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Hybrid Filament Wound Composite Tubes (Aramide Fiber/Glass Fiber)-Epoxy Resins and (Carbon Fibers/Glass Fiber)-Epoxy Resins: Volumetric, Mechanical and Hydraulic Characteristics

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In this paper volumetric, mechanical and hydraulic characteristics of filament wound composite one fiber tubes and hybrid tubes are presented.
Composite hybrid materials, produced by filament winding technology, are categorized according to different ways of classification of hybrid materials.
Four fibrous reinforcement agents (glass G600, polyamide aromatic K49, carbon T300 and carbon T800) and two impregnation agent systems (epoxy 0164 and epoxy L20) are used for manufacturing of filament wound tubes.
Density, tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure of two filament wound glass fiber/epoxy resins tubes (as starting materials) and of twelve filament wound hybrid tubes are investigated.
Four highest values of tensile strength and hydraulic burst pressure are of the next schedule: hybrid tubes mark G600-T800/L20 (the highest), hybrid tubes mark G600-T800/0164, hybrid tubes mark G600-T300/L20 and hybrid tubes mark G600-K49/L20.
Also, a row of four highest specific tensile strength and highest specific hydraulic burst pressure begins with hybrid tubes mark G600-T800/L20, but the schedule of the next three tubes is different due to density of aramide composite materials (hybrid tubes mark G600-K49/L20, hybrid tubes mark G600-T800/0164 and hybrid tubes mark G600-K49/0164).
All filament wound tubes (single fiber tubes and hybrid tubes) with epoxy L20 have a slightly lower density value but higher values of tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure than appropriate tubes impregnated with epoxy 0164.
Obtained results in this testing indicate and emphasize the importance of advanced reinforcing agents (aramide roving and carbon fibers), of impregnating agents (epoxy resin systems) and of the density of hybrid tubes, especially with aramide roving.

Key words: **Hybrid composites, tubes, filament winding technology, glass fiber, aramide fiber, carbon fiber, epoxy resin system, density, tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure.**

Introduction

TRANSFORMATION and behavior of the materials, including engineering ones, when subjected to the particular parameters of the process, determine the success of the manufacturing operation.

Beside metals, ceramics and polymers, composite materials are the fourth basic engineering material.

In a simplest sense, a composite material consists of matrix phase and reinforcement phase [1].

Matrix phase in a composite can be polymeric, ceramic and metallic. Polymer matrices can be thermoreactive and thermoplastic based, but the mostly used thermoreactive ones are epoxy and polyester resins.

Particles, fibers and laminate are basic reinforcements which form particulate composites, fibrous composites and laminate composites, respectively.

In hybrid composites there is a combination of two or more types of fibers [2]. Beside the commonly processed glass fiber, the mostly used synthetic advanced fibers for hybrid composites are aramide and carbon fibers [3, 4].

Owing to a set of specific characteristics, hybrid composites can be a better choice for demanding parts of construction than classical construction materials including conventional composites. One of the unique properties of hybrid composites is a fact that one fiber in this kind of material has certain properties and the same fiber has some other characteristics in single fiber composites (so called “synergistic” effect) [5].

Although the polymer composite materials were known and used in ancient ages, the second half of the previous century was fulfilled with synthesizing and development of numerous polymer materials and of technology for adequate processing. In some cases, synthesizing of polymers is involved during processing of continuous fiber composite. Filament winding technology and pultrusion technology, each synthesizing the polymer and forming a finishing part in one step or a sequence of steps, present an important evidence of increasing complexity of the polymer industry [6].

Regarding possible interactions connecting constituents of hybrid materials, specimens of hybrid composites produced by filament winding technology and tested in this investigation belong to so called class II hybrid materials because there are strong covalent bonds between the components [7].

Each layer of filament wound composite hybrid tubes includes one type of fiber, but as a whole the tested hybrid tubes consist of definite sequence of layers made of different fibers. Due to this fact, mentioned tested tubes are interlaminar having in mind statements of Perov and Khoroshilova regarding polymeric hybrid composite materials [8].

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Specimens of hybrid composites produced by mentioned technology and later on tested, are layer-by-layer mixtures, if configuration of hybrids material, proposed by Summerscales are considered, because one layer of this specimen is wound over another layer [9].

Hybrid filament wound composite tested specimens are ply-to-ply materials, according to the structural level of hybridization defined by Kelly, because all plies are arranged by defined manner [10].

Physical characteristics define the behavior of material in response to physical forces (excluding mechanical). Physical properties include volumetric, thermal, electrical and electrochemical properties. One of the most important volumetric characteristics is density. This property is chosen for determining the quality of single fiber filament wound composite tubes and of hybrid filament wound composite tubes, investigated in this paper.

Mechanical property represents the “answer” of a material when it is exposed to the action of external mechanical forces. Tensile test is a fundamental mechanical test in which a specimen is exposed to a controlled tension until failure. Tensile strength is the most important tensile characteristic and will be used for characterization of hybrid filament wound composite single fiber tubes and hybrid tubes, tested in this investigation.

Density and strength are important characteristics and strength/density ratio is frequently called specific tensile strength [1].

Of all hydraulic properties, internal hydraulic burst pressure is chosen for characterization of filament wound composite one fiber tubes and hybrid tubes in this investigation. Mentioned hydraulic characteristic is determined in so called water-air test i.e., water under pressure is inside the tube and air is around the tube [11].

By analogy to specific tensile strength, the ratio hydraulic burst pressure/density is called specific hydraulic burst pressure.

In this paper a volumetric, mechanical and hydraulic characteristics of two types of hybrid composite tubes, produced by filament winding technology, will be discussed. One type of hybrid tubes is based on the combination of aramide fiber and glass fiber impregnated with epoxy resins and another type of hybrid tubes is made of carbon fibers, glass fiber and epoxy resins. Concretely, a density, tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure of filament wound glass fiber/epoxy resins tubes (as a starting level) and of mentioned hybrid tubes are investigated.

Using filament winding technology, Lokman G. produced three types of hybrid tubes in which reinforcement fibers were glass and carbon roving. The arrangement of two mentioned fibers in the first type of tube were carbon fiber/glass fiber/glass fiber (shortly mark: CGG), in the second were glass fiber/carbon fiber/glass fiber (shortly mark: G/C/G) and in the third were glass fiber/glass fiber/carbon fiber (shortly mark: G/G/C). All fibers were wound under the angle of ±55° and cured tubes were exposed to the internal pressure of 3, 2 MPa and then to impact test using pendulum of 5 J, 10 J, 15 J and 20 J. Different damages were observed such as delaminating effects, cracking od surfaces, leaking, etc. It is concluded that hybrid tubes shortly marked C/G/G have the highest impact resistance and that tubes shortly marked G/C/G have no leaking effect [12].

