Materials Research Proceedings 35 (2023) 350-358 https://doi.org/10.21741/9781644902714-42

Static indentation properties of basalt fiber reinforced composites for naval applications

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Keywords: Delamination and Debonding, Naval, Composites

Abstract. In recent years, the attention toward the use of basalt fiber reinforced composite in shipbuilding is significantly grown. Basalt is a green and environmentally friendly high-tech fiber made without environmental pollution. Among the natural fibers that can be used as reinforcement, it represents one of the most interesting due to its excellent mechanical properties. The goal of this research is to mechanically characterize some laminates used by Intermarine to make several structural or non-structural parts (i.e., hulls, deck), where the glass fibers are substituted with basalt ones at varying the manufacturing process (i.e., hand-lay-up and vacuum infusion). Specifically, static indentation tests were performed with different pin diameters (i.e., 17 mm, and 20 mm) and speeds (i.e., 1.25 mm/min, and 2.50 mm/min) to study the difference between glass and basalt in terms of resistance and failure modes.

Introduction

In shipbuilding, steel has been widely used because of its mechanical properties such as high tensile strength, yield strength, resilience, hardness, and weldability. However, steel structures are characterized by several problems such as the corrosive phenomena induced by the aggressive marine environment, and the pollution issues connected to the weight of the vessels and the consequent high amount of fuel required for navigation [1]. Recently, the attention has been focused on the concept of sustainable and efficient shipbuilding with the aim of reducing greenhouse gas emissions produced by navigation, seeking materials and techniques to increase sustainability, including the construction of lighter ship weights to reduce fuel consumption [2]. This has led to the need to use multi-material systems to make structural and non-structural parts of vessels, and the most suitable materials for this purpose are composites characterized by high corrosion resistance, tensile and shear strength, impact resistance, and low weight. Basalt is a natural material that is found in volcanic rocks. It is mainly used (as crushed rock) in construction, industrial and highway engineering [3]. Due to its good properties such as chemical stability, non-toxicity, non-combustibility, corrosion and high temperature resistance, thermal and acoustic insulation, low moisture absorption and better mechanical properties than those of E-glass ones [4-5], basalt fibres began to be used as a new reinforcing material for concrete [6-8] and polymer composites as well as for hybrid composite laminates in marine applications [9-11]. The main advantages that characterise these materials include the capability to create complex geometries and the lightness. However, they are susceptible to low velocity transverse impact damage, which can be occurred during construction (i.e., accidental impacts, "falling gear") or during the use (i.e., common impact events are collisions with floating debris, other vessels, docks, groundings, strandings, all of which are low velocity impacts) [12-13]. This fact is critical, taking in account

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that in the typical glass-polyester based laminates the failure can occur for low incident energies [14].

In this study some resin-based laminated composites with glass fibres were considered, actually these products are used by Intermarine at Sarzana shipyard [La Spezia (SP), Italy] in the military ships.

Three kinds of composites, employed in different parts of the ship, were considered. The first kind is used for structural and non-structural parts (hull, decks, bulkheads, ship tanks), the second is used for internal non-structural bulkheads, the third is a new proposal to be assigned as a function of its performances. The different composites are therefore realized with different lamination sequences, employing two different technologies (i.e., hand lay-up and vacuum infusion). More details are reported in the next paragraphs.

The study describes the results of the static indentation tests, developed in the context of a research project, where a complete mechanical characterisation of these products is required, to evaluate the possibility to replace the glass fibres with the basalt ones, without losing performances of the products.

The static indentation tests have been performed both with two different pin diameters and two pin speeds. The resistance of the laminate composites has been evaluated in terms of nominal maximum stress and the mode of fracture have been determined to compare the behaviour of the different materials.

Materials and method

Laminates panels preparation

The tested laminated panels were produced by Intermarine at Sarzana shipyard [La Spezia (SP), Italy]. These last were made with a size of 1x1 m, using two different resins (i.e., a polyester resin and a vinyl ester one) through two production technologies (i.e., hand lay-up and vacuum infusion). The raw materials used in the production of the composite materials are listed in Table 1, while Table 2 shows the configurations of the laminated panels.

