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Influence of Internal Cyclic Pressure on Filamentwound Composite Tubes Quality

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In this paper the influence of internal hydraulic cyclic pressure on the quality of filamentwound composite glass fiber/polyester resin tubes was investigated. Mechanisms of composites tubes destruction which can be caused by cyclic internal stresses are described and ilustrated. During the action of changeable internal pressure neither weepage of tubes nor drop of applied pressure happened. Almost the same values of hydraulic burst pressure and final radial deformation of cyclised and noncycliced tubes pointed out that the described treatment of cycling has no negative influence on the tested tubes quality.

Key words: **composites, polymers, polyester resin, glass fiber, filament winding, tubes, cycling loading, pressure effects, hydraulic pressure.**

Introduction

SIGNIFICANT technical and technological progress in almost all areas of human activities resulted in investigation, development and production of whole spectra of different new materials.

One group of new contemporary materials developed in a last few decades are composites. In a broader sense, almost every material can be classified as a composite. because homogeneous materials are rarely used. Composite materials, in a narrower sense, must fulfill the following conditions:

- to be produced by humans.
- to represent the composition of two different materials with a clear seperation boundary at the micro scale.
- that components formed composite by their volume part ie. content and
- that composites have properties that none of components has.

Composite materials, in brief, consist of a reinforcing agent and an impregnating resin, with an important role of the interfacial surface between these two contituents.

Depending on the shape and dimensions of the reinforcing agent, there are two kinds of composite materials:

- composite with dispersed particles, and
- composite with fiber reinforcements.

The above mentioned definition of composite materials, in full sense. refers to fibre reinforced composite materials.

Using a fiber to reinforce a material was known in a distant past (800 years B.C.) when straws were used to reinforce bricks. This concept was applied in reinforcing cement with short glass fibers in the third decade of the previous century. Fiber reinforced polymeric materials (today known as fiber reinforced composites) were developed in the 1940s [1, 2].

Composites with continual fibres

Polymeric composite materials reinforced with continual fibres are now - and for a long preriod of time in the future will be - the most important and the biggest group of advanced copmposites, especially owing to development in their use and production [3]. Composite materials reinforced with continual fibres are produced by filament winding technology, using different fiber reinforcements (glass, carbon, graphite, aramide, etc.) and various resins (polyester, epoxy, phenol, polyamide, etc.) [4]. The filament winding technology, briefly. consists of the following phases:

- unwinding of continous fibers (roving) from appropriate devices at a defined tension force,
- passing of roving through a bath with resin and, at the same time, a basic impregnation of fibers by resin occurs,
- passing of resin impregnated fiber through a system of „combs” and „rings” during which an additional impregnation of fibers by resin occurs and the excess of resin from the band roving is removed,
- winding of resin impregnated band roving on an appropriate mandrel,
- curing of the wound structure at ambient or high temperature, depending on the applied resin system, and
- removing the mandrel and obtaining a filamentwound composite part.

Materials produced by the mentioned technology are characterised by a set of unique properties so they pressed back classical construction materials and very often are the only choice for numerous purposes. The facts that filamentwound composite materials have small density and exceptional mechanical properties in the load direction during the part exploatation are of extraordinary importance when loaded elements of construction are concerned.

Winding of fibrous reinforcement of the roving type can be done either on the almost entire length of the cylindrcal mandrel or over the ends of tools of different shapes. Tubes and cylindrical parts are produced by the former procedure and structures of complex shapes (balls, rocket cases, etc) by the latter. These two bassically different filament winding procedures are shown in Fig.1 [5].

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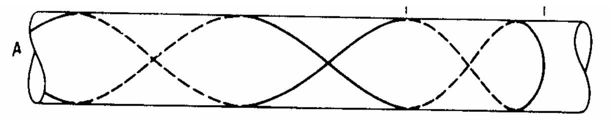
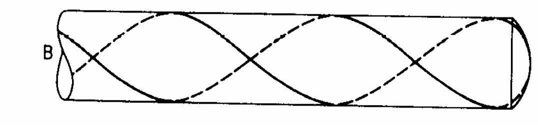


Winding on cylinder



Winding over ends

Figure 1. Procedures of filament winding technology

One of most frequent loadings in filamentwound composite tubes is internal fliud pressure. The pressure in tubes can be of constant or changeable level. It is of special importance when pressure in tubes is changed in a cyclic manner ie. when multiple increasing and decreasing of pressure level occur. Two intraconnected phenomena are possible when composite tubes are under the influence of liquid fliud internal pressure of a constant or various level. One is, so-called, weeping ie. appearance of liquid droplet at outer surface of the tubes and another is decreasing of the internal pressure level.

