of different joints in ships.

The aim of this work is to evaluate a series of glass fiber composite joints in order to determinate the minimum overlap length for them. The composite sheets are made of three layers: MAT + ROVING + MAT laminated with a polyester orthophthalic resin. The sheets are then joined with methacrylate adhesive "ITW PLEXUS MA 550", used in the Volvo Ocean Race to join the keel to the hull.

In order to evaluate the adhesive strength the composite sheets were first tested. A series of tests were carried about obtaining as result the tensile strength, the Young modulus and the Poisson coefficient.

Then the minimum joint length was computed in order to assure the joint breakage prior to the sheet. Next a series of tests were made obtaining the adhesive shear strength.

Ought to the different modulus of elasticity between the sheets and the adhesive and the specimen deformation, a bending effect appears in the join length. This is responsible of the appearing of a peeling effect over the joint.

In order to compare the result test with the manufacturing data, a Finite Element Analysis was carried about. The input material data for the FEM analysis was taken from the prior sheet characterization. The adhesive data was taken from the manufacturer due to the difficulty to test it.

Once the FEM analysis was done, the bending effect appeared and the computed mean shear stress was very similar to the tested one. The stress distributions through the joint length for different lengths were also evaluated.

2. EXPERIMENTAL

To carry out this work first one panel made of composite was made. Then several specimens were taken and tested. Once the material was characterized, then a lot of specimens were joined by a methacrylate bicomponent adhesive and then tested.

Bellow, the different parts of the experiment are described.

2.1. Test panels

The regulation UNE-EN ISO 1268 shows the procedure to make test specimens from a panel. This work intends to reproduce the materials and conditions in the shipyard, so a 12 1250 x 600 mm panel with three layers of glass fiber (MAT + ROVING + MAT).

The MAT fiber used was a M501-300 made by the company AHLSTROM. The fiber weight was 300 gr/m2 ± 5%, the thickness of 0.60 mm, the length of 50 mm and the glass quality E. This MAT is a Chopped glass fiber made of felt cut fibers, randomly oriented and joined by a chemical bond.

The roving fiber was a 9622Z/450 – 1260, a combined knitting with several layers: one of Roving 9622 R24-810 and another of MAT M-300, made by the company AHLSTROM. The fiber weight was 1260 gr/m2 ± 5%, the thickness of 1.40 mm and the glass quality E. This knitting is made of continuous fibers interlaced in both normal directions sewed with another short fiber MAT layer.

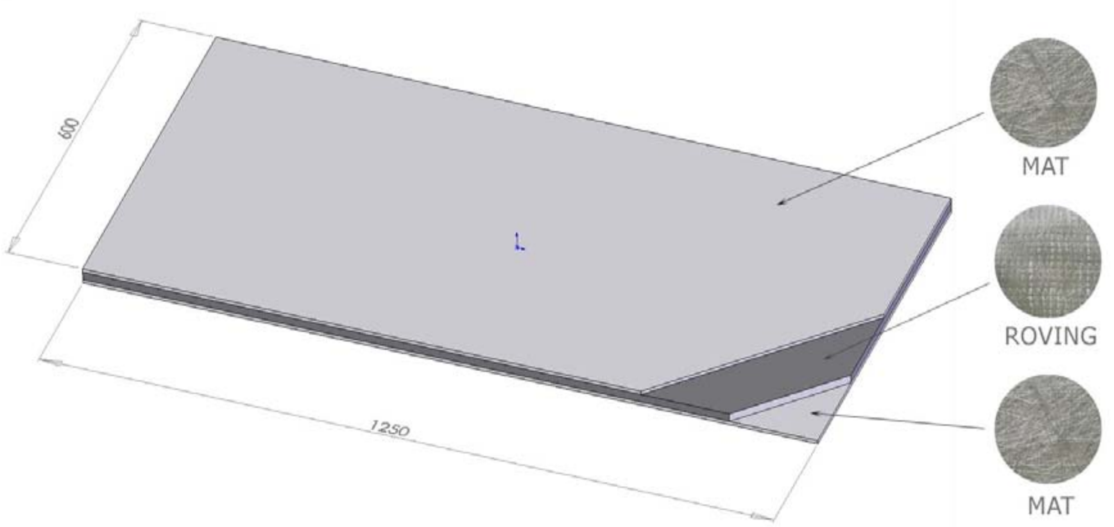

Figure 2. Composite and size of specimens panel.