Table 1: Raw materials.

Polyester resin SYNOLITE 288: 2 [kg]
Vinylester Resin ATLAC 580 AC 300: 2 [kg]
Catalyst TRIGONOX 61: 0.1 [kg]
Catalyst NOROX: 0.1 [kg]
Accelerator CP 12 PERGAQUICK: 40 [g]
Balsa 1” Diab: 0.5 [m^{2}]
Fiber glass reinforcement 1100 [g/m^2]- Jerago: 0.5 [m^2]
Basalt fiber reinforcement: 0.5 [m^2]

An identification code was used, i.e., IT “resin type”_“production type”_“fibre type”_“fibre orientation”_“indenter speed”_“indenter diameter”; where:

- IT means “item”,
- “resin type” is P or V respectively for polyester or vinylester,
- “production type” is M or I respectively for manual lay-up or vacuum infusion,
- “fibre type” is G or B for glass or basalt,
- “fibre orientation” is “or” when the fibre are oriented,
- “indenter speed” is V1 for 1.25 mm/min and V2 for 2.5 mm/min,
- “indenter diameter” is IND1 for 17 mm and IND2 for 20 mm.

For example, the test with D=17 mm V=1.25 mm/min on the first kind of panel (realized with polyester resin by manual lay-up) is coded as: IT P_M_V1_IND1.

Table 2: Characteristics of laminates.

Panel ID	Thickness [mm]	Skin	Manufacturing Process	Resin	Lamination Sequence
IT_P_M_G	10	Single-skin	Manual	Polyester	6 layers glass
IT_V_I_G	6	Single-skin	Infusion	Vinylester	7 layers glass
IT_P_M_G_or	12	Single-skin (0°,45°)	Manual	Polyester	Orientation +45°/-45°/0°/+45°/-45°/90°
IT_P_M_B	8	Single-skin	Manual	Polyester	6 layers basalt
IT_V_I_B_or	6	Single-skin (0°,45°)	Infusion	Vinylester	6 layers basalt
IT_P_M_B_or	8	Single-skin (0°,45°)	Manual	Polyester	Orientation +45°/-45°/0°/+45°/-45°/90°

Experimental tests

Static indentation tests were carried out using a Zwick Roell Z600 tensile machine, in accordance with ASTM D6264 standard [15]. Each item was tested using two different indenter's diameters (i.e., 17 and 20mm) with two different test's speeds (i.e., 1.25 and 2.5 mm/min). Figure 1 shows the test set-up.

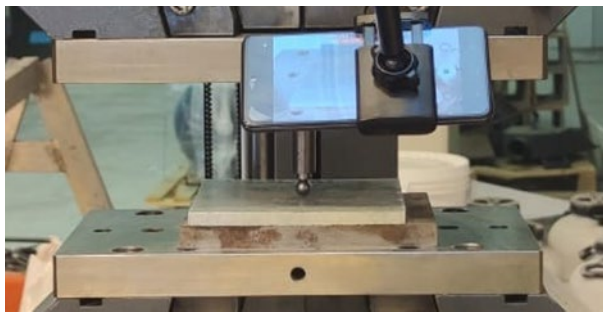

Fig. 1: Static Indentation Test set-up.

Results and discussion

Static indentation test

A typical load – displacement curve is reported in Figure 2 for each kind of sample by varying both speed and indenter diameter.

The curves show similar trends and similar maximum load values by considering the samples with glass fibre (top) and the ones with basalt fibers (bottom image). After a first quasi-linear elastic trend, a series of drops in the load are present when the fibres start to break.

With the aim to better evidence both the effect of this substitution and the effect of the speed and indenter diameters, the maximum stress was evaluated as the ratio between the standard force generated by the indenter on the surface of the specimen:

$$\sigma_{max} = \frac{F}{S_0}\,[MPa] \quad (1)$$

Therefore, the stress values at the maximum load of all laminates, subjected to the action of the two indenters and the two speeds, are summarized in Figure 3.

