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Numerical and Experimental Analysis of Interphase of New Environmental Low-energy Composites

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Abstract. Composite materials are now increasingly used for their properties in all areas of industrial production for high specific strength. Their use offers a significant weight savings and reduced production energy performance. But current composite properties are not at maximum level, and therefore the efforts of development on further improving are focused. This complex problem includes in a study and description of an interface between phases. Experimental and numerical analysis dealing with the mechanical properties at the micro level for new types of energy-efficient fiber composites with reduced environmental impact has been compiled. Analyses were focused on the cohesion and stress at the interface of the system fiber-matrix-core. From the results can be seen that the specific orientation of the reinforcement relative to the direction of applied force significantly affects the resulting elastic modulus. When investigating the delamination of the layers, the influence of the fiber orientation of the reinforcement is evident.

Introduction

The large amounts of energy required for the production of steel structures and their susceptibility to corrosion caused by climatic conditions and the external environment are well known. Nevertheless, the issue of protection of structures against corrosive and aggressive environments such as seawater has yet to be satisfactorily resolved. Many methods have been developed which protect the material against corrosion for a while but this protection needs to be renewed after a certain period of time. The hitherto acknowledged methods of protection include (Galvanization, Galvannealing, Coating or spraying, etc.). All of the trademarked methods either require the addition of other materials, energy and time to create a closed anti-corrosion surface or they are otherwise unsuitable (e.g. they can only be applied to a limited size of parts). None of the above methods are environmentally friendly, they require maintenance and the treatment of the structure needs to be renewed. The above disadvantages of the applied materials especially when used for structures in seawater could be addressed by using light low-energy composite materials with reduced environmental impact. These materials are suitable for a variety of reasons, including in particular their high specific strength, light weight, toughness, corrosion resistance, and thermal stability, etc. Composite materials consist of a matrix and reinforcement, with the majority of materials used for this purpose being highly resistant to sea and salt water. This is why composites are ideal for creating energy-efficient corrosion-resistant structures. These composites are used for structural parts sea structures such as drilling platforms, wind turbines etc. and deeper knowledge will be used for improving of mechanical properties of said composites. But current composite properties are not at maximum level, and therefore the efforts of development on further improving are focused. This complex problem includes in a study and description of an interface between phases. Experimental and numerical analysis dealing with the mechanical properties at the micro level for new types of energy-efficient fiber composites with reduced environmental impact has been compiled. The complexity of the problem of researching interphase interfaces is given by the fact that the inner surface of the composite produces a molecular system which is the integral of the contact surfaces of each of the individual phases present and determines the degree of contact and the forces applied to the interlayer [1-4]. The interlayer is an expression associated with the phenomena that arise from the interaction of substances that are on both sides of the contact. The actual voltage can be transferred from phase A to phase B either ideally by direct contact (not directly on the composite action) or by the C phase interface. The interface of two C phases is not only the contact area between them, where cohesion applies, but also near the surface influenced by the contact of the phases. If they are created on the interfaces of subphases C_1 and C_2 (which may be created by additional subphases $C_{11,111,...1n}$, C_{21},2_{11},...2_n), whose behaviour does not correspond to component A or B, it can be described as a composite effect.

Materials and Methods

Theory

A damage mechanism of composite with continuous endless fiber *f*, which are wound around the geometry of the core connected by a matrix m is a complex analytical problem difficult to describe. This composite has strength χ_S (Eq. 1-2) that is done with synergy depending on the properties of individual components, which form a compact structural system. Scattering of the strength of the fibers and the influence of microstructural defects can be roughly defined by introducing the strength of the fiber bundle χ_f as well as an efficiency coefficient of matrix ψ. Properties of the fiber composites also significantly affect the fiber orientation relative to the loading direction. If the angle of deflection of the fibers is greater than 10 °, the strength is reduced. Therefore, the strength is proportional to the deflection of the fibers. Near the fibers the strength of the matrix, the adhesion of the matrix to the fibers and interfacial strength of the interface are crucial parameters. Interfacial interface is affected by a transverse tensile strength (perpendicular to the fiber direction), which is highly dependent on the strength of the fibers in contact with the matrix and the tensile strength of the matrix. The structure of the composite can fail in the interface by a shear type of damage χ_S^I – type I or out-phase damage χ_S^{II} – type II (Eq. 3). The strength of the composite significantly reduces the presence of pores *a*, which can be identified in many cases only microscopically (Eq. 4).