A tube failure can take place if reinforcement and resin and structure winding (number of layers and angles of winding) are not properly chosen and if technological parameters of the filament winding procedure and other elements are not correctly defined. This tube failure can appear at a much lower internal pressure level than expected.

It is considered that the fiber-resin interface is the weakest link in composite materials.

One of essential components in continous filament glass fibre products is polymeric coating or the size. This coating performs three main functions:

a) it prevents the breakage of filaments and protects them from abrasive damage which would weaken their strength drastically. This is essential in all stages of production, subsequent processing and composite manufacture.

b) It binds the individual filaments into a convinient geometrical form for handling or for use as reinforcing elements. Fiber bundles may be retained in this form in composite products or may be dispersed into single filaments in some matrices or processes.

c) It improves the properties of final compopsite products, in a way, either by increasing the strength of the fiber-matrices interfacial bond thus improving its resistance to degradation in moist conditions or by affecting the fiber strength.

In order to fulfill these functions, the size normally contains the following components:

1. *Film forming* polymer binds filaments together and provides protective coating. Polyvinil acetate emulsions have formed the basis for many sizes. In aqueous enviroments glass surface became anionic and recent size developments have been based on water soluble polymers with the cationic centre. The anionic glass surface attracts the cationic centre of sizes and, after a drying process, a strong bond is formed. Sizes for fibres, intended to be used use with polyester resins, are based on acrylic copolymers and polyesters. For fibres that will be used in composites with epoxy resins, a size contains alkanoamines which react with the epoxy group.
2. *Lubricant* protects both the glass fiber surface and the polymeric size from abrasion. Modern lubricants are, often, based on cationic active agents (to bond to the anionic glass surface) and aliphatic chains.
3. *Active agent* provides a „chemical“ bond between the glass fibre surface and the matrix in reinforced polymeric composite materials. Modern active or coupling agents are complex organosilanes compounds (usually haloganide silane) in general formulae $R\text{-}Si\text{-}(CH_2)_n\text{-}X_3$ where R is an organofunctional group (usually hydrocarbon radical) and X is a hydrolyzable group (usually halogen element atoms). For a production of polyester based resin composites, vinyl and metacryloxy groups are chosen, and for composites wth epoxy resins, amino groups are used. The choice of an incorrect coupling agent for a particular resin can lead to poor fiber-matices bonding, A smooth glass fibre surface consists of oxides (SiO_2, Al_2O_3, Fe_2O_3). Coupling or active agents are brought to the glass surface in wet conditions and the hydrolysis of halogenide silane occur and the silanol of the general formulae $R\text{-}Si\text{-}(CH_2)_n\text{-}(OH)_3$ is formed. The obtained silanol, by formed OH groups, reacts with oxygen from the present metal oxides (Si, Al, Fe) and so-callled covalent siloxane bridges between glass fibre and one end of the active agent are formed. With their other organofunctional or hydrocarbon R-end, silanol molecules form a strong chemical bond with the present resin, especially during the curing process of the wound structure [3, 6]. A strong „chemical“ bond on the interfacial surface polymer resin-glass fiber is formed, protecting fiber surface from water influence because silanol forms a strong water-resistant bond with glass fibres.

The starting point in the weeping process in internally fluid stressed filamentwound tubes ie. in the appearance of fluid droplets on the tube outer surface is the initiation of resin damage on the inner surface of the cylindrical part, transversal to the fibre length. The initiation of damage appear in resins at places sensitive to load and these are cracks on the surface and present defects such as crazing, pores. etc. These failures are initiated at a number of places and they continue to grow. The tip of the failure is moving through the resin and comes in contact with the interfacial resin-fiber surface. This surface is a weak spot in the structure and the damage is spread along the fibre. The crack of interfacial resin-fibre surface propagates along the fibre and causes damage ie. cracking of resin in the perpendicular direction between two fibres or between two layers of fibres. The propagation of cracking in the transversal direction between layers, practically, create a path for fluid passage. Cracking ie. damage of fibre-reinforced composite materials occurs by failure spreading which has a much more complex character than cracking of homogeneous materials. When applied, internal hydraulic pressure is significantly lower than the load that causes damage initiation in the perpendicular direction, weeping or wetting at the tube outer side, eventually, appear after a long period of time, This fact points out that damage in the transversal direction is a factor that, mostly, causes a described phenomenon [3, 7].