In Table 3 the results of ANOVA, applied on the maxium stress, are reported.

The results allow to affirm that both the kind of material and the diameter are significant factors affecting the resistance of the material (p-value < 0.05), while the effect of the speed of the indenter is not significant (p-value > 0.05). The effect of the diameter is to slightly reduce the resistance of the materials. To evidence how the resistance changes at varying the material, the data were evaluated by using the Tukey test that compares all the couple of materials. The result of such test is reported in Figure 4.

If the interval of the differences of the SigmaMax means values includes the "0" than the two materials compared cannot be considered significantly different.

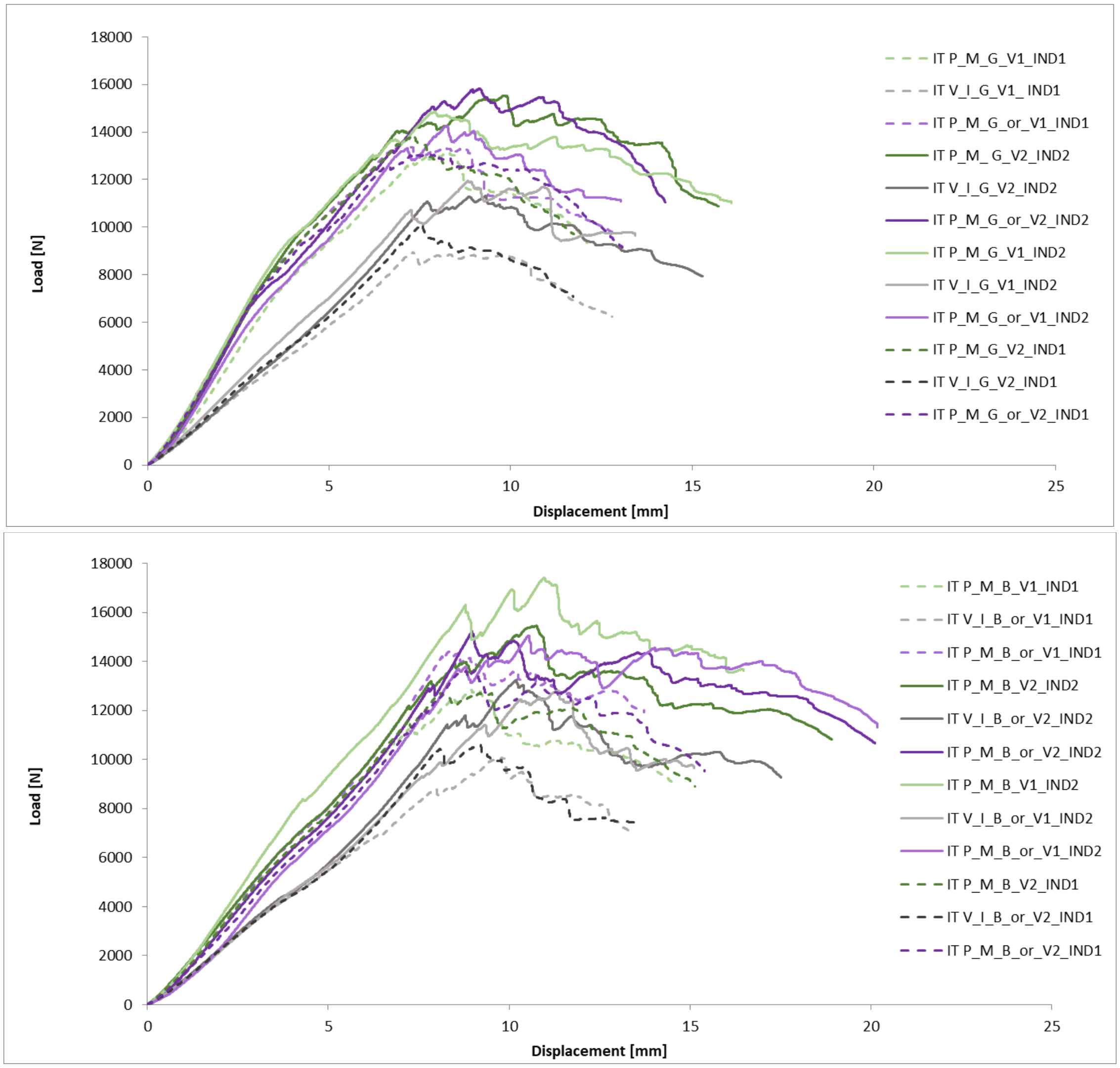

Fig.2: Typical load and laminate displacement curves for glass fiber and basalt samples at indenter speeds V1 and V2 with diameter D1 and D2.

By examining the position of the intervals for all the couples "basalt-glass" (i.e: IT P_M_G vs IT_P_M_B, IT V_I_G vs IT_V_I_B_or, IT P_M_G_or vs IT P_M-B_or) is evident that there is no significant difference in substituting the basalt with the glass, maintaining the other factors, for all kind of laminates.

Moreover, to evaluate the effect of the changing in orientation of the fibres the samples IT P_M_G vs IT P_M_G_or, and IT P_M_B vs IT P_M_B_or are compared. Also in this case, it is evident that the change has no effect on the resistance of the laminates.

To evaluate the effect of changing the production technology, the couples IT P_M_G vs IT V_I_G, and IT P_M_B vs IT V_I_B_or are compared. In this case the change causes the reduction of the laminate resistance, more in the ones with glass than in the basalt.

Finally, the comparison of IT P_M_G and IT V_I_B_or, allows to determine that replacing the glass with the basalt and changing the technology from manual lay-up to infusion leads to a significant reduction in the laminate resistance.