In the published paper, Ercan S. studied the functionality of hybrid carbon/glass composite shaft produced by filament winding technology. In practice, the outer layers of the shaft are more stressed than inner layers so the first mentioned layers must be wound using carbon fiber while internal layers can be produced using carbon and less expensive glass fiber. Experimental data of completely carbon shaft and hybrid shaft with carbon and glass fibers (with same dimensions) are discussed. Positive and negative effects of using hybrid shaft regarding one fiber shaft are presented [13].

In the present study, Turla P. and others investigated three filament wound composites: one only with glass (G) fiber, another only with carbon (C) fiber and the latest with glass and carbon fiber (so called hybrid material). Flexural strength of the mentioned one fiber and hybrid composites were tested. The optimum layer orientation for hybrid composite is [0^{o}C/45^{c}G/45^{o}C/-45^{o}G/-45^{o}C/90^{o}G/90^{o}C]s. Hybrid material has significantly higher tested characteristics (542,94 MPa) than the glass fiber composite (475,27 MPa) and carbon fiber composite (304,81 MPa) [14].

Sayer M. and others investigated two hybrid composite materials with two arrangements of layers. One hybrid composite was with aramide and glass fibers and another with aramide and carbon fibers. The impact resistance and visual appearance were tested. It is concluded that the structure [0^0/90^0/45^0]s for both investigated hybrid composites has a better property for 5 % than the appropriate hybrid composites with structure [0^o/0^o/90^o/90^o]s [15].

Ahmad F. and others described how composites woven glass fabric (WF), woven Kevlar 49 fabric (WF) and hybrid woven glass fabric (WF)/woven Kevlar 49 fabric (WF), all impregnated with polyester and epoxy resin, are made. Each of six mentioned types of composites has different volume percent of reinforcements. It is concluded that tensile characteristics of woven glass fabric (WF)/polyester resin and woven Kevlar 49 fabric (WF) /polyester resin increase with the increasing of the volume percent of the fabrics. Hybrid woven glass fabric (WF)/woven Kevlar 49 fabric (WF), impregnated with polyester resin, are of higher quality than other polyester composites, regarding tensile characteristics. Hybrid woven glass fabric (WF)/woven Kevlar 49 fabric (WF) specimens with epoxy resin have high tensile strength and tensile modulus of elasticity [16].

In this study, Naresh K. and others tested one fiber specimens (glass fiber/epoxy and carbon fiber/epoxy) and hybrid specimens (glass fiber-carbon fiber/epoxy) exposed to tensile stress with different strain rate. Tensile characteristics (tensile strength and tensile modulus of elasticity) of glass/epoxy specimens and of hybrid glass fiber-carbon fiber/epoxy specimens increase with increasing of changeable test parameter, while two mentioned properties of carbon/epoxy specimens do not change with change of strain rates. Obtained results can be used for designing of large composite parts, which are expected to be exposed to impact in practice [17].

In this paper Jesthi D.K. and Nayak R.K. investigated the possibility of replacement of metallic parts with hybrid composite consisting of expensive carbon fiber and cheap glass fiber. Specimens with different arrangement of glass (G) and carbon (C) fibers were produced. They concluded that hybrid specimen type $[CG2_CG]_S$ lost only 5 % of tensile strength, 6 % of impact strength and 18 % of flexural strength after sinking in seawater for a period of three months at the laboratory temperature [18].

Naik N.K. investigated one fiber composites based on plain weave E-glass fiber and twill weave carbon T300 fiber and a set of hybrid composites based on two mentioned reinforcements. All three composites are obtained using epoxy impregnation matrix. Specimens of all three composites were exposed to impact loading and, after that, to compressive stress. It is concluded that glass/epoxy and carbon/epoxy composites are more notch sensitive than hybrid composites. Among hybrid composites, specimens with glass fiber inside and carbon fiber outside have better notch resistivity than other tested specimens [19].

Shan Y. and Liao K. produced two composites: one reinforced only with glass fiber and another with glass and carbon fibers. In both composites, impregnated with epoxy resin, fibers are in one direction (so called unidirectional material). Specimens were exposed to tension-tension fatigue test in different environments. When both composites were cyclically tested at 85 % of ultimately tensile strength (shortly UTS) no difference of fatigue life was detected nevertheless environments (in air and in distilled water). At 65 % and 45 % of UTS an influence of water was observed. Both tested composites have longer fatigue lives in air than in water. Another important observation is that one fiber composite has a lower degree of structural integrity than hybrid composite, both tested in water. The reason for this fact is the occurrence that carbon fiber has better resistance to water than glass fiber [20].

Zhang et. al. produced a set of hybrid composite specimens of different arrangements of layers containing glass fabric and layers with carbon fabric, impregnated with epoxy resin. Tensile property, compressive strength and flexural strength were tested. Hybrid specimen with 50 % of carbon fiber placed external has the highest flexural strength. The highest compressive strength has hybrid specimen with alternating carbon/glass arrangement. Good correlation between data of analytical solutions and experimental data for three tested characteristics were observed [21].

In order to establish a convenience of composites for marine applications authors produced five types of specimens: the first reinforced only with glass fabric (mark [G]s), the second reinforced only with carbon fabric (mark [C]s), the third, the fourth and the fifth reinforced with glass and carbon fabric (marks $[G_3C_2]S$, $[G_2C_2G]S$ and $[GCG_2C]S$). All five types of specimens (two of one fiber and last three of hybrid composites) were exposed to the influence of seawater for thirteen weeks. Based on the obtained tested data, it is concluded that hybrid composite mark $[GCG_2C]_S$ has better characteristics than one fiber composite mark [G]s (tensile strength for 14 % and flexural strength for 43 %) [22].

Experimental part

For a manufacturing of filament wound one fiber tubes and hybrid tubes (internal diameter about 100 mm), tested in this investigations, glass roving GR600 (shortly: glass G600), polyamide aromatic roving (shortly: aramide K49), carbon roving T300 (shortly: carbon T300), carbon roving T800 (shortly: carbon T800), epoxy system 0164/HX/BDMA (shortly: epoxy 0164) and epoxy system EPR L20/EPH 960 (shortly: epoxy L20) are used.

Detailed information about used reinforcements, used matrices, filament winding machine, preparing of rovings, technological parameters and cure schedules are published elsewhere [4].

For the purpose of this paper, filament wound composite tube (from inside toward outside) consisting of one layer of glass G600 wound under the angle of 90° (regarding longitudinal axis of the tube), then of three layers of glass G600 wound under the angle of 61° and of one layer of glass G600 wound under the angle of 90°, all impregnated with epoxy 0164, are denoted as G6/0164. Using epoxy L20 for impregnating glass G600 (same number and stacking of layers and angles of winding as with epoxy 0164), the filament wound composite tube tested in this investigation is marked as G6/L20.

