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ALUMINUM, AN ALTERNATIVE TO GRP FOR MANUFACTURING OF SPORTS BOATS

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ABSTRACT

Pollution is being discussed more and more in the world. It is known that the production of Glass Fiber Reinforced Polyester (GRP) is a polluting process. Also, the implementation of GRP is a process that can cause various ailments to the personnel who apply it. Over time, boats made of GRP suffer degradation due to interaction with the environment: cracks, exfoliation of the outer layer of gelcoat, etc. These degradations must be remedied, operations that involve the application of substances that are also polluting. More and more traditional manufacturers of sports boats are replacing GRP with aluminum. This, although the process of obtaining it from the ore is not without toxic components, is less polluting and friendlier to the executors than GRP. In this paper, we seek to elucidate the advantages that aluminum has over GRP in the construction of sports boats.

Keywords: sports boats, GRP, Aluminum, adhesive, experimental tests.

1. INTRODUCTION

Sports boats, regardless of their size, are generally built today from polyester reinforced with glass fiber (GRP). This material is easy to use, the boat manufacturing process being sufficiently optimized. However, in the manufacturing process, GRP is polluting through the release of harmful gases. Also, the weights of these boats are high, therefore requiring high propulsion powers. Propellers, being generally internal combustion engines, are also polluting. We are looking for solutions to replace GRP with other less polluting materials or to lead to lighter boats that require lower propulsion powers, so less polluting engines. Thus, in the paper we want to demonstrate the fact that Aluminum (Al) can be a successful substitute for GRP in the construction of sports boats.

2. COMPARISONS BETWEEN THE MECHANICAL CHARACTERISTICS, FROM THE SPECIALIZED LITERATURE OF GRP AND ALUMINIUM

GRP is a product obtained from a glass fiber cloth impregnated with a polyester (matrix). This process is long-lasting because the components must carry out their chemical reactions to form the composite. Regarding aluminum, the process of obtaining it from ore is shorter in duration, even if it is almost as polluting. From this point of view, aluminum throughout the entire manufacturing process saves time and implicitly material resources. The nominal composition of aluminum type 6061 is 97.9% Al, 0.6% Si, 1.0%Mg, 0.2%Cr and 0.28% Cu. The density of aluminum alloy 6061 is 2.7 g/cm3. Aluminum alloy 6061 is heat treatable, easy to form, weldable and good against corrosion.

Table 1 shows the mechanical characteristics for Al6061 and GRP (from the literature [1])

Material	Tensile strength (MPa)	Longitudinal modulus of elasticity (MPa)	Specific weight (kg/m^3)
GRP	300-375	3902	1800
Al 6061	310	6890	2700

The mechanical behavior of GRP is affected by the appearance of the so-called spider's web. These are microcracks that appear in the GRP structure that can lead to the appearance of large cracks with serious implications for the safety of the boat. As you can see, GRP is "lighter" than Al. In the construction of sports boats made of GRP, due to their resistance structure, which is more elaborated than in the case of using Al, they are "heavier". This leads to an increase in the resistance of the advance (by increasing the draft and implicitly the watered surface) and hence the increase in the amount of fuel consumed for propulsion, therefore more pronounced pollution.

Also, GRP has poor fatigue behavior. We have previously mentioned the appearance of microcracks that can lead to the appearance and propagation of cracks through the thickness of the layers, which can lead to the destruction of the layer and implicitly compromising the structural resistance of the sports boat.

Also, the repairs of boats built from GRP are more difficult to perform, requiring special environmental conditions (temperature and humidity) at the repair site.

3. MECHANICAL TESTS PERFOR-MED TO DETERMINE THE BEHAVIOR OF ALUMINUM UNDER THE ACTION OF STATICALLY APPLIED LOADS

The behavior of Al under loads is less known, because it has only been used for the construction of resistance structures for a few decades. It is often used in the aviation industry, in the car industry and in the last 20 years also in the shipbuilding industry.

For this reason, it is necessary to fully know how Al responds to the action of loads, and especially under the action of time-varying loads.

METHOD

For this investigation, samples were taken from a 3 mm thick Al6061 plate. In order not to influence the mechanical characteristics for cutting, a water jet cutting machine and special granite granules were used. The samples were charged according to the standards of mechanical tests. The model according to which the specimens were cut is presented in figure 1.

The samples were taken with standard dimensions with an active area of 100x10 mm.

A number of 25 samples were taken from Al6061 sheet 3 mm thick (as is presented in figure 1), and from GRP cast plates also 3 mm thick to have the same terms of comparison. Test sets of: traction, compression, bending and fatigue were performed.