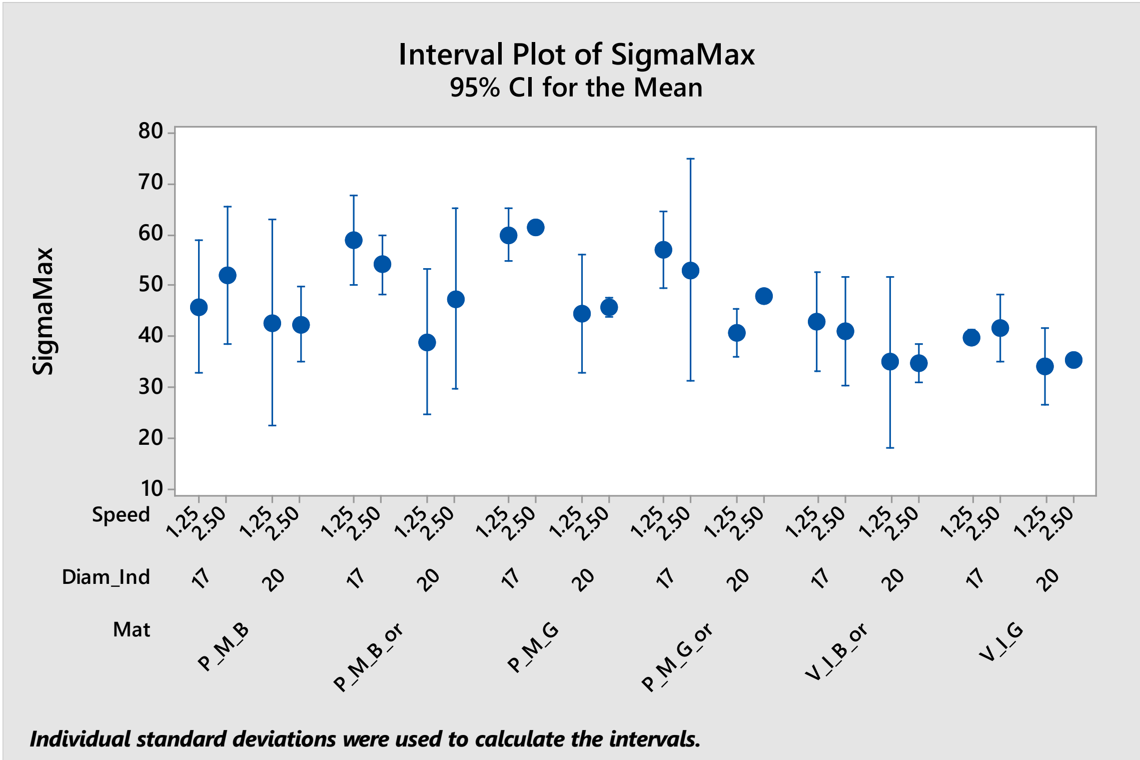

Fig.3: Interval plot for Sigma-max 95% CI for the Mean.

Table 3: ANOVA SigmaMax versus Mat; Speed; Diam_Ind.

Factor Information

Factor	Levels	Values
Mat	6	P_M_B; P_M_B_or; P_M_G; P_M_G_or; V_I_B_or; V_I_G
Speed	2	1.25; 2.50
Diam_Ind	2	17; 20

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	23	4376.22	190.27	9.70	0.000
Linear	7	3805.14	543.59	27.72	0.000
Mat	5	2263.18	452.64	23.08	0.000
Speed	1	31.92	31.92	1.63	0.208
Diam_Ind	1	1688.14	1688.14	86.08	0.000
2-Way Interactions	11	290.56	26.41	1.35	0.231
Mat*Speed	5	24.95	4.99	0.25	0.935
Mat*Diam_Ind	5	221.81	44.36	2.26	0.064
Speed*Diam_Ind	1	40.88	40.88	2.08	0.156
3-Way Interactions	5	213.96	42.79	2.18	0.072
Mat*Speed*Diam_Ind	5	213.96	42.79	2.18	0.072
Error	46	902.09	19.61		
Total	69	5278.31			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.42839	82.91%	74.36%	61.55%