For designation of hybrid filament wound composite tubes tested in this investigation (in which two different fibers are used for production of one tube), a slightly modified system of notation, regarding the abovementioned system for filament wound composite tubes with one roving, is used.

Hybrid filament wound composite tube (from inside towards outside) consisting of one layer of aramide K49 wound under the angle of 90° (regarding longitudinal axis of the tube), then of three layers of glass G600 wound under the angle of 61° and of one layer of glass G600 wound under the angle of 90°, all impregnated with epoxy 0164, are denoted as K49-G6/0164. In a similar way, hybrid filament wound composite tube consisting of one layer of glass G600 wound under the angle of 90°, then of three layers of aramide K49 wound under the angle of 61° and of one layer of aramide K49 wound under the angle of 90°, all impregnated with epoxy 0164, are denoted as G6-K49/0164.

Two other hybrid filament wound composite tubes, in which a carbon T300 and glass G600 are wound in the same manner as aramide K49 and glass G600 in above-described hybrid tubes, both impregnated with mentioned epoxy 0164, are marked as T300-G6/0164 and G6-T300/0164, respectively.

In hybrid filament wound composite tubes marked T800-G6/0164 and G6-T800/0164, both impregnated with epoxy 0164, the carbon T800 and glass G600 are wound in the same manner as carbon T300 and glass G600 in the above-described hybrid tubes.

Hybrid filament wound composite tube (from inside towards outside) consisting of one layer of aramide K49 (the angle of 90°), three layers of glass G600 (the angles of 61°) and of one layer of glass G600 (the angle of 90°), all impregnated with epoxy L20, are denoted as K49-G6/L20. In a similar way, hybrid filament wound composite tube consisting of one layer of glass G600 (the angle of 90°), then of three layers of aramide K49 (the angles of 61°) and of one layer of aramide K49 (the angle of 90°), all impregnated with epoxy L20, are denoted as G6-K49/L20.

Two hybrid filament wound composite tubes, in which a carbon T300 and glass G600 are wound in the same manner as in the above-marked hybrid tubes T300-G6/0164 and G6-T300/0164, but impregnated with epoxy L20, are denoted as T300-G6/L20 and G6-T300/L20, respectively.

Hybrid filament wound composite tube (from inside towards outside) consisting of one layer carbon T800 (the angle of 90°), three layers of glass G600 (the angles of 61°) and of one layer of glass G600 (the angle of 90°), all impregnated with epoxy L20, are denoted as T800-G6/L20. In a similar way, hybrid filament wound composite tube consisting of one layer of glass G600 (the angle of 90°), then of three layers of carbon T800 (the angles of 61°) and of one layer of carbon T800 (the angle of 90°), all impregnated with epoxy L20, are denoted as G6-T800/L20.

Results and discussion

Experimental data, obtained by testing described one fiber tubes i.e., single fiber tubes and hybrid tubes are presented in tables and diagrams.

Numerical data for density, tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure i.e., single values X_i and arithmetic mean values $\bar{X}$ for the mentioned volumetric, mechanical and hydraulic characteristics are shown in Tables 1 to 14.

Specified characteristics of single fiber tubes G6/0164 and G6/L20 are in Tables 1 and 2, respectively.

Table 1. Specified characteristics of single fiber tubes G6/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.98	2.00 ± 0.02	430.6	449.58 ± 18.48	234.04	224.64 ± 8.89	33.6	34.96 ± 1.58	17.06	17.53 ± 0.51
2.02		464.8		230.25		36.7		18.07	
1.99		451.1		235.94		34.6		17.47	
2.02		438.1		226.68					
1.99		475.1		222.77					
1.97		421.8		209.85					
2.03		450.0		221.26					
2.01		465.1		216.38					

Table 2. Specified characteristics of single fiber tubes G6/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
2.01	1.99 ± 0.01	478.2	477.31 ± 14.69	249.51	239.96 ± 5.58	34.9	35.93 ± 1.11	18.46	18.09 ± 0.37
2.00		470.5		246.60		37.1		18.08	
2.00		473.5		239.51		35.8		17.72	
1.99		493.1		240.32					
1.98		468.5		239.11					
1.98		454.2		237.63					
1.98		479.0		236.60					
1.97		501.5		230.51					

Tables 3 and 4 content specified characteristics of hybrid tubes based on aramide K49, glass G600 and epoxy 0164, while in Tables 5 and 6 are the same properties of hybrid tubes with two mentioned fibers and epoxy L20.

Table 3. Specified characteristics of hybrid tube K49-G6/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.88	1.90 ± 0.02	452.1	472.11 ± 19.41	258.45	247.97 ± 7.78	35.9	36.87 ± 1.19	19.19	19.49 ± 0.36
1.92		488.1		254.37		36.5		19.41	
1.91		473.7		255.54		38.2		19.89	
1.89		460.0		248.02					
1.90		498.8		242.10					
1.87		442.9		248.04					
1.93		472.5		240.48					
1.91		488.4		236.84					

Table 4. Specified characteristics of hybrid tube G6-K49/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.42	1.44 ± 0.02	508.11	531.61 ± 23.17	383.97	368.45 ± 11.77	40.9	40.83 ± 1.22	28.24	28.42 ± 0.43
1.46		548.50		382.26		42.2		28.90	
1.44		532.32		375.68		40.2		28.11	
1.43		516.90		367.10					
1.45		560.62		368.75					
1.42		497.73		361.47					
1.46		531.04		357.82					
1.46		558.12		350.49					

Table 5. Specified characteristics of hybrid tube K49-G6/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.92	1.89 ± 0.02	504.51	503.56 ± 15.49	275.62	266.54 ± 5.45	37.5	37.96 ± 1.26	20.05	20.15 ± 0.33
1.91		496.42		272.31		37.0		19.89	
1.90		499.53		265.92		39.4		20.52	
1.89		520.21		266.92					
1.88		494.32		265.73					
1.88		479.21		264.01					
1.87		505.30		264.31					
1.86		529.11		257.62					

Table 6. Specified characteristics of hybrid tube G6-K49/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.46	1.42 ± 0.02	534.92	561.64 ± 20.49	407.03	395.75 ± 8.27	43.4	42.01 ± 1.31	28.24	28.35 ± 0.50
1.39		557.51		405.81		41.8		27.92	
1.44		561.12		396.92		40.8		28.90	
1.40		584.31		395.10					
1.43		555.21		396.63					
1.40		538.21		384.43					
1.42		567.60		395.40					
1.41		594.31		384.81					

Chosen volumetric, mechanical and hydraulic characteristics of hybrid tubes T300-G6/0164 and G6-T300/0164 are shown in Tables 7 and 8, respectively.