The used resin was **Crystic 2-406PA**, a pre-accelerated and tixotropic polyester resin with low styrene emission made by the company **SCOTT BADER**. The curing reaction is achieved by adding the catalyzer CATALYST M (or BUTANOX M50) at room temperature. The quantity added was weight of 2%.

2.2. Tensile test specimens

The test specimens were cutted from two panels laminated by hand, using the described layers. The specimens dimensions were: length 250 ± 0.2 mm, width 25 ± 0.1 mm and thickness of 2.6 ± 0.1 mm.

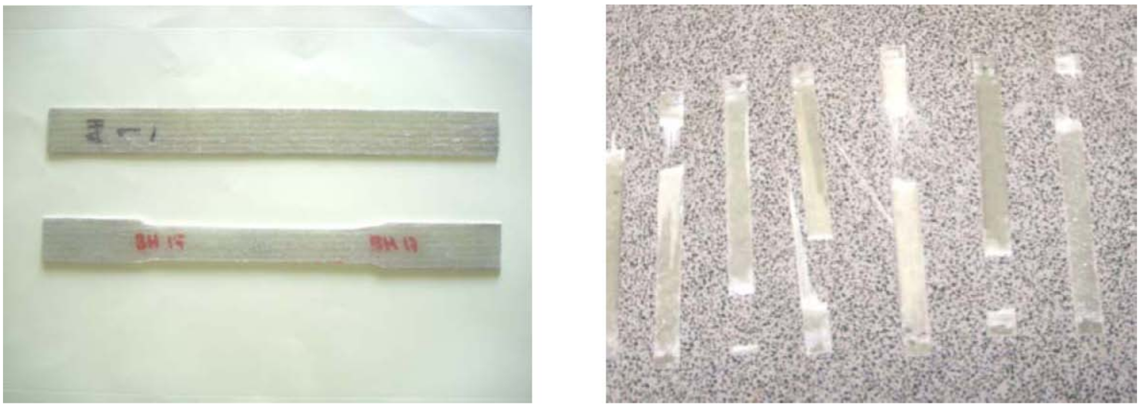

Figure 3. Tested specimens.

2.3. Test machine

The tests were made with a self made tensile test machine for composite materials. It is prepared to carry about tensile, elastic modulus and poisson coefficient tests, with load, time and speed PID control.

Figure 4. Test machine and acquisition equipment.

2.4. Adhesive

The tests were carried about with an adhesive of the company ITW PLEXUS as request of the sponsoring company. The adhesive used was the PLEXUS MA 550 because of its high feature/price ratio.

Designation PLEXUS	Action time (min.)	Fixing time (min.)	Strength (MPa)	Young Modulus (MPa)	Strain at break (%)	Cohesion strength (MPa)
MA 420	4 -6	15 - 18	18,6 – 20,6	517 - 689	100 – 125	12 – 15,5
MA 425	30 - 35	80 - 90	13,7 – 17,2	275,8 –344,8	120 – 140	10,3 – 12,4
MA 550	40 - 45	70 – 75	12 – 13,7	275,8 –344,8	35 – 45	8,9 – 12,4
MA 556	40 - 45	110 - 120	17,2 – 20,6	275,8 –344,8	140 – 160	8,6 – 10,3
MA 557	13,7 – 17,2	180 - 220	13,7 – 17,2	379 - 448	120 – 160	8,6 – 10,3
MA 1025	20 - 25	40 - 45	12 – 13,7	414 - 552	90 – 110	5,8 – 8,2

Table 1. Technical specifications of Plexus adhesives.

2.5. Shear test specimens

The shear strength test of rigid substrate joints was determined by the regulation UNE-EN 1465:1994.

The joint length has been previously determined in order to ensure previous break at the joint rather than in the substrate [5]. To do this, tensile test results were taken. The specimen had both heels in an opposite direction in order to obtain an aligned force onto the adhesive joint, so that no flexure or peel effect was introduced in the test. The specimen heels where joined to the substrate in an appropriate length to avoid the described defect.

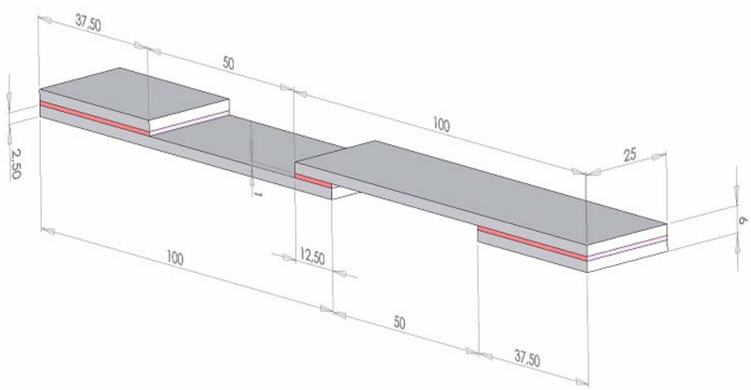

Figure 5. Shear test specimen dimensions.