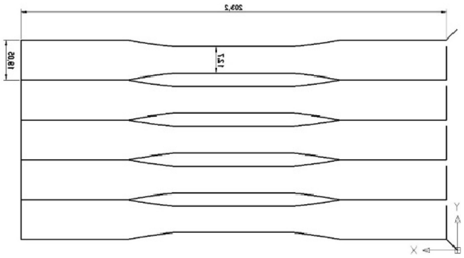


Fig. 1

3.1 THE TENSILE TEST

The tensile test (as well as the rest of the mechanical tests) was carried out on an INSTRON universal testing machine from the laboratory equipment of the Research and Development Center for Composites with Thermoset Matrices of the "Dunarea de Jos" University of Galati.

This equipment is rigged with a process computer which, at the end of the tests, provides all the necessary data for the characterization of the tensile tested material.

Figure 2 shows the sample made of PAFS attached to the car's chassis prepared for the traction test.

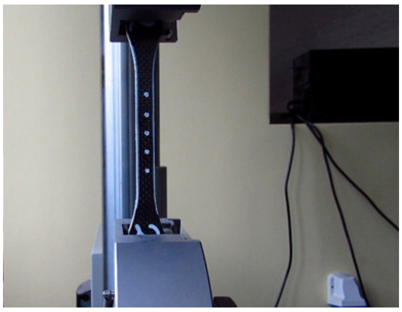


Fig. 2

Figure 3 shows the variation graph of displacement as a function of load for one of the Al6061 samples tested.

Table 2 shows the results load – displacement provided by the INSTRON equipment at the end of the tensile test.

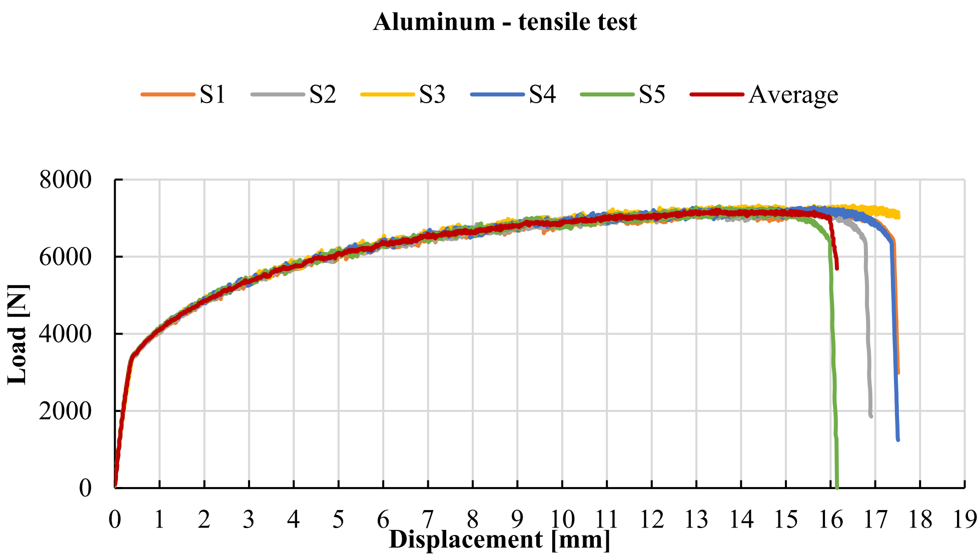


Fig. 3 The variation graph of displacements depending on the load

Table 2. Mechanical characteristics of Al6061 (tensile results)

	Module [MPa]	Elastic limit load [N]	Maximum load [N]	Breaking load [N]
Average	5398	7165	7308	6401
Deviation (max/min)	48.5	155.9	15.5	64.2

As can be seen from table 2, the break occurs at a stress force lower than the maximum. This behavior is similar to steel tested in tension.

Table 3 shows the same values for tests on samples made of GRP, with the same dimensions as those made of Al6061.

The variation graphs for GRP are NOT presented anymore because they are known from the specialized literature of recent years.

Table 3. Mechanical characteristics of GRP (tensile results)

	Module [MPa]	Elastic limit load [N]	Maximum load [N]	Breaking load [N]
Average	4985	6854	5210	4850
Deviation (max/min)	59.4	184.2	27.8	47.8

3.2 THE COMPRESSION TEST

The compression test was performed on the same equipment.

Figure 4 shows the displacement graph as a function of load for one of the Al6061 samples tested.