The same mentioned properties of hybrid tubes T300-G6/L20 and G6-T300/L20 are shown in Tables 9 and 10, respectively.

Table 7. Chosen volumetric, mechanical and hydraulic characteristics of hybrid tubes T300-G6/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.98	1.94 ± 0.03	458.59	476.40 ± 16.86	231.61	244.12 ± 9.89	39.1	37.31 ± 1.70	19.75	19.20 ± 0.48
1.90		495.02		251.27		35.8		18.84	
1.97		480.42		243.87		36.9		19.02	
1.91		466.57		238.05					
1.97		449.22		231.56					
1.91		479.25		250.92					
1.96		495.33		259.34					
1.94		486.81		246.37					

Table 8. Chosen volumetric, mechanical and hydraulic characteristics of hybrid G6-T300/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.69	1.66 ± 0.02	516.72	539.46 ± 22.17	305.75	324.97 ± 12.22	41.5	41.91 ± 2.40	24.85	25.11 ± 1.06
1.63		570.12		339.36		44.4		26.27	
1.68		557.76		332.21		39.7		24.20	
1.64		558.12		333.99					
1.68		541.13		327.96					
1.64		525.72		320.56					
1.67		506.16		308.63					
1.63		540.0		331.29					

Table 9. Chosen volumetric, mechanical and hydraulic characteristics of hybrid tubes T300-G6/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.95		534.10		273.89					
1.89		525.15		270.69					
1.94		510.13		262.95		37.2		20.36	
1.89	1.92 ± 0.02	509.28	508.33 ± 15.65	265.25	264.54 ± 5.66	39.5	38.3 ± 1.2	19.89	19.97 ± 0.35
1.94		504.28		259.94		38.2		19.68	
1.90		501.08		263.72					
1.92		498.923		255.94					
1.94		483.72		263.98					

Table 10. Chosen volumetric, mechanical and hydraulic characteristics of hybrid tubes G6-T300/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.68		601.80		273.89					
1.60		591.722		270.69					
1.67		574.80		262.95		42.2		26.05	
1.61	1.64 ± 0.03	573.84	572.78 ± 17.63	265.25	264.54 ± 5.66	44.5	43.2 ± 1.8	26.49	26.39 ± 0.31
1.66		568.21		259.94		42.9		26.64	
1.62		564.62		263.72					
1.65		545.04		255.94					
1.64		562.21		263.98					

Mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes T800-G6/0164 and G6-T800/0164, are shown in Tables 11 and 12, respectively.

In Tables 13 and 14 are mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes T800-G6/L20 and G6-T800/L20, respectively.

Table 11. Mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes T800-G6/0164

Density (g/cm3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.99		473.71		239.24					
1.92		511.31		256.93					
1.98		496.23		250.61		37.0		19.27	
1.92	1.96 ± 0.03	481.93	493.86 ± 20.31	261.15	251.65 ± 11.10	40.4	38.61 ± 1.70	19.60	19.75 ± 0.58
1.98		517.82		244.62		38.4		20.40	
1.96		463.21		236.33					
1.98		490.53		255.47					
1.97		516.31		268.90					

Table 12. Mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes G6-T800/0164

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.74		651.10		379.54					
1.65		625.52		376.36					
1.73		594.71		361.56		50.7		30.73	
1.67	1.70 ± 0.03	660.40	628.51 ± 26.91	343.76	368.95 ± 13.96	56.9	53.83 ± 3.10	32.08	31.90 ± 1.1
1.73		613.31		360.76		53.9		32.89	
1.68		631.51		375.89					
1.73		648.72		388.44					
1.70		602.81		365.33					

Table 13. Mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes T800-G6/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.96		546.64		278.89					
1.91		504.16		257.22					
1.96		542.41		264.04		39.1		20.36	
1.92	1.94 ± 0.02	522.11	525.12 ± 13.65	278.16	270.17 ± 7.36	42.3	41.03 ± 1.70	21.38	21.11 ± 0.65
1.95		520.04		267.75		41.7		21.58	
1.94		526.10		268.05					
1.96		521.91		274.01					
1.95		517.55		273.25					

Table 14. Mentioned volumetric, mechanical and hydraulic characteristics of hybrid tubes G6-T800/L20

Density (g/cm^3)		Tensile strength (MPa)		Specific tensile strength ($MPa\ cm^3/g$)		Hydraulic burst pressure (MPa)		Specific hydraulic burst pressure ($MPa\ cm^3/g$)	
X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$	X_i	$(\bar{X})$
1.70		697.10		410.06					
1.64		695.77		411.70					
1.69		690.34		408.48		55.8		36.0	
1.65	1.67 ± 0.02	671.61	678.77 ± 19.05	399.77	405.86 ± 5.42	61.2	59.3 ± 3.03	36.25	35.43 ± 1.22
1.69		674.62		406.39		60.9		34.03	
1.66		681.64		410.75					
1.68		658.71		397.22					
1.66		660.17		402.54					

Arithmetic mean $(\bar{X})$ and standard deviations values for density and tensile characteristics, for single fiber filament wound tubes (as can be seen in Tables 1 and 2) and for hybrid filament wound tubes (presented in Tables 3 to 14), are based on eight single values (X_i). Data for hydraulic burst pressure and specific hydraulic burst pressure, presented in all mentioned Tables, are based on three single values.

Based on data in all the presented Tables, one can conclude that (X_i) of certain volumetric, mechanical and hydraulic properties are equalized because standard deviations are under the 5 % of $(\bar{X})$.

For the purpose of a diagram presentation, a shortened way of designation of single fiber tubes and hybrid tubes will be used.

Designation of single fiber tubes marked G6/0164 and single fiber tube G6/L20 will be only G6 and epoxy resin systems labels will be presented in an understandable and visible way.

Hybrid tubes labeled K49-G6/0164 and K49-G6/L20, will be marked only K49G6 and hybrid tubes G6-K49/0164 and G6-K49/L20 will be marked only G6K49.

Hybrid tubes marked T300-G6/0164 and T300-G6/L20, will have designation only T3G6 and hybrid tubes G6-T300/0164 and G6-T300/L20 will be marked only G6T3.

Signs of hybrid tubes T800-G6/0164 and T800-G6/L20, will be only T8G6 and marks of hybrid tubes G6-T800/0164 and G6-T800/L20 will be shortened to G6T8.

Density of single fiber tubes and hybrid tubes, (with epoxies 0164 and L20) versus structure are in Figures 1 and 2, respectively.

