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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК РЕСПУБЛИКИ КАЗАХСТАН»
ЧФ «Халық»

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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ON THE DEVELOPMENT OF TANKS FOR PETROLEUM PRODUCTS MADE OF COMPOSITE MATERIAL

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Abstract. The article reflects information about the technology of obtaining tank shells from composite material – fiberglass. Such tanks have an extended service life due to the absence of corrosion, reduced own weight, low wettability of the surface. In particular, the influence of the winding angle of the glass fiber on the cylindrical surface is investigated. Unlike traditional materials, in the case of composite, the creation of the product occurs simultaneously with the creation of the material. Therefore, the load-bearing capacity of the structure and its resource significantly depend both on the choice of the initial components and on the technology of their connection. Therefore, the calculation of a composite product is closely related to solving the problem of its creation. Improper organization of the technical process, unsatisfactory preparation of the initial components, non-compliance with technological and many other reasons can significantly change the properties of finished products. Depending on the molding technology, the values of the properties of polymer composites may differ several times. The choice of technology depends on the design of the product, its operating conditions, the volume of manufacture and available production resources. The paper discusses some issues related to the process of obtaining a composite. The influence of the technological process on the properties of the composite is investigated, especially in the statistical aspect. The authors consider a cylindrical shell consisting of a large number of layers of glass fiber connected by a binding material. The relations are determined by which optimal material structures can be determined for other possible reinforcement schemes of the material, for example, winding in a spiral with different angles. The condition of optimality of the structure of a cylindrical shell loaded with internal pressure and axial force is determined. With the help of this ratio, it is possible to determine the optimal winding angle of the glass.

Keywords: winding, tank, glass roll, winding angle, fiberglass, optimal material structure

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МҰНАЙ ӨНІМДЕРІНЕ АРНАЛҒАН КОМПОЗИТТІК МАТЕРИАЛДАН ЦИСТЕРНАЛАР ӘЗІРЛЕУ МӘСЕЛЕСІНЕ

Аннотация. Мақалада композиттік материалдан — шыны талшықтан цистерналардың қабығын алу технологиясы туралы мәліметтер көрсетілген. Цистернаның бұл түрі коррозияның болмауына байланысты ұзақ қызмет етеді, ыдыстың өзіндік массасы төмендейді, бетінің ылғалдылығы төмен. Атап айтқанда, шыны талшықты орау бұрышының цилиндрлік бетке әсері зерттелді. Дәстүрлі материалдардан айырмашылығы, композит жағдайында өнімді жасау материалды жасаумен қатар жүреді. Сондықтан құрылымның жүк көтергіштігі, оның ресурсы бастапқы компоненттерді таңдауға да, оларды қосу технологиясына да байланысты. Сондықтан композициялық материалдан жасалған өнімді есептеу оны жасау мәселесін шешумен тығыз байланысты. Технологиялық процестің дұрыс ұйымдастырылмауы, бастапқы компоненттердің қанағаттанарлықсыз дайындалуы, технологиялық талаптардың сақталмауы және басқа да көптеген себептер дайын өнімнің қасиеттерін айтарлықтай өзгерте алады. Қалыптау технологиясына байланысты полимерлі композиттердің қасиеттерінің мәні бірнеше рет өзгеруі мүмкін. Технологияны таңдау өнімнің дизайнына, оны пайдалану шарттарына, өндіріс көлеміне, сондай-ақ қолда бар өндірістік ресурстарға байланысты. Жұмыста композитті алу процесіне байланысты кейбір мәселелер қарастырылады. Технологиялық процестің композиттің қасиеттеріне әсері, әсіресе статистикалық аспектіде зерттеледі. Авторлар байланыстырушы материалмен байланысқан шыны талшықтардың көптеген қабаттарынан тұратын цилиндрлік қабықты қарастырады. Материалды нығайтудың басқа мүмкін схемалары үшін материалдың оңтайлы құрылымдарын анықтауға болатын қатынастар анықталды, мысалы, әртүрлі бұрыштары бар спиральды орау. Ішкі қысым мен остік күшпен жүктелген цилиндрлік қабық құрылымының оңтайлы шарты анықталды. Осы арақатынастың көмегімен сіз шыны талшықтыораудың

оңтайлы бұрышын анықтай аласыз және алынған өнімнің сапасын едәуір жақсарта аласыз.