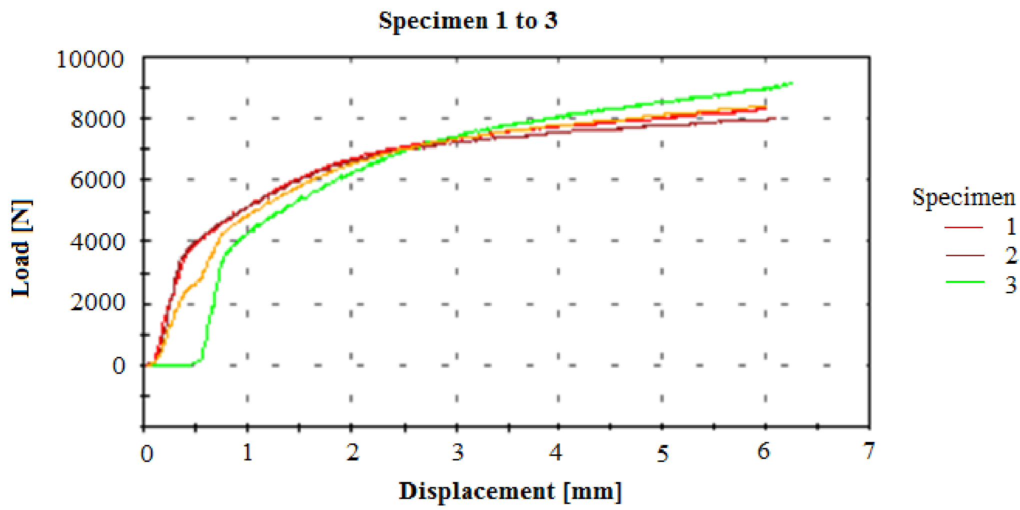


Fig. 4 The variation graph of displacements depending on the load

Table 4 shows the sizes provided by the INSTRON equipment.

Table 4. Mechanical properties of Al6061 (compression results)

	Module [MPa]
Average	1733.8
Standard deviation	8.6

Table 5 shows the same values for tests on samples made of GRP, with the same dimensions as those made of Al6061. As in the case of the traction test, the variation graphs for GRP are no longer presented because as was mentioned is shown in literature.

Table 5. GRP mechanical characteristics (compression results)

	Module [MPa]
Average	1487.2
Standard deviation	13.2

3.3 THE BENDING TEST

Using the same test equipment used with specific bars, they were performed on samples made of Al6061 and GRP.

Figure 5 shows a sample made of GRP placed between the trays of the testing equipment and subjected to bending.

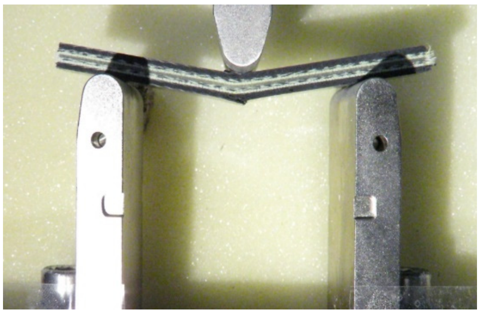


Fig. 5

Figure 6 shows the graph of the bending behavior of a sample made of Al6061.

Table 6 shows the sizes provided by the INSTRON equipment at the end of the tensile test.

Table 7 shows the same values for tests on samples made of GRP.

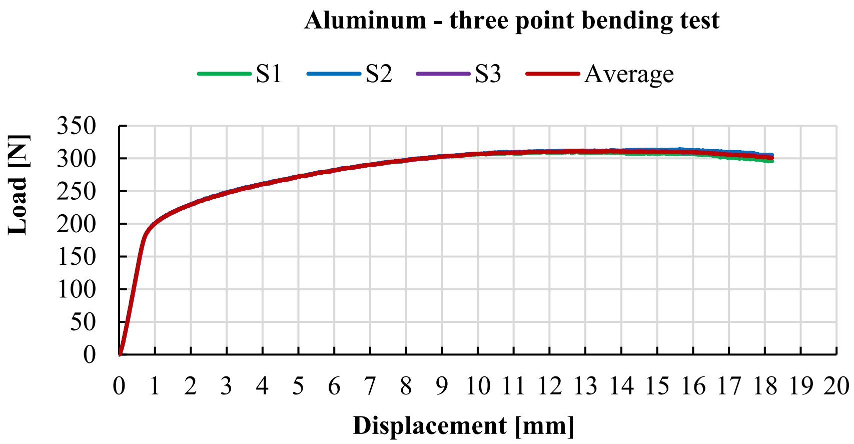


Fig. 6 The variation graph of displacements depending on the load

Table 6. Mechanical characteristics of Al6061 (bending results)

	Module [MPa]	Elastic limit load [N]	Maximum load [N]	Breaking load [N]
Average	5398	7165	7308	6401
Deviation (max/min)	48.5	155.9	15.5	64.2

Table 7. GRP mechanical characteristics (bending results)

	Module [MPa]	Elastic limit load [N]	Maximum load [N]	Breaking load [N]
Average	4985	6854	5210	4850
Deviation (max/min)	59.4	184.2	27.8	47.8

3.4 CONCLUSIONS FOR THE STATIC TESTS PERFORMED

As can be seen from the analysis of the data in tables 2,...,6, the mechanical characteristics resulting from mechanical tensile, compression and bending tests in static mode indicate that Al6061 presents a series of advantages compared to GRP.