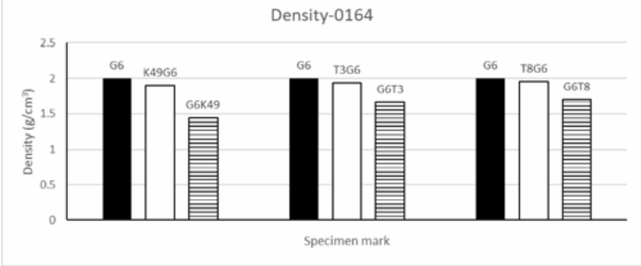

Figure 1. Density of single fiber tubes and hybrid tubes with epoxy 0164

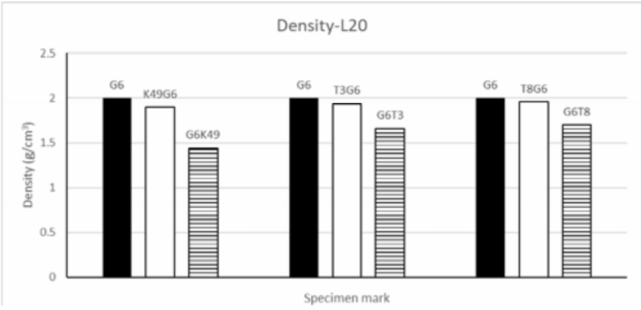

Figure 2. Density of single fiber tubes and hybrid tubes with epoxy L20

Figures 1 and 2 presented three groups of tubes, of which each contains three members. As it can be seen from Figures 1 and 2, in each three-member group, the highest density has single fiber tubes (consisting only of glass G600) and the lowest values have hybrid tubes which predominantly contain reinforcing agents other than glass.

Single fiber tubes and hybrid tubes with epoxy 0164 have slightly higher density than the appropriate tubes with epoxy L20.

Tensile strength of single fiber tubes and hybrid tubes, with epoxy 0164, are presented in Fig.3.

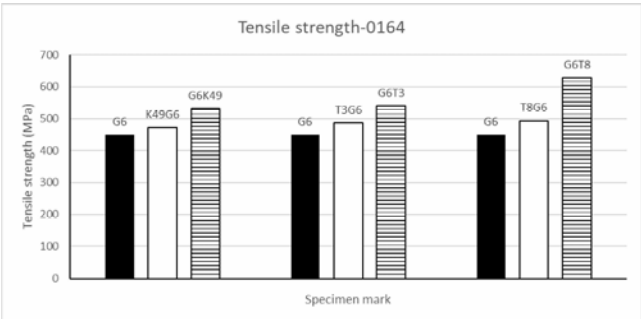

Figure 3. Tensile strength of single fiber tubes and hybrid tubes with epoxy 0164

Fig.4 presents tensile strength of single fiber tubes and hybrid tubes with epoxy L20.

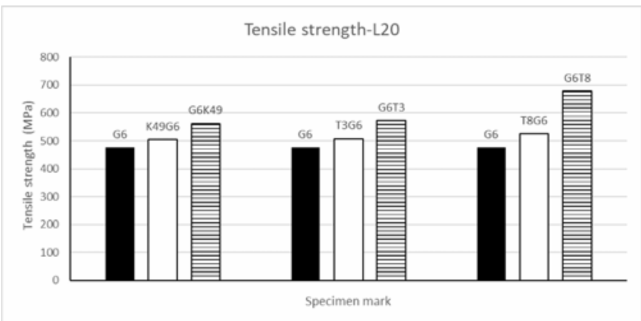

Figure 4. Tensile strength of single fiber tubes and hybrid tubes with epoxy L20

Figures 3 and 4 indicate that in each three-member group, the highest tensile strength is in hybrid tubes with predominant content of other reinforcing roving than glass fiber and the lowest tensile strength is in single fiber tubes.

Specific tensile strength of single fiber tubes and hybrid tubes with epoxy 0164 are presented in Fig.5.

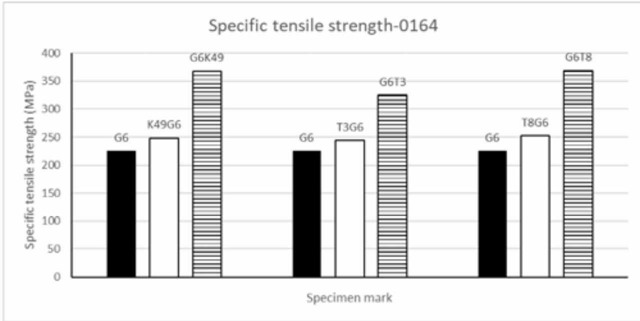

Figure 5. Specific tensile strength of single fiber tubes and hybrid tubes with epoxy 0164

Fig.6 presents specific tensile strength of single fiber tubes and hybrid tubes with epoxy L20.

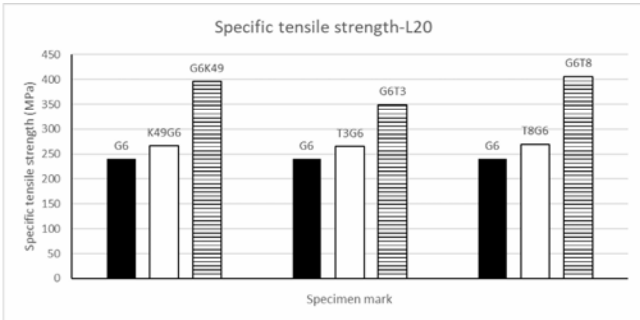

Figure 6. Specific tensile strength of single fiber tubes and hybrid tubes with epoxy L20

The dependance of specific tensile strength of tube structure, presented in Figures 5 and 6, are similar to dependance of tensile strength, presented in Figures 3 and 4, in each of three-member groups, but the difference between the hybrid tube with the highest specific tensile strength and the single fiber tube with the lowest specific tensile strength are much more visible, due to the influence of density.

Values of specific tensile strength of hybrid tubes with predominant content of reinforcing carbon roving T800 mark G6T8 (369 MPa with epoxy 0164 and 406 MPa with L20) are similar to the values of specific tensile strength of hybrid tubes with predominant content of reinforcing aramide roving K49 mark G6K49 (368 MPa with epoxy 0164 and 396 MPa with L20), although there are visible differences between tensile strength of hybrid tubes mark G6T8 (629 MPa with epoxy 0164 and 679 MPa with L20) and hybrid tubes mark G6K49 (532 MPa with epoxy 0164 and 562 MPa with L20). Similar values of specific tensile strength of hybrid tubes mark G6T8 and of specific tensile strength of hybrid tubes mark G6K49 can be ascribed to the influence of lower density of later mentioned composite material.