$$\chi_S = \psi \chi_f V_f + (\sigma_m)_{\varepsilon_f \lim} V_m \Big|_{\psi = \langle 1 \div 2 \rangle} \tag{1}$$

$$\chi_S^{\perp} = (\sigma_m)_{\varepsilon_f \lim} \chi_{fm} \left[1/\chi_{fm} + \sqrt{4V_f/\pi} - 1/\chi_{fm} \sqrt{4V_f/\pi} \right] \tag{2}$$

$$\chi_S^I = \frac{G_m}{V_m + V_f G_m / G_f} \quad \text{or} \quad \chi_S^{II} = 2V_f \sqrt{\frac{E_f E_m V_f}{3V_m}} \tag{3}$$

$$\chi_S = \chi_S^{I,II} \left(1 - a + a^2\right) / (1 + a) \tag{4}$$

where V_f, V_m is the volume of the fibers and the matrix, E_f, E_m is the elastic modulus of the fibers and the matrix, G_f, G_m is the shear modulus of the fibers and the matrix, σ_m is the stress in the matrix, χ_{fm} is the tensile strength of the fibers in contact with the matrix, $a = \upsilon/(1-V_f)$, υ is the pore volume in the composite.

Experimental and Numerical Analysis

With the help of new technology [1], four types (see Fig. 1a) of composite structures with reduced environmental impact were produced. Composites were reinforced with carbon fibers that were wound on a PU tubular core. An winding angle α was 0 °, 20 °, 45 ° and 60 °. Mechanical properties of composites through tensile tests were studied. For the study of an interfacial stress and interface damage was built numerical model using composite Chamis model [2,3]. Physical parameters of the model are put in Table1.

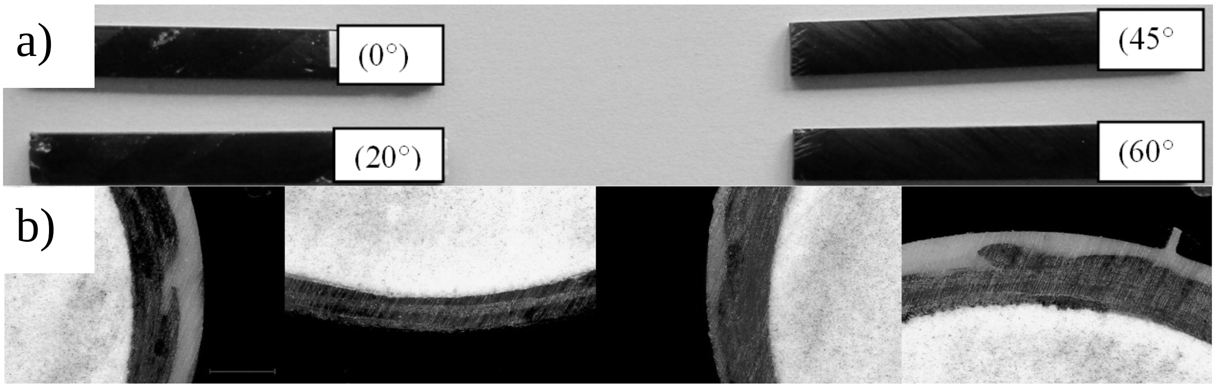

Fig.1. a) samples of new environmental low-energy composites, b) detail of section cut.

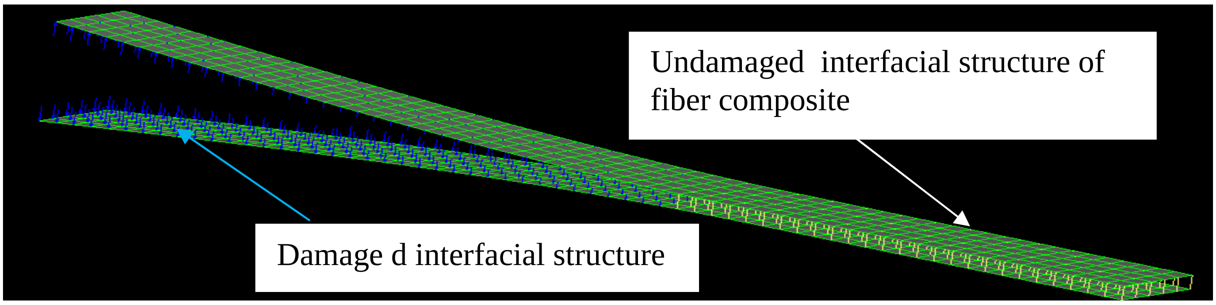

Fig. 2. Experimental analysis of interphase (above), Numerical analysis of interphase (below).

Table 1. Physical parameters of the material in numerical simulation.