It can be noted that:

1 - in traction there are differences in favor of Al6061 compared to GRP of 7.65% for the modulus of elasticity and 24.23% for the maximum breaking force.

2 - in compression due to the fragility of GRP [2], only the elasticity mode could not be determined, the difference being 0.07% in favor of Al6061.

3 - the same differences are found in bending as in tensile stress, namely 7.65% in the modulus of elasticity and 24.23% in the breaking strength.

From the analysis of the previously synthesized results, it can be concluded that from a static point of view, Aluminum (even in the form of Al6061) has superior mechanical qualities to GRP. This, until now, recommends Aluminum to be used in the naval industry (construction of sports boats and not only).

3.5 MECHANICAL TESTS PERFORMED TO DETERMINE THE BEHAVIOR OF ALUMINUM UNDER THE ACTION OF DYNAMICALLY APPLIED LOADS (FATIGUE TEST)

During navigation, there are situations when the surface of the water has waves of various heights and frequencies. They require variable loads over time, which can lead to the appearance of the phenomenon of fatigue of the materials from which the floats are made. It is known that most of the accidents that have occurred are due to the failure of the structure of the floats as a result of the decrease in the resistance capacity due to the fatigue of the material.

To elucidate the fatigue behavior of Al and PAFS, tensile fatigue tests were performed on the same INSTRON equipment. The same type of samples was used as in the previous tests. This was done precisely to be able to compare the results obtained with each other for the same type of tested specimens.

For this reason, the work gives great importance to this request.

Fatigue tests were performed for 20,000, 50,000 and 100,000 cycles. On the end of each test the equipment broke the specimen.

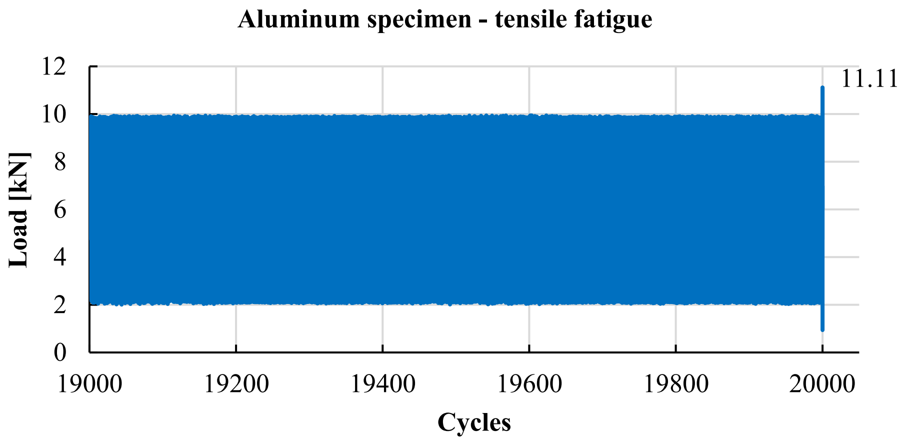
3.5.1 TENSILE FATIGUE TEST

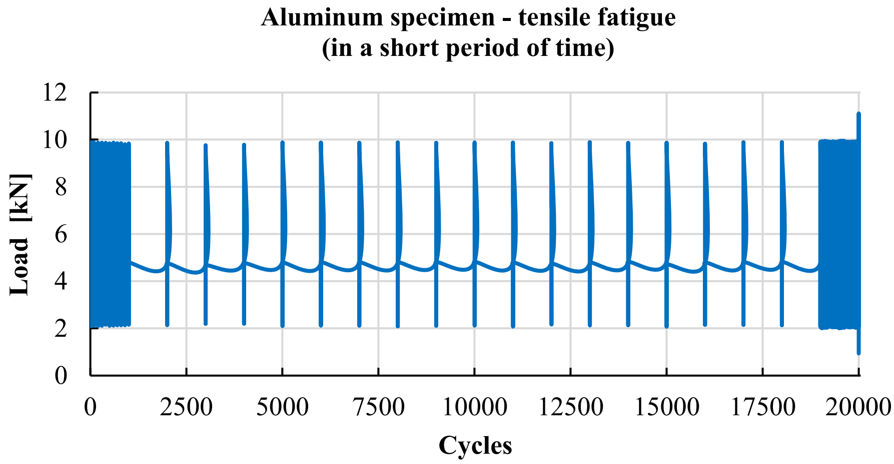
Test graphs will be presented only for a single number of cycles out of the three number of cycles chosen for the test.