The tensile strength and specific tensile strength of hybrid tubes with predominantly glass roving are between the same two characteristics of single fiber tubes and hybrid tubes with predominant content of reinforcing roving other than glass fiber, in each of three-member groups.

Hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy 0164 are presented in Fig.7.

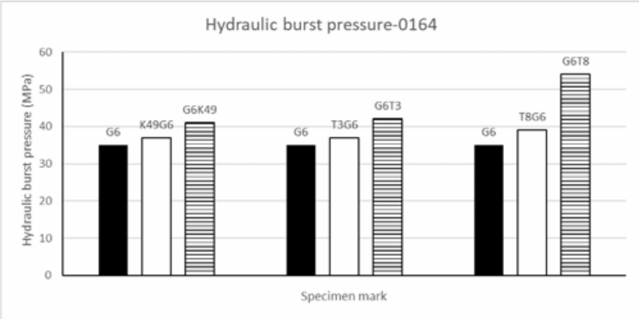

Figure 7. Hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy 0164

Fig.8 shows a hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy L20.

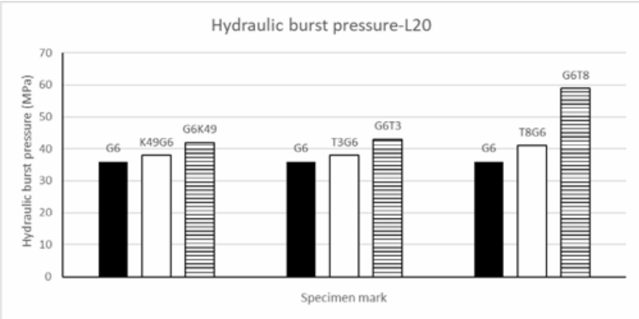

Figure 8. Hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy L20

In Figures 7 and 8 it is clearly visible that in all three groups (each contain three members) the highest value of hydraulic burst pressure is in hybrid tubes with predominant content of reinforcing roving other than glass fiber. The distinctly highest value of hydraulic burst pressure is in hybrid tubes shortly marked G6T8 which contain one inside layer of glass G600 (angle 90°), three layers of carbon T800 (angles 61°) in the middle and one layer of carbon T800 (angle 90°) outside.

Specific hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy 0164 are in Fig.9.

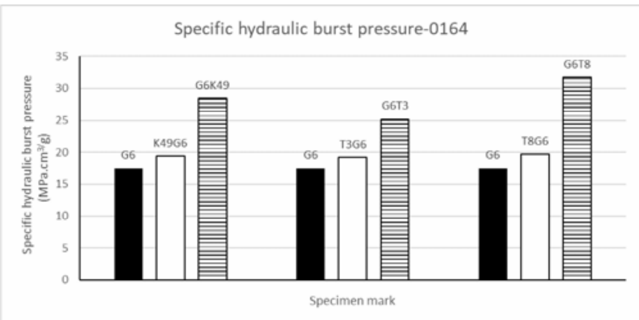

Figure 9. Specific hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy 0164

Fig.10 contains data for specific hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy L20.

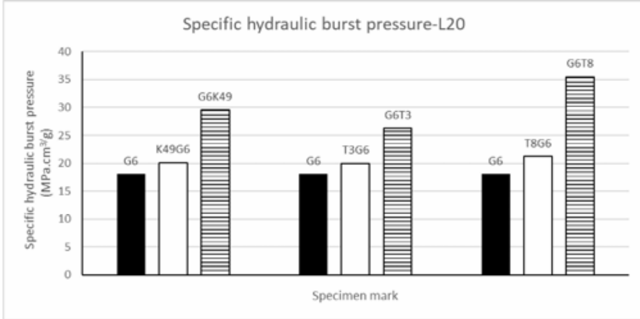

Figure 10. Specific hydraulic burst pressure of single fiber tubes and hybrid tubes with epoxy L20

Figures 7 and 8 pointed out that the highest hydraulic burst pressure is in hybrid tubes marked G6T8 (54 MPa with epoxy 0164 and 59 MPa with L20) while this property is similar for hybrid tubes marked G6T3 (41 MPa with epoxy 0164 and 43 MPa with L20) and hybrid tubes marked G6K49 (42 MPa with epoxy 0164 and 42 MPa with L20).

Detailed analysis of data presented in Figures 9 and 10 imposes interesting statements. Hybrid tubes marked G6T8, also, have the highest specific hydraulic burst pressure (31.7 MPa with epoxy 0164 and 35.5 MPa with L20), while the values of this characteristic for hybrid tubes marked G6K49 (28.4 MPa with epoxy 0164 and 29.6 MPa with L20) are higher than specific hydraulic burst pressure for hybrid tubes marked G6T3 (25.2 MPa with epoxy 0164 and 26.3 MPa with L20) due to a lower density of composite material with predominant aramide roving K49 in regard to composite material with predominant carbon roving T300.

Tensile strength of all fourteen-filament wound composite materials versus epoxies 0164 and L20 are in Fig.11.

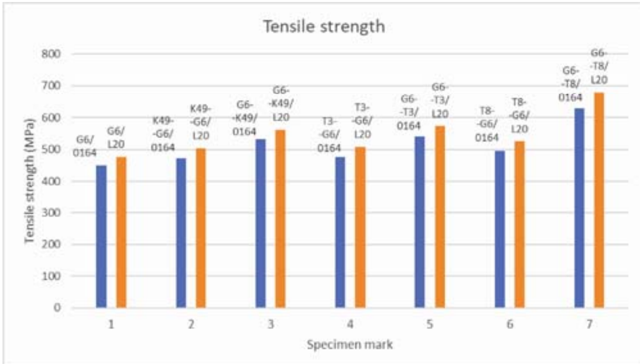

Figure 11. Tensile strength of fourteen filament wound composite materials versus epoxies 0164 and L20

Specific tensile strength of two single fiber and twelve hybrid filament wound composite materials versus epoxies 0164 and L20 are shown in Fig.12.

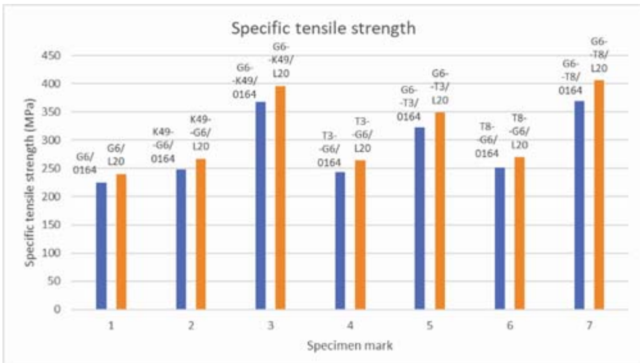

Figure 12. Specific tensile strength of two single fiber and twelve hybrid filament wound composite materials versus epoxies 0164 and L20

In Figures 11 and 12 are presented seven groups of tubes, of which each contains two members. As it can be seen from Figures 11 and 12, in each two-member group, either single fiber tubes or hybrid tubes with epoxy 0164 have slightly lower two presented tensile characteristics than appropriate tubes with epoxy L20.