3. NUMERICAL ANALYSIS

Once characterized the substrate material and the adhesive joint, a finite element model for the test was developed. The aim of this work is to compare the numerical results with the real ones in order to establish a correlation between them, so that a complete numerical model for the ship joints could be obtained in a future[3, 6].

First, the geometry was modeled using the program Proengineer Wildfire 5.0. Next, it was imported by the finite element software Ansys Workbench 12.0. Then the material data for the substrate and adhesive were introduced.

Following the model was meshed and then constrained and loaded.

The constraints and loads were: A frictionless support on heel sides, a fixed support on one end and a force of 2022N on the other. This load was determined from the shear tests, taking as reference the mean tensile strength.

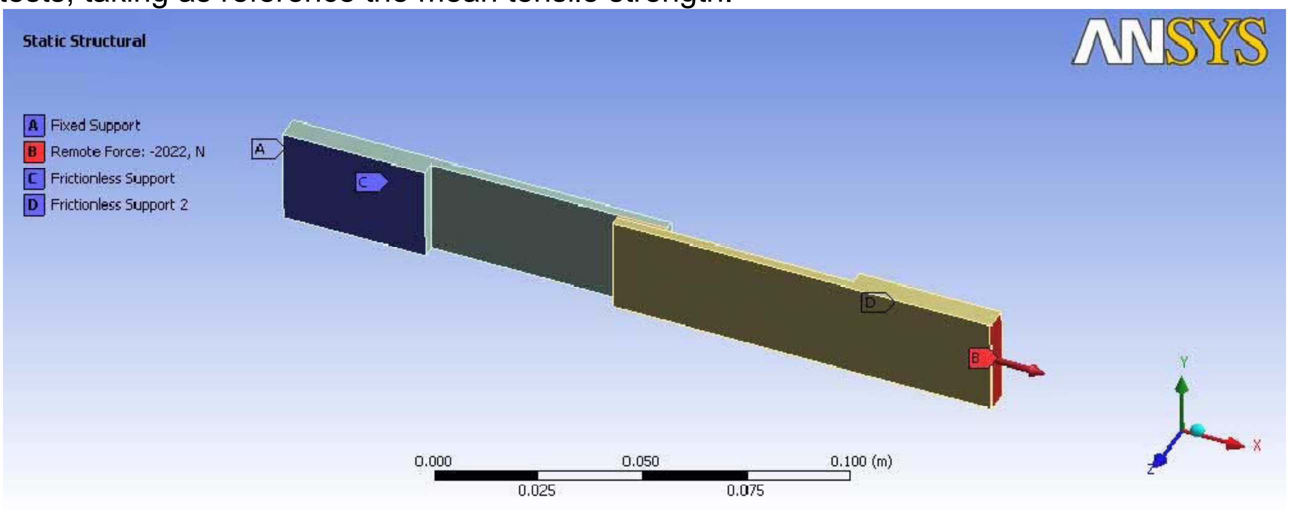

Figure 6. Shear test specimen dimensions.

4. RESULTS AND DISCUSSION.

Following the tensile test results are shown.

Average tensile strength	σ_{avg}	189,77 MPa
Standard deviation	s	±11,18 MPa
Repetitiveness criteria	2,5 x s	27,94 MPa

Table 2. Tensile test results.

The mean Young modulus and Poisson coefficients were:

Young Modulus	E	10770 MPa
Poisson coefficient in length dir.	μ_b	0,3065
Poisson coefficient in width dir.	μ_h	0,3065

Table 3. Elasticity coefficients.

Next the shear strength tests are shown:

Test specimen	Length	Width	Area	Break load	Shear strength
	mm	mm	mm2	N	MPa
BH21	13	24,4	317,20	2154,86	6,79
BH18	15,7	24,7	387,79	2212,54	5,71
AH13	13,1	25	327,50	2148,72	6,56
AH14	13,3	25,8	343,14	2480,01	7,23
BH13	13,5	25,8	348,30	1795,35	5,15
BH14	13,5	25,8	348,30	2419,52	6,95
BH15	13,8	25,7	354,66	2403,17	6,78
BV07	14,3	25,4	363,22	2408,28	6,63

Table 4. Shear test results on simple overlapped specimens.