Figure 7 a) shows the variation graph of the number of tensile fatigue loads for a number of 20,000 cycles. Since the presentation of the entire stress cycle due to the density of the cycles does not result in the maximum load that the material can withstand in figure 7 b), an isolation of an interval of 1000 cycles was achieved.

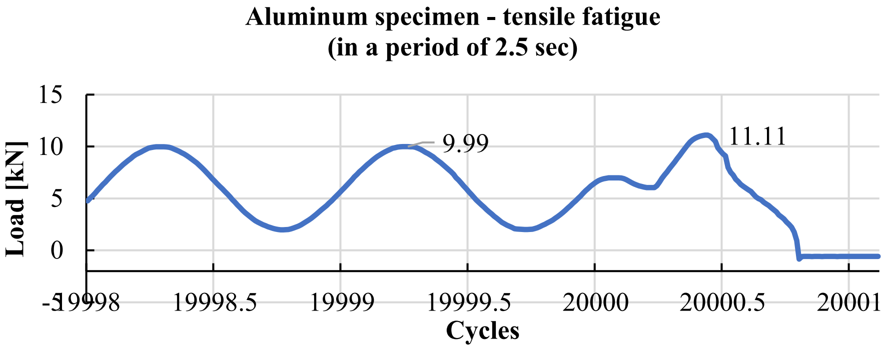
METHOD.

An initial elongation of 2 mm is applied to the specimen arranged between the trays of the INSTRON testing machine. The machine is adjusted for the maximum intensity of the application force. The number of cycles is chosen and the test gets started.





a)



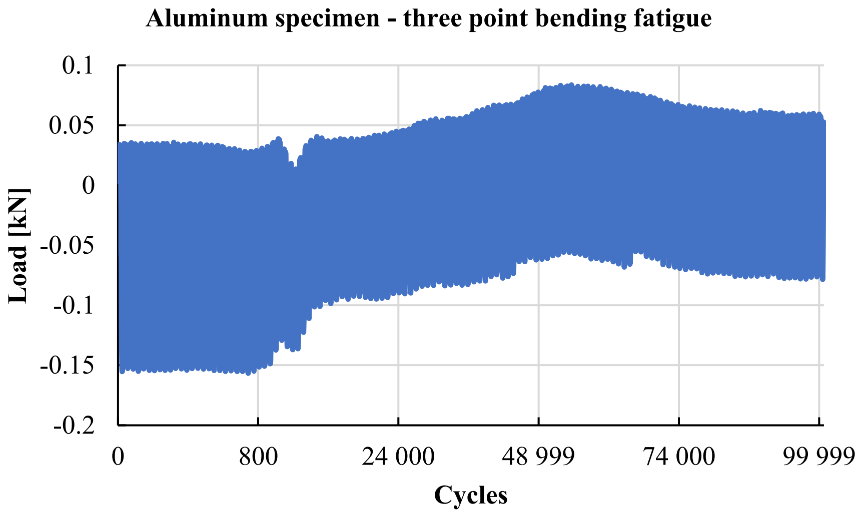
b)

Fig. 7 Traction for 20,000 application cycles

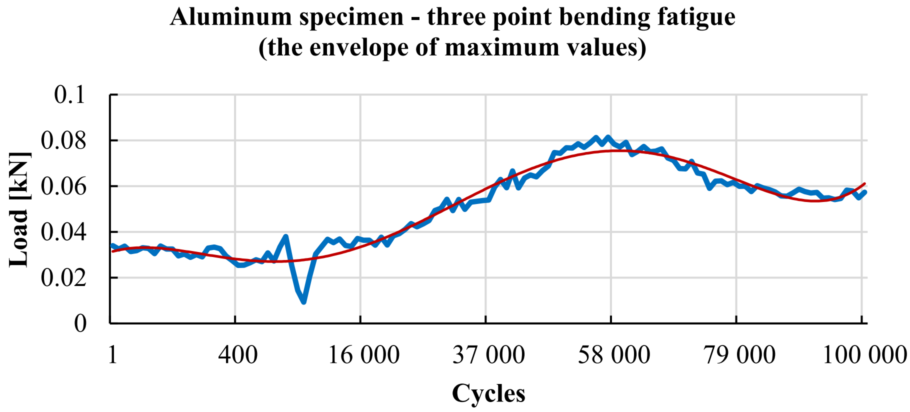
3.5.2 BENDING FATIGUE TEST

The working method is identical to that of the tensile fatigue test.