The mechanism of weeping ie. water crossing through composite material polymeric resin-glass fiber can be presented in phases, shown in Fig.1.

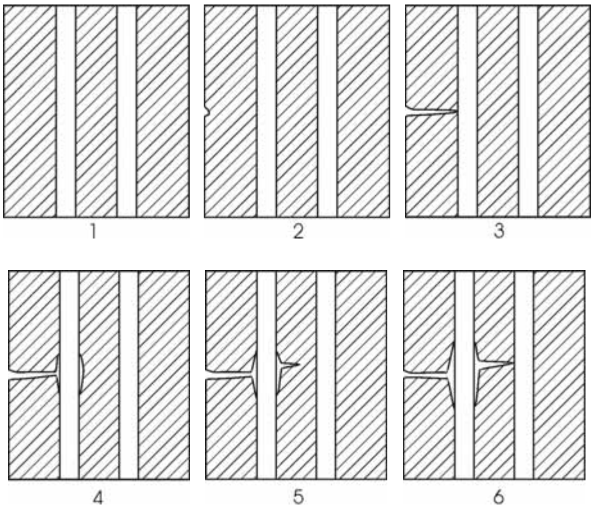


Figure 1. Phases of water crossing through a composite material polymeric resin-glass fiber

1. Composite resin-fiber before the formation of initial damage.
2. Initial damage appears on the resin surface in the perpendicular direction to the fiber length.
3. Initial damage transforms into cracking, which propagates through the resin layer. The tip of cracking, first, is in the contact with the interfacial resin-fiber surface and then with the surface of the first fiber.
4. Cracking is spreading along the interfacial resin-fiber surface ie. along the first fiber.
5. Cracking is propagating along the interfacial surface of the first fiber and through the resin layer towards the second fiber.
6. The tip of cracking is in the contact with the second fiber surface and the interfacial surface resin-first fiber is more damaged.

This paper presents the results of the investigation of influence of multiple increasing and decreasing of internal hydraulic pressure on filamentwound composite tubes polyester resin-glass fiber characteristics. Filamentwound composite tubes, made of polyester resin-glass fibers, with two different winding structures, were exposed to cyclic internal hydraulic pressure. The values of the applied pressure and radial deformations were recorded and, also, the appearence of water droplets on the tube outer surface and the level of internal pressure were visually observed. After cycling treatment, these tubes as well as the tubes that were not exposed to the cyclic process, were tested under the influence of continually increased internal pressure and the values of internal pressure and radial deformation in the bursting moment of tubes were recorded. The influence of internal cyclic pressure on filamentwound composite tubes was defined by comparing the hydraulic burst pressure values and the final radial deformation values of cycliced and noncycliced tubes.

Experimental part

A polyester resin system trade mark DUGAPOL H230, made by the resin manufacturer “DUGA” - Belgrade, adapted for filaments winding technology, and glass roving trade mark R 2117, produced by the glass fiber manufacturer “ETEKS” – Baljevac on Ibar, were used for making tube samples.

The tubes were produced by the filament winding technology on the cylindrical mandrel using the PLASTEX machine PLA 500 type produced by the machine manufacturer PLASTEX – MANUHRIN France.

By machining process, tube samples 400 mm long were produced from cured tubes.

The marks, the winding structure (from the inside toward the outside), the internal diameter, the outer diameter and the wall thickness of two groups of tube samples are presented in Table 1. The test samples are of similar structures because all of them have outer layers with the winding angle 90°, but they also differ since in the middle of the structures of test samples marked 1 and 3 there are layers with 61° angles and the test samples marked 2 and 4 have layers under 45° angles.