Hydraulic burst pressure of all filament wound composite tubes tested in this investigation versus epoxies 0164 and L20 are in Fig.13.

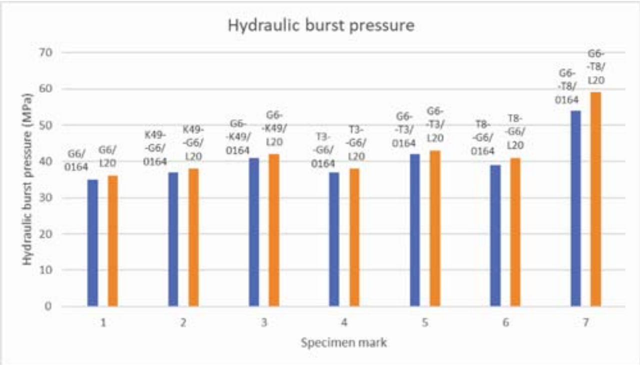

Figure 13. Hydraulic burst pressure of all filament wound composite tubes tested in this investigation versus epoxies 0164 and L20

In Fig.14 are presented specific hydraulic burst pressure of single fiber tubes and hybrid tubes versus epoxies 0164 and L20.

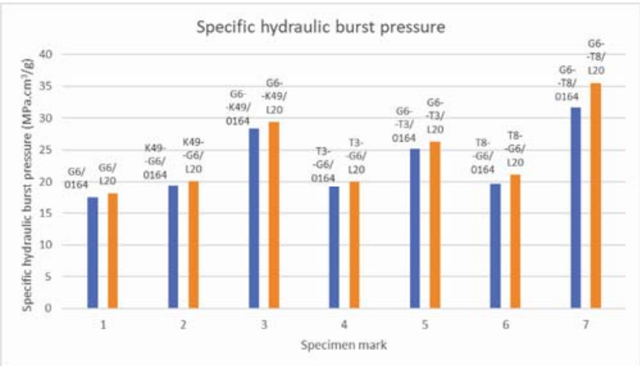

Figure 14. Specific hydraulic burst pressure of single fiber tubes and hybrid tubes versus epoxies 0164 and L20

Comparing hydraulic burst pressure (Fig.13) and specific hydraulic burst pressure (Fig.14) of single fiber tubes and hybrid tubes impregnated with epoxy 0164 and with epoxy L20, it can be noticed that composite products with first mentioned matrix have a little lower presented characteristics.

Conclusions

1. Using filament winding technology, tubes consisting of one fiber (so called single tubes) and tubes consisting of two fibers (so called hybrid tubes), impregnated with appropriate resin systems, are produced.
2. Density, tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure of two single tubes (consisting of glass fiber G600 and epoxies 0164 and L20) and of twelve hybrid tubes (four consisting of glass fiber G600, aramide fiber K49 and epoxies 0164 and L20, four consisting of glass fiber G600, carbon fiber T300 and epoxies 0164 and L20, and four consisting of glass fiber G600, carbon fiber T800 and epoxies 0164 and L20) are investigated.
3. Values of tensile strength and hydraulic burst pressure are declining by the next schedule: hybrid tubes mark G600-T800/L20 (the highest), hybrid tubes mark G600-T800/0164, hybrid tubes mark G600-T300/L20, hybrid tubes mark G600-K49/L20 …. hybrid tubes mark K49-G6/0164 and single fiber tubes mark G6/0164 (the lowest).
4. Hybrid tubes mark G600-T800/L20, also, have the highest specific tensile strength and the highest specific hydraulic burst pressure but the schedule of the following tubes is different in regard to tensile strength and hydraulic burst pressure schedule: (hybrid tubes mark G600-K49/L20, hybrid tubes mark G600-T800/0164 and hybrid tubes mark G600-K49/0164….) due to the density of the mentioned composite materials with aramide fiber.
5. If the quantity of used fibers (aramide K49, carbon T300 and carbon T800) in the structure of filament wound hybrid tubes is raising, the specified mechanical and hydraulic characteristics, in regard to the appropriate properties of single fiber tubes, are increased.
6. Single fiber tubes and hybrid tubes, with epoxy L20 have better characteristics than the appropriate tubes with epoxy 0164 (slightly lower density value but higher values of tensile strength, specific tensile strength, hydraulic burst pressure and specific hydraulic burst pressure).
7. The importance of advanced reinforcing agents (aramide roving and carbon fibers), of impregnating agents (epoxy resin systems) and of the density of hybrid tubes (especially with aramide roving) in manufacturing of filament wound composite hybrid tubes is established by realized investigations.

Literatura

[1] GROOVER M.P.: *Fundamentals of Modern Manufacturing, Materials, Processes and Systems*, John Wiley and Sons Inc., Hoboken, 2010, ISBN 978-0470-467008.

[2] Sabu Thomas, Kuruvilla Joseph, Sant Kumar Malhotra, Koichi Goda and Meyyarappallil Sadasivan Sreekala, (Editors), Polymer Composites: Volume 1, First Edition, Published 2012 by Wiley-VCH Verlag GmbH & Co. KGaA.

[3] Jawaid M., Tariq M. and Saba N., (Editors) Durability and Life Prediction in Biocomposites, Fiber-Reinforced Composites and Hybrid Composites, 2019, Woodhead Publishing Series in Composites Science and Engineering, ISBN 978-0-08-102290-0.

[4] Radulović J., Hybrid Filamentwound Materials: Tensile Characteristics of (Aramide Fiber/Glass Fiber)-Epoxy Resins Composite and (Carbon Fibers/Glass Fiber)-Epoxy Resins Composites, Scientific Technical Review, 2020, Vol. 70, No.1, pp. 36-46, BelGade, DOI: 10.5937/str 2001036R.

[5] Hai Nguyen, Wael Zatar and Hiroshi Mutsuyoshi, Mechanical properties of hybrid polymer composite in Hybrid Polymer Composite Materials, Properties and Characterization, 2017, pp. 83-113, 2017, Elsevier Ltd.

[6] Dave R.S. and Loos A.C., (Editors), Processing of composites, Carl Hanser Verlag, Munich, 2000.

[7] Mundra,R.R.: Hybrid Materials, https://prezi.com/svsgpadl_hvu/hybrid-composite-materials.

[8] Perov B. V. and Khoroshilova I. P., Soviet Advanced Composites Technology Series book series (SACTS, volume 4) in Polymer Matrix Composites, (ed. Shalin R. E.), pp. 269-304, © Chapman & Hall 1995.