In the case of Al6061, the specimen was arranged on the 2 supports as in figure 5. The request was applied in the middle of the opening. As in the previous case, only the test for a single number of test cycles will be presented. The choice of the request cycle was made by analyzing the results obtained, in order to present the most eloquent ones. Figure 8 (a) shows the graph of the bending fatigue test for the entire stress cycle with 100,000 cycles. In figure 8 (b), a representation of the maximum bending stress load over the entire number of cycles was made.



a)



b)

Fig. 8 Bending fatigue for 100,000 stress cycles

For GRP, the bending fatigue test was irrelevant because the specimen broke at the first request so that the fatigue loading cycle could not be performed. So, for GRP we cannot talk about bending fatigue.

3.5.3 CONCLUSIONS FOR THE PERFORMED DYNAMIC TESTS

For GRP, the tensile and/or bending fatigue tests were not relevant because the specimens broke at the first load so that the fatigue test cycle could not be performed. The delamination process that GRP suffer makes a fatigue test impossible.

From the analysis of the results and the AL6061 fatigue test, it can be observed that before reaching the maximum number of cycles (before the specimens' break), an increase in the stress force (fig. 7 b) and 8 b)). This indicates that Al6061 suffers a hardening phenomenon, as a result of which AL6061 changed its mechanical characteristics in the sense of increasing them.

This phenomenon of material strengthening following the application of a cold mechanical treatment is called the Bauschinger effect (after the name of the person who discovered it).

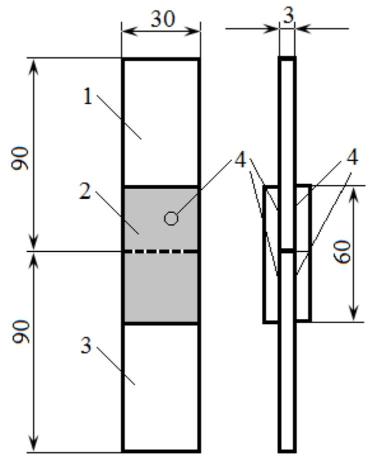
4. THE USE OF INNOVATIVE METHODS FOR ASSEMBLING THE COMPONENT ELEMENTS OF SPORTS BOATS

One of the shortcomings of the aluminum used in the construction of boats is the welding process of the various component elements. Because of the heat flows, the local dilatations that occur deform the structure of the boat, making it necessary to use special putties to obtain external surfaces comparable in appearance to the boats made of GRP.

In this sense, the research group tried the use of adhesives for the assembly of the component elements of the co-made aluminum boats.

Thus, several solutions were tried:
1. Aluminum bonded with double-sided tape;
2. Aluminum bonded with silicone adhesive;
3. Aluminum bonded with epoxy resin
4. Primed aluminum bonded with epoxy resin.

In order to detect the behavior under loads of the solutions adopted for the assembly of the component elements of the sports boats, samples were made as shown in figure 9.



1. Flatbar 90x30x3
2. Flatbar 60x30x3
3. Flatbar 90x30x3
4. Adhesive solutions

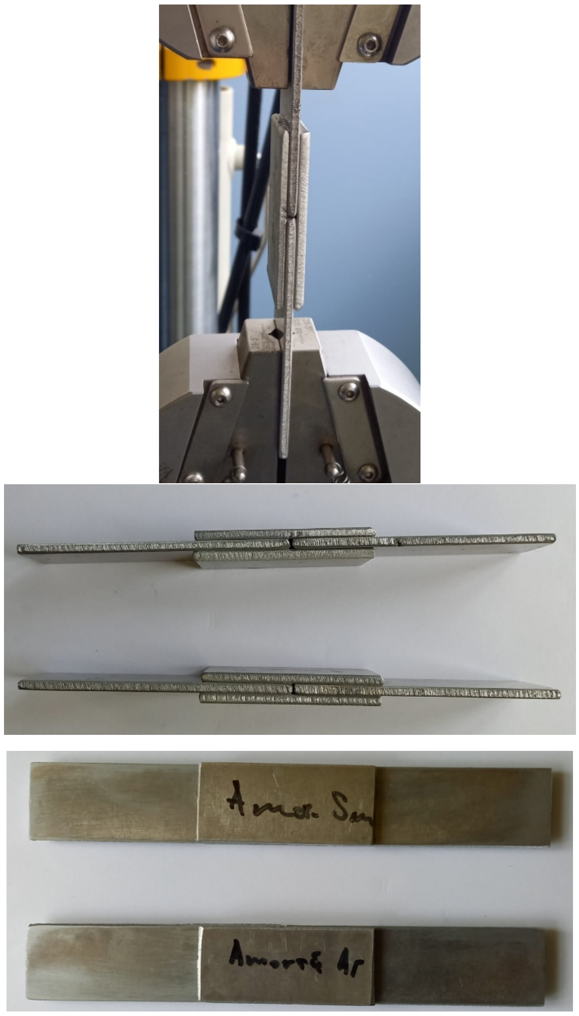
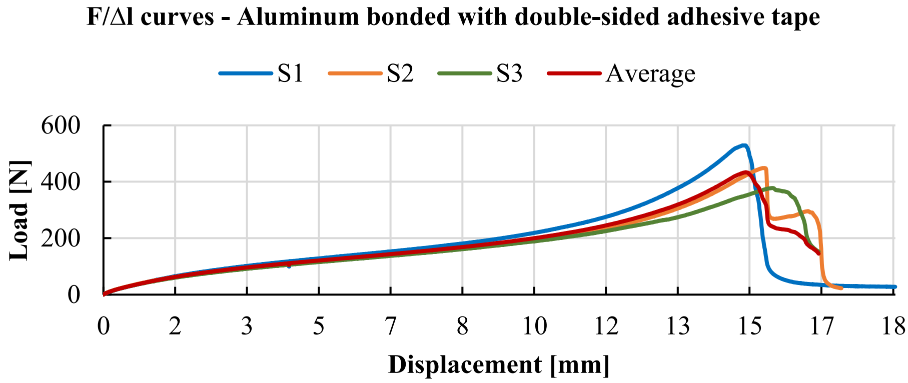