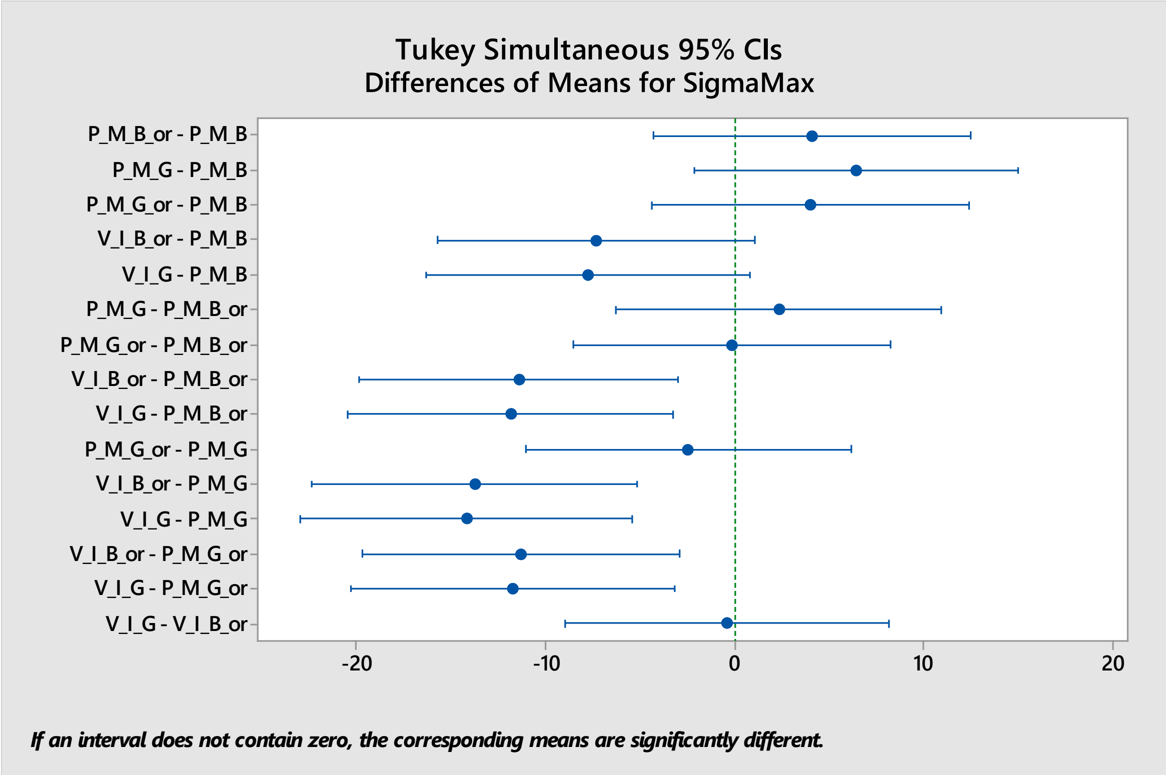

Fig.4: Tukey simultaneous test on the Means for SigmaMax.

Fracture modes

The failure modes that occur on the specimens are shown in Figure 5. In all tested samples, the fracture propagates throughout the thickness of the specimens, and it has been noted that the sizes of the damage depend mainly on the diameter of the indenter. In fact, it is possible to observe that the increase in the indenter diameter increases the extension of the damage.

As it was expected, the changing in technology, from manual lay-up to vacuum infusion reducing the presence of air in the product, causes that the delamination is almost absent, and the fracture is more concentrated around the area of the indenter. In this case the fracture is due to both large crack propagation and breakage of the fibres.

The employ of an oriented structure of the fibre (substitution of mat with 0°/45° skin) induces a preferential direction of the delamination, thus qualitatively, the fracture appears more extended in the "or" samples.

The substitution of the glass with basalt does not determine changing in the kind of fracture, even though the fracture is more extended in the laminates with basalt fibres. It occurs for delamination coupled with splits.

Finally, is possible to observe, by analysing the corresponding load/displacement curves (Figure 2), that the occurrence of fracture in the glass-based laminates is more abrupt than in the basalt one (i.e. the fracture of the fibres is completed for lower values of displacement in the grass samples than in the basalt ones, of about 20%).

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https://doi.org/10.21741/9781644902714-42