[9] Summerscales,J.: Hybrid composites, https://www.slideserve.com/nevin/hybrid-composites.

[10] Kelly A., Concise Encyclopedia of Composite Materials, Pergamon Press, Oxford, 1988, ISBN 0-08-034718-9.

[11] Radulović J., Development and Characterization of Non Standard Extruded Poly(vynil chloride) Products, Scientific Technical Review, 2016, Vol. 66, No.1, pp. 48-56, Belgrade.

[12] Lokman Gemi, Investigation of the effect of stacking sequence on low velocity impact response and damage formation in hybrid composite pipes under internal pressure. A comparative study, Composites Part B: Engineering, 2018, Volume 153, 15 November, pp. 217-232.

[13] Ercan Sevkat, Finite element analysis of functionally hybridized carbon/glass composite shafts, Journal of Reinforced Plastics and Composites, Volume: 33, Issue: 13, pp. 1226-1236, first published online: February 20, 2014; Issue published: July 1, 2014.

[14] Prashanth Turla, S. Sampath Kumar, P. Harshitha Reddy, K. Chandra Shekar, Processing and Flexural Strength of Carbon Fiber and Glass Fiber Reinforced Epoxy-Matrix Hybrid Composite, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 4, April 2014.

[15] Sayer M., Bektaş N. B. and Çallioğlu H., Impact behavior of hybrid composite plates, Journal of Applied Polymer Science, 2010, 118(1), pp. 580–587. doi:10.1002/app.32437, Published online 21 May 2010 in Wiley InterScience (www.interscience.wiley.com).

[16] Faiz Ahmad, M. Ridzuan A. Latif and Harris Nisar, Hybrid Composites for Engineering Application, COMPOSITES TECHNOLOGIES FOR 2020, Proceedings of the Fourth Asian-Australasian Conference on Composite Materials (ACCM-4), University of Sydney, Australia, 6-9 July, 2004, Edited by L. Ye, Y.-W. Mai and Z. Su, Woodhead Publishing Limited, Abington Hall, Abington 2004.

[17] Naresh K., Shankar K., Rao B.S. and Velmurugan R., Effect of high strain rate on glass/carbon/hybrid fiber reinforced epoxy laminated composites, Composites Part B: Engineering,2016, Volume 100, 1 September, pp. 125-135.

[18] Dipak Kumar Jesthi and Ramesh Kumar Nayak, Evaluation of mechanical properties and morphology of seawater aged carbon and glass fiber reinforced polymer hybrid composites, Composites Part B: Engineering, 2019, Volume 174, 1 October, 106980

[19] N.K.Naik, R.Ramasimha, H.Arya, S.V Prabhu and N.Shama Rao, Impact response and damage tolerance characteristics of glass–carbon/epoxy hybrid composite plates, Composites Part B: Engineering, 2001, Volume 32, Issue 7, October, pp. 565-574.

[20] Y. Shan and K. Liao, Environmental fatigue of unidirectional glass–carbon fiber reinforced hybrid composite, Composites Part B: Engineering, Volume 32, Issue 4, 2001, pp. 355-363.

[21] Jin Zhang, Khunlavit Chaisombat, Shuai He and Chun H.Wang, Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures, Materials & Design,2012,Volume 36, pp. 75-80.

[22] Dipak Kumar Jesthi and Ramesh Kumar Nayak, Improvement of mechanical properties of hybrid composites through interply rearrangement of glass and carbon woven fabrics for marine application, Composites Part B: Engineering, Volume 168, 1 July 2019, pp. 467-475.

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Hibridne mokronamotane kompozitne cevi (aramidno vlakno/stakleno vlakno)-epoksi smola i (ugljenična vlakna/stakleno vlakno)-epoksi smola: zapreminske, mehaničke i hidraulične karakteristike

U ovom radu prikazane su zapreminske, mehaničke i hidraulične karakteristike mokronamotanih kompozitnih cevi sa jednim vlaknom i hibridnih cevi.
Kompozitni hibridni materijali, proizvedeni tehnologijom mokrog namotavanja, kategorizovani su prema različitim načinima klasifikovanja hibridnih materijala.
Za proizvodnju mokronamotanih cevi korišćena su četiri sredstva za ojačanje (stakleno vlakno G600, poliamidno aromatsko vlakno K49, ugljenično vlakno T300 i ugljenično vlakno T800) i dva sistema za impregnaciju (epoksi 0164 i epoksi L20).
Ispitane su gustina, zatezna čvrstoća, specifična zatezna čvrstoća, hidraulični pritisak prskanja i specifični hidraulični pritisak prskanja dve mokronamotane cevi stakleno vlakno/epoksi smole (kao osnovni materijali) i dvanaest mokronamotnih hibridnih cevi.
Na osnovu eksperimentalno dobijenih rezultata, zaključeno je da su četiri najveća rezultata prekidne čvrstoće i hidrauličnog pritiska prskanja sledećeg redosleda: hibridna cev oznake G600-T800/L20 (najveća), hibridna cev oznake G600-T800/0164, hibridna cev oznake G600-T300/L20 i hibridna cev oznake G600-K49/L20.
Niz od četiri najveće specifične zatezne čvrstoće i najveća specifična hidraulična pritisaka prskanja, takođe, počinje hibridnom cevi oznake G600-T800/L20, ali raspored sledeće tri cevi je drugačiji zbog gustine kompozitnih materijala sa aramidnim vlaknom (hibridna cev oznake G600-K49/L20, hibridna cev oznake G600-T800/0164 i hibridna cev oznake G600-K49/0164).
Sve mokronamotane cevi (sa jednim vlaknom i hibridne cevi) impregnisane epoksi sistemom L20 imaju nešto manju vrednost gustine ali veće vrednosti zatezne čvrstoće, specifične zatezne čvrstoće, hidrauličnog pritiska prskanja i specifičnog hidrauličnog pritiska prskanja nego odgovarajuće cevi impregnisane epoksi sistemom 0164.
Dobijeni rezultati u ovom ispitivanju ukazali su i naglasili značaj savremenih sredstava za ojačanje (aramidni roving i ugljenična vlakna), sredstava za impregnaciju (sistemi epoksi smole) i gustine hibridnih cevi, posebno onih sa aramidnim vlaknima.

Ključne reči: **Hibridni kompoziti, cevi, tehnologija mokrog namotavanja, stakleno vlakno, aramidno vlakno, ugljenično vlakno, sistem epoksi smole, gustina, zatezna čvrstoća, specifična zatezna čvrstoća, hidraulični pritisak prskanja i specifični hidraulični pritisak prskanja.**