Fig. 9 The samples used for testing bonding solutions

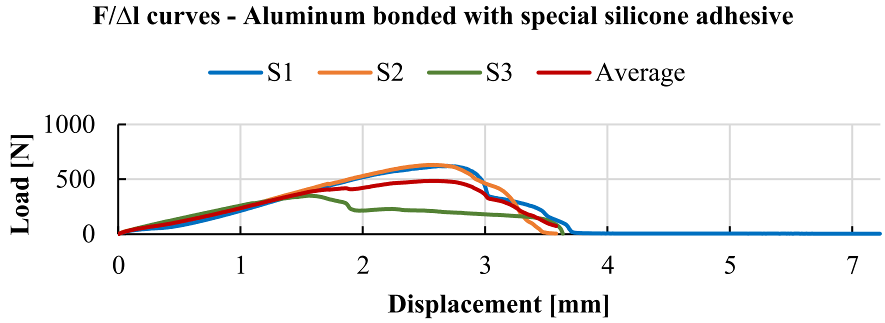
As you can see, the bonding surface is 2x30x60 mm2. The plates 2 were arranged on both sides of the plates 1 so that when the load is applied, the load acts along the longitudinal axis of the specimen (to have only tensile loads not bending).

Only the tensile test was performed because it was primarily interested in determining the appropriate strength of the joint.

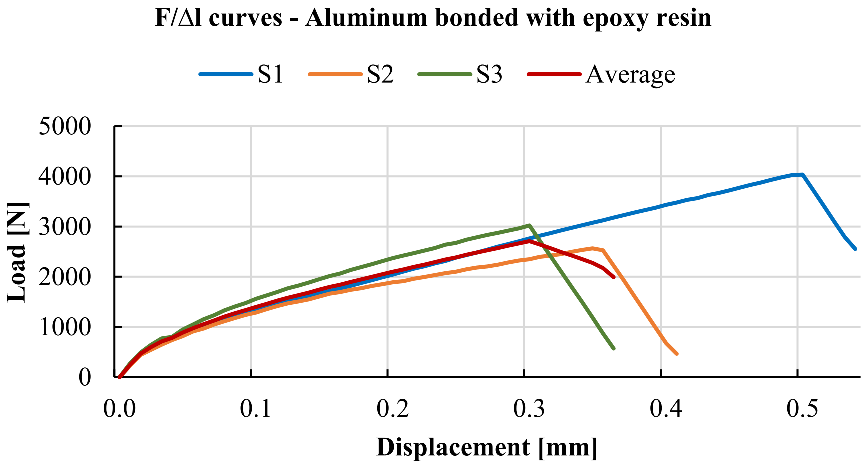
Following the tensile test of the samples obtained using the presented adhesive solutions, the behaviors shown in figure 10 resulted.