Table 1. Marks, the winding structure, the internal diameter, the outer diameter and the wall thickness of tube samples

Tubes mark	Winding structure	Internal diameter (mm)	Outside diameter (mm)	Wall thickness (mm)
1 and 3	1 x 90° 2 x 61° 1 x 90°	64.20	67.60	1.70
2 and 4	1 x 90° 2 x 45° 1 x 90°	64.20	67.60	1.70

The outer diameter was obtained by machining in a way that only the final layer of pure resin was removed from the tube outer surface, so the final glass fiber layer was undamaged.

Two one-axis strain gauges HBB 10/120 LA 11 manufactured by the strain gauges manufacturer HOTTINGER BALDWIN MESSTECHNIK. Gmbh, Germany, were glued to the outer surfaces of tube samples 1 and 3 using the adhesive X 60 produced by same manufacturer.

The one-axis strain gauges were positioned in the middle of the tubes, one opposite the other, transversally to the longer axis of tubes in order to register radial deformations. A tube sample with two glued one-axis strain gauges is shown in Fig.2.

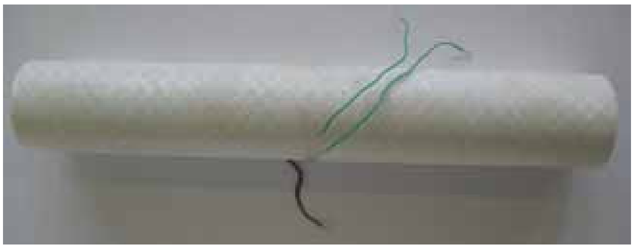


Figure 2. Tube sample with two glued one-axis strain gauges

The tube samples 1 and 3 were first exposed to the action of cyclic internal pressure and, after that, to the continual pressure growth to bursting. The tube samples 2 and 4 were, without previous cyclic treatment, exposed to continual pressure growth to bursting.

The characteristics of the tube samples were experimentally determined by a device for hydraulic pressure, produced by the hydraulic pressure machine manufacturer WALTER & BAI, Germany, range 200 MPa, along with protection equipment, a specific tool for testing tubes hydraulic burst pressure and piezoelectric pressure converter trade mark 601H range 100 MPa manufactured by the measuring devices manufacturer KISTLER, Germany.

Loading and unloading of tubes samples by internal hydraulic pressure were performed in a way that the valve on the mentioned device was opened and closed manually.

A digital oscilloscope NICOLET 4094B along with additional equipment produced by the measuring devices manufacturer NICOLET INSTRUMENTS, USA, was used for simultaneous detection of internal hydraulic pressure and radial deformations of tube samples.

Results of testing and analysis

Tube samples 1 were exposed to the cyclic action of internal hydraulic pressure in the following manner:

- tube samples were loaded by 3 MPa internal hydraulic pressure; two parameters of the tube samples (pressure and radial deformations) were recorded; the appearance of water droplets on the tube samples outer surface and a level of internal pressure were visually controlled.
- tube samples were unloaded and immediately after a drop of internal pressure two mentioned parameters (pressure and radial deformations) were recorded.
- three minutes after unloading of tube samples, internal hydraulic pressure and radial deformations were, again, recorded and visual inspection of the outer surface of tube samples was done; in this way one cycle of testing was completed.

Tube samples 1 were exposed to ten described cycles with 3 MPa internal hydraulic pressure.

Tube samples 2 were exposed to the influence of ten cycles, but in first five cycles the internal hydraulic pressure of 3 MPa was applied and in the last five cycles the internal hydraulic pressure of 6 MPa.

Results of the investigation of the cyclic action of internal hydraulic pressure and the analysis

The cycle numbers, loading types, hydraulic pressure and radial deformations (single values and arithmetic mean values) during the investigation of tube samples 1 are shown in Table 2.

Table 2. Cycle number, loading type, hydraulic pressure and radial deformations of tube samples 1