Material	Density [kg.m^{-3}]	Module of elasticity [GPa]		Module of shear [GPa]		Tensile strength [GPa]	Elongation [%]
		Long. E	Trans. E	Long. G	Trans. G		
Fibers of carbon	1750±150	250	14	23	5.4	2.3	1.14
Epoxy resin (matrix)	1150±370	3.2	3.2	1. 24	1. 24	0.067	1.1
Core	50±0.36	0.0026		-	-	-	-

Result and Discussion

From tensile tests it was determined that new types of composites with reduced environmental impact have quaziisotropic course of the force-elongation stress-strain dependence. The orientation of fibers affects not only the connections of fibers and matrix, but also a damage of resulting delamination of the composite structure (see Fig.3). Experimental and numerical analysis has shown that the reinforcement oriented in the direction of the load (angle between load axis and fiber axis is 0°) the elastic modulus E is 57,9±7,3 MPa. If the angle between load axis and fiber axis is 20° the elastic modulus is approximately 46,3±5,67 MPa. If the reinforcement is oriented at larger angles, the modules report lower values (for 45° is E = 19,6±2,1 and for 60 ° is E = 11,2±1,9).

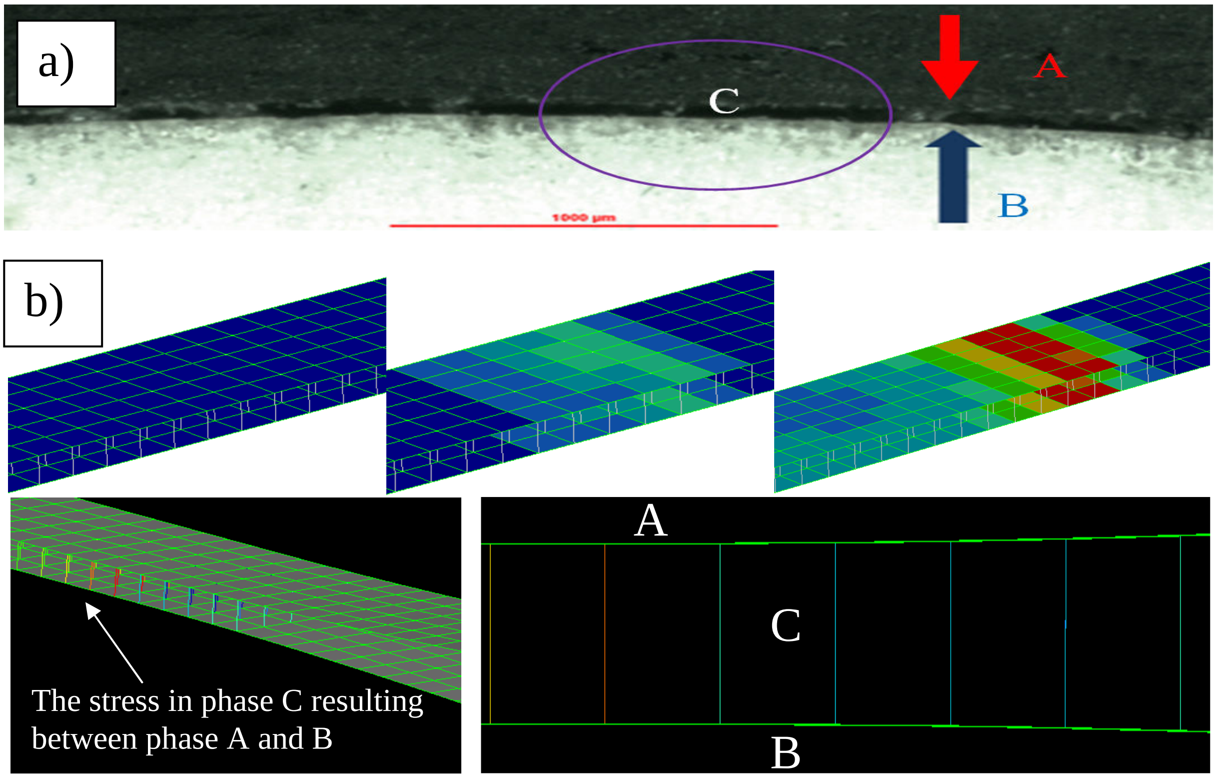

Fig. 3. a) Image analysis of interface, b) study delamination through the numerical model.

Conclusions and Acknowledgements

Experimental and numerical stress analyses of new types of composites with reduced environmental impact were carried out. These composites are developed for the construction placed in the sea. From the results it was determined that the direction of fiber orientation also has an effect on the integrity and the creation of interface and also significantly affects the size V_f, where the fiber volume increases significantly with winding angle α . On the contrary higher fiber volume does not necessarily mean higher strength, because for the tensile stress has been established that winding angle 20° shows that *E* about 15 % lower compare to $\alpha = 0°$.

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