F/Δl curves - Aluminum bonded with double-sided adhesive tape
S1
S2
S3
Average
Load [N]
0
200
400
600
0 2 3 5 7 8 10 12 13 15 17 18
Displacement [mm]

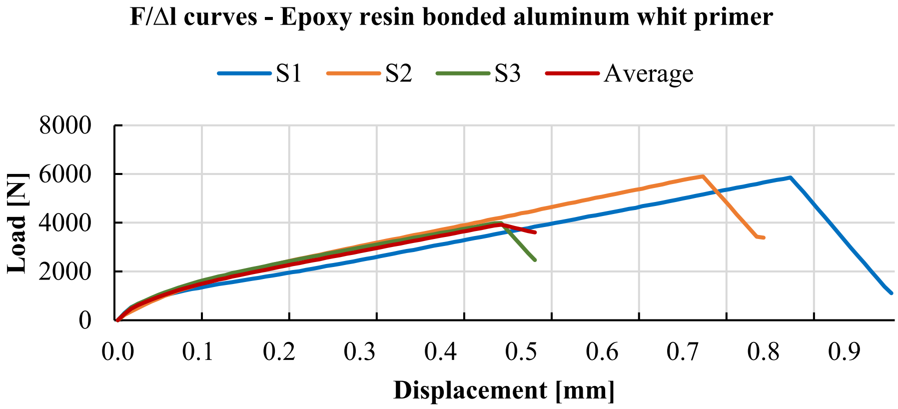
1)


F/Δl curves - Aluminum bonded with special silicone adhesive
S1
S2
S3
Average
Load [N]
0
500
1000
0 1 2 3 4 5 7
Displacement [mm]

2)


F/Δl curves - Aluminum bonded with epoxy resin
S1
S2
S3
Average
Load [N]
0
1000
2000
3000
4000
5000
0.0 0.1 0.2 0.3 0.4 0.5
Displacement [mm]

3)



4)
Fig. 10

Table 8 shows, numerically, the behavior of the 4 types of solders used.

In the graph in figure 11, the behavior of these solders is intuitively represented.

Table 8.

	Maximum load [N]			
	Aluminum soldered with double-sided tape	**Aluminum soldered with silicone adhesive**	**Aluminum soldered with epoxy resin**	**Aluminum with soldered primer with epoxy resin**
Average	415.06	632.08	3609.13	5999.83
Deviation	35.63	3.67	568.15	93.60

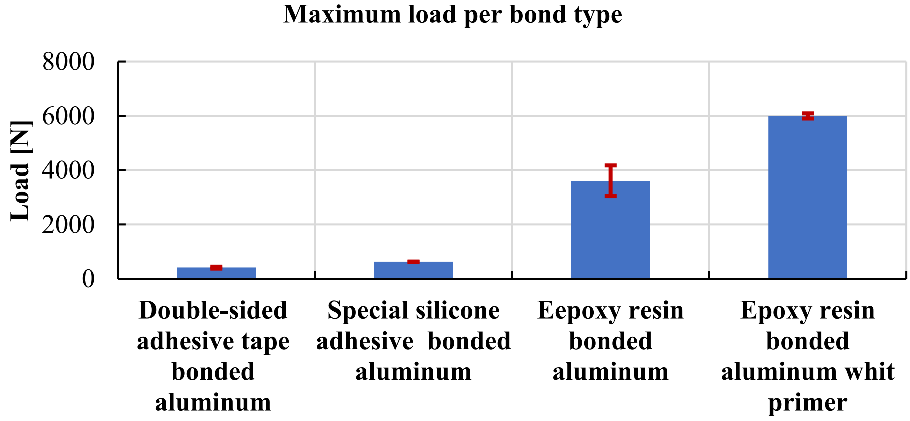


Fig. 11

5. COMPARISONS, CONCLUSIONS, FUTURE RESEARCHES

As it results from the tables with the results provided by the INSTRON test equipment, it can be deduced that Aluminum (Al6061) clearly has a superior behavior under loads compared to PAFS. Also, due to its better behavior in dynamic demands, Aluminum is recommended to replace PAFS in the construction of sports boats.

By the behavior under load resulting from the tests carried out, it can be concluded that the structures of the boats made of aluminum are lighter than those made of PAFS. This leads to a decrease in fossil fuel consumption (where the engines used are internal combustion), therefore implicitly in pollution. The powers of the engines installed on boats made of aluminum are lower compared to the same boat made of PAFS.

From the analysis of the results obtained on the samples obtained by gluing, it can be observed that the use of primer when gluing with epoxy resin gives the best results. This type of adhesive that has a breaking strength of 5999.83 N, which, compared to the tensile strength of aluminum of 6401 N, can be used to assemble the skeleton elements of sports boats.

For the future, other types will be tried of adhesive to find the best solution for gluing the resistance elements to the hull of sports boats. Then we will try to build such a boat of maximum 6 m long, 2.5 m wide with a maximum draft of 0.5 m, to ensure propulsion with an internal combustion engine of 50 HP and not with a 100 HP engine as boats built from GRP are equipped.

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