Cycle number	Loading type	Hydraulic pressure (MPa)	Radial deformation 1 (mm/m) $x10^{-3}$	Radial deformation 2 (mm/m) $x10^{-}$	Radial deformation arithmetic mean (mm/m) $x10^{-3}$
First cycle	Loading	3.52	1.90	1.98	1.94
	Immediately after unloading	0.024	0.04	0.05	0.05
	Three minutes after unloading	0.014	0.01	0.01	0.01
Second cycle	Loading	3.68	2.17	2.25	2.21
	Immediately after unloading	0.040	0.20	0.20	0.20
	Three minutes after unloading	0.016	0.06	0.05	0.05
Third cycle	Loading	2.64	1.83	1.92	1.88
	Immediately after unloading	0.016	0.09	0.08	0.09
	Three minutes after unloading	0.008	0.00	0.00	0.00
Fourth cycle	Loading	3.84	2.55	2.69	2.62
	Immediately after unloading	0.024	0.08	0.09	0.09
	Three minutes after unloading	0.015	0.04	0.09	0.06
Fifth cycle	Loading	4.24	2.68	2.70	2.69
	Immediately after unloading	0.012	0.15	0.14	0.15
	Three minutes after unloading	0.008	0.05	0.04	0.04
Sixth cycle	Loading	3.84	2.17	2.25	2.21
	Immediately after unloading	0.016	0.04	0.03	0.04
	Three minutes after unloading	0.008	0.00	0.00	0.00
Seventh cycle	Loading	3.13	2.08	2.16	2.12
	Immediately after unloading	0.080	0.03	0.03	0.03
	Three minutes after unloading	0.024	0.00	0.03	0.01
Eighth cycle	Loading	3.20	2.07	2.17	2.12
	Immediately after unloading	0.040	0.07	0.09	0.08
	Three minutes after unloading	0.008	0.01	0.01	0.01
Nineth cycle	Loading	2.56	2.00	2.06	2.03
	Immediately after unloading	0.032	0.11	0.10	0.11
	Three minutes after unloading	0.000	0.03	0.04	0.03
Tenth cycle	Loading	4.40	2.90	3.01	2.96
	Immediately after unloading	0.040	0.18	0.22	0.20
	Three minutes after unloading	0.008	0.03	0.02	0.02

The cycle numbers, loading types, hydraulic pressure and radial deformations (single values and arithmetic mean values) during the investigation of tube samples 2 are shown in Table 3.

Table 3. Cycle number, loading type, hydraulic pressure and radial deformations of tube samples 2

Cycle number	Loading type	Hydraulic pressure (MPa)	Radial deformation 1 (mm/m) x 10^{-3}	Radial deformation 2 (mm/m) x 10^{-3}	Radial deformation arithmetic mean (mm/m) x 10^{-3}
First cycle	Loading	2.17	1.79	1.86	1.83
	Immediately after unloading	0.08	0.09	0.09	0.09
	Three minutes after unloading	0.06	0.02	0.02	0.02
Second cycle	Loading	2.88	1.96	2.15	2.06
	Immediately after unloading	0.064	0.09	0.13	0.11
	Three minutes after unloading	0.016	0.00	0.04	0.02
Third cycle	Loading	3.04	2.10	2.01	2.05
	Immediately after unloading	0.008	0.12	0.13	0.13
	Three minutes after unloading	0.008	0.01	0.00	0.00
Fourth cycle	Loading	3.14	2.13	2.21	2.17
	Immediately after unloading	0.008	0.07	0.08	0.08
	Three minutes after unloading	0.06	0.01	0.00	0.00
Fifth cycle	Loading	3.60	2.09	2.17	2.13
	Immediately after unloading	0.008	0.09	0.12	0.11
	Three minutes after unloading	0.008	0.01	0.01	0.01
Sixth cycle	Loading	4.64	3.52	3.65	3.62
	Immediately after unloading	0.032	0.25	0.28	0.27
	Three minutes after unloading	0.016	0.17	0.28	0.22
Seventh cycle	Loading	6.34	4.38	4.56	4.47
	Immediately after unloading	0.016	0.12	0.15	0.14
	Three minutes after unloading	0.016	0.08	0.09	0.08
Eighth cycle	Loading	5.04	4.26	4.46	4.36
	Immediately after unloading	0.032	0.47	0.50	0.49
	Three minutes after unloading	0.008	0.39	0.42	0.40
Nineth cycle	Loading	4.72	3.59	3.74	3.67
	Immediately after unloading	0.008	0.11	0.18	0.14
	Three minutes after unloading	0.008	0.01	0.03	0.02
Tenth cycle	Loading	7.20	4.54	4.37	4.46
	Immediately after unloading	0.064	0.19	0.21	0.20
	Three minutes after unloading	0.024	0.16	0.18	0.17

On the basis of the analysis of the obtained results. shown in Table 2. it can be concluded:

- in each of ten cycles at 3 MPa internal hydraulic pressure, radial deformations were about 2 x 10^{-3} mm/m.
- immediately after unloading ie. after drop of 3 MPa internal hydraulic pressure, in every cycle, radial deformations decreased to about 0.1 x 10^{-3} mm/m.
- the water droplets appearance on the tube sample outer surface was not recorded neither during not after a drop of 3 MPa internal hydraulic pressure, in any cycle.
- in every cycle, three minutes after unloading of tube samples, radial deformations decreased to near the zero value in most cases.
- after 10 cycles, radial deformations are mostly close to the zero value and on the tube samples outer surface water droplets were not recorded.