The statistical results for the test are:

Average shear strength	τ_{avg}	6,47 MPa
Standard deviation	s	±0,69 MPa
Repetitiveness criteria	2,5 x s	1,73 MPa

Table 5. Shear test results.

Once calculated the shear stress, the von Mises equivalent mean stress is computed for a plane stress state, giving a value of 10,39 MPa.
This result represents almost exactly the mean value for the cohesion force of this adhesive in Table 1.
Following the numerical results are written, showing the relationship between them and the test result.
Results of simulation are interesting in the sense that they repeat some effects seen in the test. As can be appreciated the tensile specimen suffers combination of tension and bending. The last one is owed to the rigidity of the joint and the adhesive.

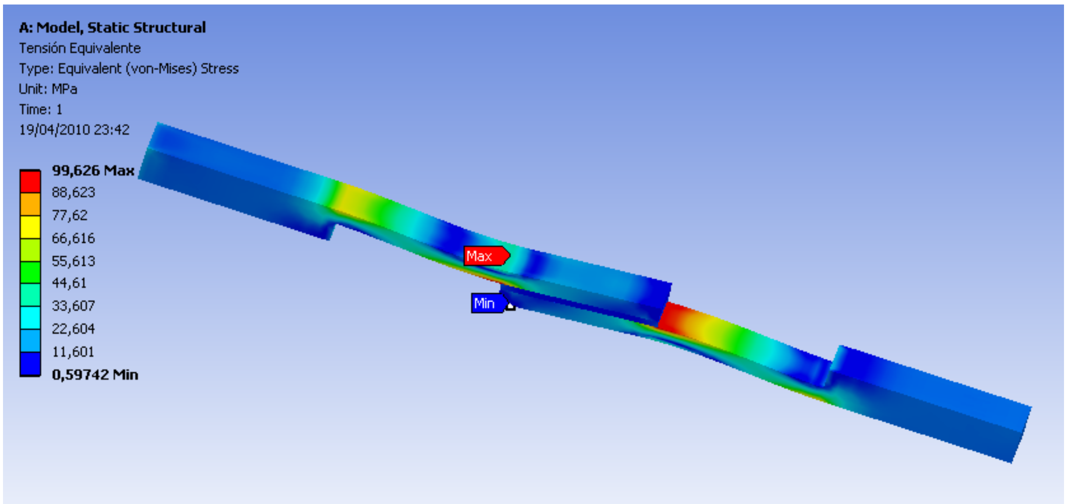

Figure 7. Test specimen bending.

The following figures represent the longitudinal stress distribution over the adhesive joint.

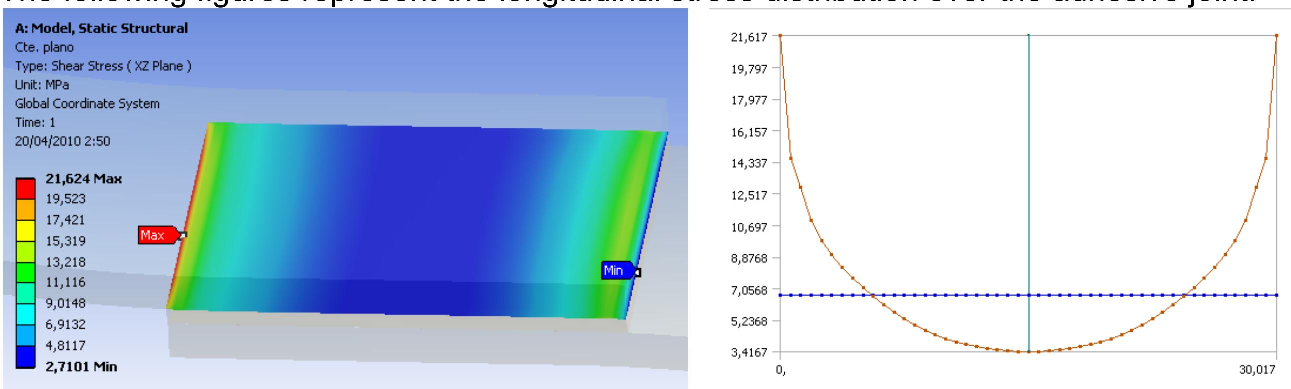

Figure 8. Test specimen shear distribution.

As can be shown the maximum shear stress is higher than the one obtained in tests. This is owed to the fact that the test represents the average stress distribution. If the average stress is calculated a value of 6,87 MPa is obtained which is slightly higher than the test one.