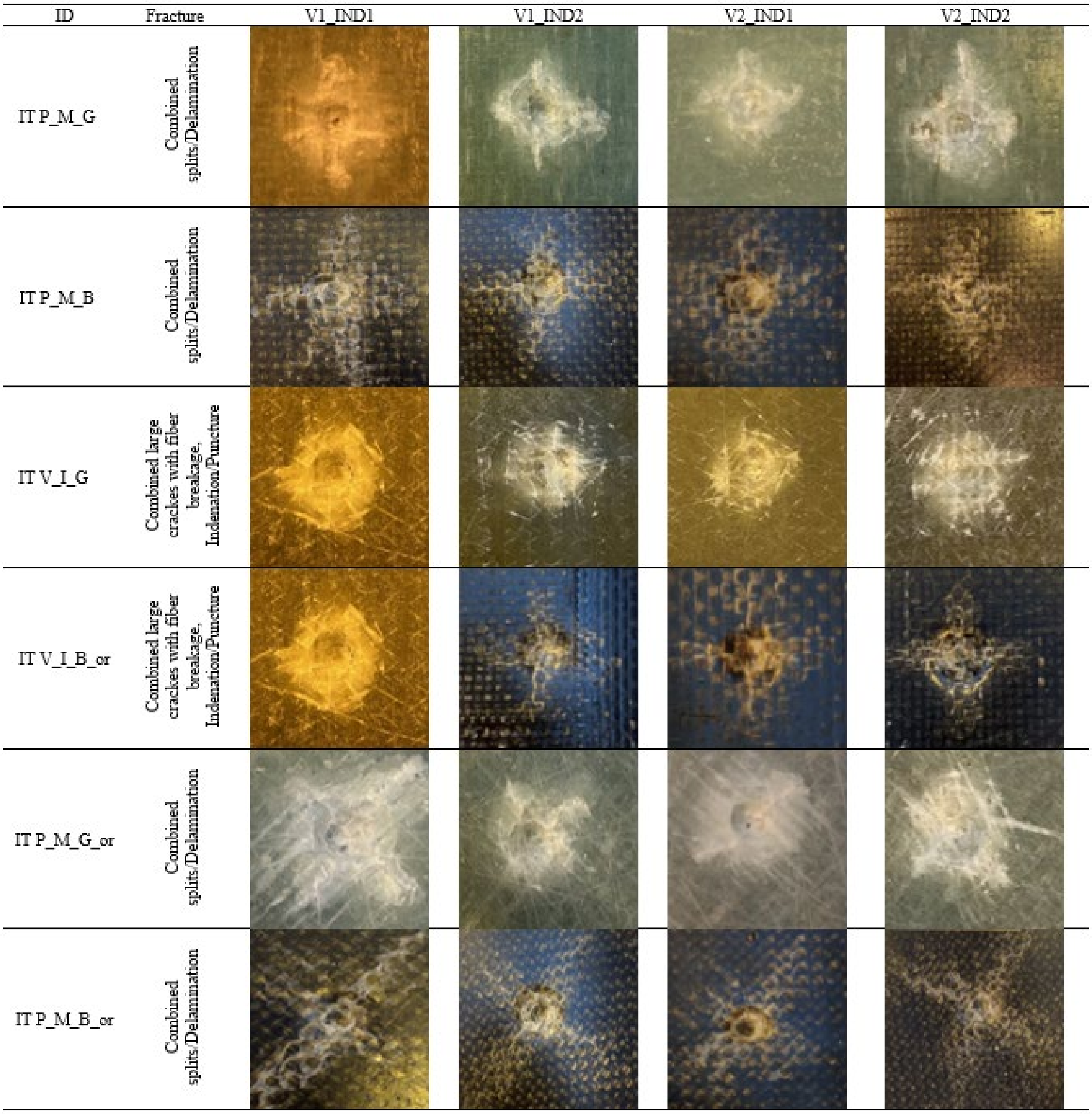

Fig. 5: Failure Mode Comparison of laminate samples tested with IND1and IND2 diameters and at V1 and V2 velocities.

Conclusion

Static indentation tests, conducted on laminated materials made with vinylester and polyester resins, produced through hand lay-up and vacuum infusion processes, have shown that glass fibre composite materials exhibit similar loads than those made from basalt fibres.

The ANOVA on the Sigma max data allow to conclude the following.

- among the analysed factors, both the materials and the indenter diameters influence the final resistance (particularly the increase in diameter from 17 to 20 mm, induced a reduction in the resistance from 10% to 25% depending on the kind of sample),
- the changing in speed, in the considered range, is not significant.

The Tukey test allows comparing the means of samples taken in pairs. The result of this last tests allows to draw out that:

- replacing glass fibre with basalt fibre does not lead to significant changing in the resistance of any kind of sample,

- the Vacuum Infusion technology has led to a worsening in mechanical resistance under indentation. By employing vacuum infusion technology, it is possible to halve the thickness with respect to the manual lay-up obtaining a poorer product (the Sigma max reduction ranges from 17% to 27% depending on the kind of sample).

By analysing the failure modes, it can be noticed that the failure is influenced by the technology, kind, and orientation of fibres.

The samples produced by Vacuum and the presence of orientation in the fibres limits the delamination phenomena.

The glass fibres determine a more abrupt fracture of the samples with respect to the basalt ones.

The results of this experimentation confirm that basalt fibre-reinforced composites are generally a suitable alternative to the use of glass fibre-reinforced composites and thus can be considered for marine applications.

This campaign is being finalized with other tests, where flexural and drop tests are expected to complete the mechanical behaviour of the laminates.