On the basis of the results of testing of tube samples 2. shown in Table 3. for the first five cycles with 3 MPa internal hydraulic pressure, it can be stated:

- in each of five cycles, during the action of 3 MPa internal hydraulic pressure, radial deformations were about 2 x 10^{-3} mm/m.
- during loading of tube samples in all five cycles, a drop of 3 MPa internal hydraulic pressure was not recorded.
- immediately after unloading ie. after a drop of 3 MPa internal hydraulic pressure, in every cycle, radial deformations decreased to about 0.1 x 10^{-3} mm/m.
- in every cycle, three minutes after unloading of tube samples radial deformations decreased to near zero value in most cases.
- neither during nor after an action of 3 MPa internal hydraulic pressure, water droplets on the tube samples outer surface were recorded.

After being loaded with 3 MPa internal hydraulic pressure in five cycles tube samples 2 were exposed to 6 MPa internal hydraulic pressure, also in five cycles. On the basis of the results of testing tube samples 2 in the last five cycles, shown in Table 3. it can be concluded:

- in each of these five cycles, radial deformations about 4 x 10^{-3} mm/m were recorded.
- during these last five cycles, when tube samples 2 were loaded with 6 MPa internal hydraulic pressure. Decreasing of this parameter was not recorded.
- immediately after unloading tube samples 2 ie. a drop of internal pressure in each of the last five cycles, radial deformations decrease to about 0.2 x 10^{-3} mm/m.
- neither during nor after an action of 6 MPa internal hydraulic pressure, water droplets on the tube samples outer surface were recorded.
- radial deformation values decreased after the stop of the action of internal hydraulic pressure in each of the last five cycles and approached the zero value in most of the cases.
- after five cycles with 3 MPa internal hydraulic pressure and five cycles with 6 MPa internal hydraulic pressure, radial deformations are close to zero value and water droplets did not apprear on the tube samples 2 outer surface.

Results of the investigation of the continual action of internal hydraulic pressure and the analysis

Tube samples 1 and 2 were first exposed to a cyclic action of internal hydraulic pressure in the described treatment. After a cycling procedure, tube samples 1 and 2 were loaded by contunualy increasing internal hydraulic pressure to bursting. Tube samples 3 and 4 were exposed, without previous cycling to the action of contunually increasing internal hydraulic pressure to bursting.

The values of internal hydraulic pressure and radial deformation at the bursting moment (hydraulic burst pressure and final radial deformation) caused by contunual growth of internal hydraulic pressure in previously cycliced tube samples 1 and noncycliced tube samples 3, which have same winding structure, are shown in Table 4.

Table 4. Hydraulic burst pressure and final radial deformation of previously cycliced tube samples 1 and noncycliced tube samples 3

Tube mark	Hydraulic burst pressure (MPa)	Final radial deformation (mm/m) x 10^{-2}
1	22.01	2.19
3	22.34	2.13

Based on the results of the investigation, shown in Table 4, it can be concluded:

- hydraulic burst pressure of tube samples 1 which have been previously exposed to the action of 3 MPa internal hydraulic pressure in ten cycles (22.01 MPa) insignificantly differs from hydraulic burst pressure of tube samples 3 with same winding structures which have not been exposed to cyclic treatment (22.34 MPa).
- similar relations exist concerning the radial deformations at the bursting moment, ie. tube samples 1 which were cycliced by the described treatment have final radial deformations (2.19 x 10^{-2} mm/m) at the nearly same level as tube samples 3 (2.13 x 10^{-2} mm/m) which were not exposed to the cycling procedure.

The results of the investigation of the hydraulic burst pressure and the final radial deformation caused by contunual growth of internal hydraulic pressure in previously cycliced tube samples 2 and noncycliced tube samples 4, which have same winding structure, are shown in Table 5.