Next, the Von Mises equivalent stress is computed in order to determine if the bending effect that was appreciated has any influence.

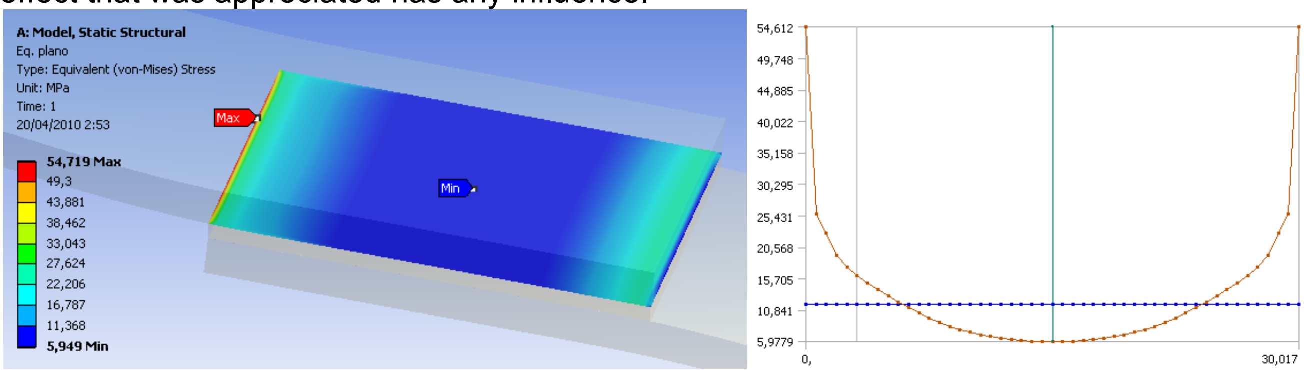

Figure 9. Test Von Mises equivalent stress distribution.

As the previous result, the maximum equivalent stress is several times the mean one obtained in tests. In this case, the mean stress (11,69MPa) is slightly higher than the obtained in the previous test. However, the peak stress is several times greater than the shear peak stress. This is owed to the bending that introduces a peeling effect in the extreme of the joint. The next figure shows the stress distribution of the peeling stress:

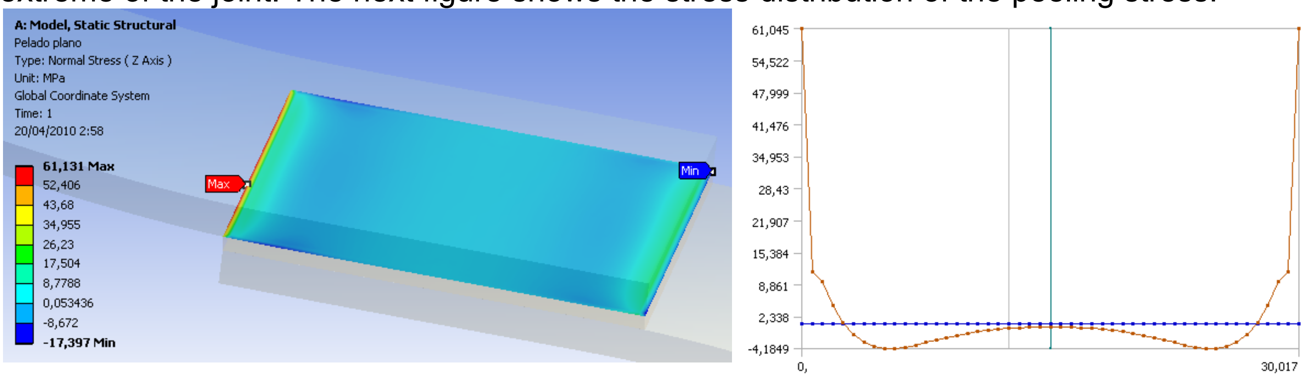

***Figure 10. Test specimen peeling stress*.**

As can be shown, average stress for the peeling stress is almost null (0,963 MPa). However, the peak stress is greater than the equivalent one, and almost six times the value of the average tensile strength. So, the peeling mechanism is responsible of the joint breakage.

6. CONCLUSIONS.

The tests carried out combined with the simulations give similar results in a qualitative and quantitative way. These results are also in concordance with the manufacturer test data. So it can be concluded that the test procedure and the numerical simulation are trusted.
From this moment, it will be possible to simulate more complex ships structures like the mentioned ones in the introduction.

7. REFERENCES

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