Funding
This research was funded by Ministry of Economic Development on the resources provided by the Decree 5 March 2018 Chapter III, as part of the project "Development of Ahead Systems and Processes for Highly AdvaNced TechnOlogies for low Magnetic Signature and HIghly eFFicient Electromagnetic shielded eco-friendly vessel – DAS PHANTOMSHIFFE", grant number F/190001/01/X44.

References

[1] I. Zivkovic, C. Fragassa, A. Pavlovic, T. Brugo, Influence of moisture absorption on the impact properties of flax, basalt and hybrid flax/basalt fiber reinforced green composites, Compos Part B 111 (2017) 148-164. https://doi.org/10.1016/j.compositesb.2016.12.018

[2] Information on https://cordis.europa.eu/article/id/422007-major-step-towards-sustainable-and-efficient-ship-construction.

[3] K. Van de Velde, P. Kiekens, L. Van Langenhove, Basalt fibres as reinforcement for composites, In: Proceedings of 10th International Conference on Composites / Nano Engineering ICCE/10, International Community for Composites Engineering and College of Engineering, University of New Orleans (2003).

[4] Z. Li, J. Ma, H. Ma, X. Xu, Properties and Applications of Basalt Fiber and Its Composites. In IOP Conference Series: Earth and Environmental Science, IOP Publishing: Banda Aceh, Indonesia, 186 (2018). https://doi.org/10.1088/1755-1315/186/2/012052

[5] V. Dhand, G. Mittal, K.Y. Rhee, S-J. Park, D. Hui. A short review on basalt fiber reinforced polymer composites, Comp B 73 (2015) 166-180. https://doi.org/10.1016/j.compositesb.2014.12.011

[6] C. Jiang, K. Fan, F. Wu, D. Chen, Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete, Mater Des, 58 (2014) 187-193. https://doi.org/10.1016/j.matdes.2014.01.056

[7] C.H. Jiang, T.J. McCarthy, D. Chen, Q.Q. Dong, Influence of basalt fibre on performance of cement mortar, Key Eng Mater, 426-427 (2010) 93-96. https://doi.org/10.4028/www.scientific.net/KEM.426-427.93

[8] D.P. Dias, C. Thaumaturgo, Fracture toughness of geopolymeric concretes reinforced with basalt fibres, Cem Concr Compos, 27 (2005) 49-54. https://doi.org/10.1016/j.cemconcomp.2004.02.044

Materials Research Proceedings 35 (2023) 350-358 https://doi.org/10.21741/9781644902714-42

[9] V. Fiore, T. Scalici, G. Di Bella, A. Valenza, A review on basalt fibre and its composites, Compos Part B, 74 (2015) 74-94. https://doi.org/10.1016/j.compositesb.2014.12.034

[10] V. Fiore, G. Di Bella, A. Valenza, Glass-basalt/epoxy hybrid composites for marine applications, Mater Des 32 (2011) 2091-2099. https://doi.org/10.1016/j.matdes.2010.11.043

[11] P. Davies, W. Verbouwe, Evaluation of Basalt Fibre Composites for Marine Applications, Appl Compos Mater 25 (2018) 299-308. https://doi.org/10.1007/s10443-017-9619-3

[12] L.S. Sutherland, C. Guedes Soares, Contact indentation of marine composites, Comp Struct 70 (2005) 287-294. https://doi.org/10.1016/j.compstruct.2004.08.035

[13] L.S. Sutherland, A review of impact testing on marine composite materials: Part I - Marine impacts on marine composites, Comp Struct 188 (2018) 197-208. https://doi.org/10.1016/j.compstruct.2017.12.073

[14] L.S. Sutherland, C. Guedes Soares, Impact characterisation of low fibre-volume glass reinforced polyester circular laminated plates, Int J Impact Eng 31 (2005) 1-23 https://doi.org/10.1016/j.ijimpeng.2003.11.006

[15] C. Borsellino, L. Calabrese, G. Di Bella, Windsurf board sandwich panels under static indentation, Appl Compos Mater 15 (2008) 75- 86. https://doi.org/10.1007/s10443-008-9058-2