Table 5. Hydraulic burst pressure and final radial deformation of previously cycliced tube samples 2 and noncycliced tube samples 4

Tube mark	Hydraulic burst pressure (MPa)	Final radial deformation (mm/m) x 10-2
2	18.38	1.84
4	18.04	1.87

Data in Table 5 pointed out that:

- the hydraulic burst pressure values of cycliced tube samples 2 (18.38 MPa) are almost the same as the hydraulic burst pressure values of noncycliced tube samples 4 (18.04 MPa) which have the same winding structure.
- in final radial deformation the same relation is observed, ie. cycliced tube samples 2 have this characteristic at the same level (1.84 x 10^{-2} mm/m) as noncycliced tube samples 4 with the same winding structure (1.87 x 10^{-2} mm/m).

Conclusions

Based on the everything written above, it can be concluded:

1. Filamentwound composite glass fiber/polyester resin tubes, which have two different winding structures, were exposed to cyclic treatment by internal hydraulic pressure.
2. The described cyclic treatment has no influence on the quality of the investigated tube samples because the values of hydraulic pressure and radial deformation in the moment of bursting of previously cycliced and non-cycliced tube samples are almost the same.
3. During the cyclic action of internal hydraulic pressure neither water droplets apprear on the outer tube samples surface nor decreasing of defined internal hydraulic pressure was recorded.

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Uticaj cikličnog unutrašnjeg pritiska na kvalitet mokronamotanih kompozitnih cevi

U ovom radu ispitivan je uticaj cikličnog unutrašnjeg hidrauličkog pritiska na kvalitet mokronamotanih kompozitnih cevi stakleno vlakno/poliestarska smola. Opisane su i skicama prikazane faze mehanizma oštećenja kompozitnih cevi. koji može da se desi pod dejstvom unutrašnjeg cikličnog naprezanja. Tokom dejstva promenljivog unutrašnjeg pritiska nije došlo do curenja cevi ni do pada primenjenog pritiska. Skoro iste vrednosti hidrauličkog pritiska prskanja i konačnih radijalnih deformacija cikliranih i necikliranih cevi ukazuju da opisani postupak cikliranja nema negativan uticaj na kvalitet ispitivanih cevi.

Ključne reči: **kompozitni materijali, polimerni materijali, poliesterska smola, stakleno vlakno, mokro namotavanje, cev, ciklično opterećenje, uticaj pritiska, hidraulični pritisak.**

Влияние циклического внутреннего давления на качество композитных мокронаматываных труб

В настоящей работе исследовано влияние циклического внутреннего гидравлического давления на качество мокронаматываных композитных труб стекляное волокно / полиэстарская смола. Здесь описаны и при помощи рисунков показаны фазы механизма повреждения композитных труб, которые возможны под влиянием внутреннего циклического напряжения. В течении действия изменяемого внутреннего давления не произошли вытечка труб и упадок применимого давления. Почти одинаковы значения гидравлического давления трещин и конечных радиальных деформаций труб в цикле и труб вне цикла указывают на то, что описаный поступок цикла не оказывает отрицательное влияние на качество исследованых труб.

Kly~evwe slova: **композитные материалы, полимерные материалы, полиэстарская смола, стекляное волокно, мокрое наматывание, труба, циклическая нагрузка, влияние давления, гидравлическое давление.**

Influence de la pression interne cyclique sur la qualité des tubes composites à filament enroulé

Dans ce travail on a étudié l'effet de la pression cyclique interne sur la qualité des tubes composites à filament enroulé en fibre de verre /résine polyester. On a décrit et présenté en forme d'esquisses les phases du mécanisme d'endommagement des tubes composites qui peur se produire sous l'action des contraintes cycliques internes. Pendant l'action de la pression variable interne il n'y avait ni fuite de tube ni diminution de la pression utilisée. Les valeurs presque identiques de la pression hydraulique de l'éclatement et les déformations radiales finales des tubes (cyclisées ou non cyclisées) démontrent que le procédé du cyclage décrit n'a aucun effet négatif sur la qualité des tubes étudiées.

Mots clés: **matériaux composites, matériaux polymériques, résine polyester, fibre de verre, filament enroulé, tube, charge cyclique, effet de pression, pression hydraulique.**