Түйін сөздер: орау, цистерна, шыны, орау бұрышы, шыны талшық, материалдың оңтайлы құрылымы

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К ВОПРОСУ РАЗРАБОТКИ ЦИСТЕРН ИЗ КОМПОЗИТНОГО МАТЕРИАЛА ДЛЯ НЕФТЕПРОДУКТОВ

Аннотация. В статье отражены сведения о технологии получения оболочек цистерн из композитного материала — стеклопластика. Такие цистерны имеют увеличенный срок эксплуатации из-за отсутствия коррозии, сниженную собственную массу, низкую смачиваемость поверхности. В частности, исследовано влияние угла намотки стеклонити на цилиндрическую поверхность. В отличие от традиционных материалов, в случае композита создание изделия происходит одновременно с созданием материала. Поэтому несущая способность конструкции, ее ресурс существенно зависят как от выбора исходных компонентов, так и от технологии их соединения. Следовательно, расчет изделия из композита тесно связан с решением проблемы его создания. Неправильная организация техпроцесса, неудовлетворительная подготовка исходных компонентов, несоблюдение технологических и многие другие причины могут значительно изменять свойства готовых изделий. В зависимости от технологии формования значения свойств полимерных композитов могут отличаться в несколько раз. Выбор технологии зависит от конструкции изделия, условий его эксплуатации, объема изготовления и имеющихся производственных ресурсов. В работе рассматриваются некоторые вопросы, связанные с процессом получения композита. Исследуется влияние технологического процесса на свойства композита, особенно в статистическом аспекте. Авторами рассматривается цилиндрическая оболочка, состоящая из большого числа слоев стеклонити, соединенных связующим материалом. Выявляются соотношения, с помощью которых могут быть определены оптимальные структуры материала для других возможных схем армирования материала, например намотки по спирали с разными углами. Определяются условия оптимальности структуры цилиндрической оболочки, нагруженной внутренним давлением и осевой силой. С помощью данного соотношения можно вычислить оптимальный угол намотки стеклонити.

Ключевые слова: намотка, цистерна, стеклонить, угол намотки, стекловолокно, оптимальная структура материала

Introduction

Tanks for transportation and storage of petroleum products are traditionally made of various grades of steel. The use of fiberglass for the manufacture of tanks reduces operating costs due to the resistance of fiberglass to the effects of aggressive loads, lower thermal conductivity compared to steel and sufficiently high mechanical strength with significantly lower own weight. In turn, saving the weight of the boiler due to the use of fiberglass in its design can increase the useful load capacity of each mobile unit by 3–5 %.

Focusing on the oil and gas industry, the development of commercial fiberglass tanks appeared around the 1960s and were quickly used to transport oil and natural gas onshore and offshore, from the wellhead to households and commercial users, at higher pressures compared to civilian applications. (Amani et al., 2017; Ashraf et al., 2017)

Fiberglass surfaces, due to their high purity and smoothness, as well as poor wettability of the walls, are less polluted by the transported goods. The use of polymer materials is described in detail in (Ćwiek et al., 2022; Aktaş et al., 2019).

For the production of such tanks, it is necessary to choose a method of manufacturing fiberglass. The following methods of production of products made of reinforced plastics find the greatest practical application:

- contact molding with the laying of resin-impregnated fibrous canvas on the mold;
- spraying of a fiber-polymer composition on the surface of the mold;
- various methods of forming in a closed form;
- winding of resin-impregnated fiber on the mold;
- forming of profile products by broaching the fiber through a polymer bath and a calibration die.

Depending on the molding technology, the values of the properties of polymer composites may differ several times. The choice of technology depends on the design of the product, its operating conditions, the volume of manufacture and available production resources.

Improper organization of the technological process, unsatisfactory preparation of the initial components, non-compliance with technological modes (pressing pressure, duration and temperature of the process, requirements for the preparation of raw materials and materials) and many other reasons can significantly change the properties of finished products. Therefore, it is very important not only to competently, taking into account the design and operating conditions of products, to build a technological process, but also to strictly observe technological modes during its implementation. To this end, it is necessary at all stages of the process to carry out current control of the technological parameters and properties of the manufactured product.

Materials and research methods

An expedient method of producing a fiberglass boiler is the winding method.

Winding is the process of manufacturing high–strength reinforced products, the shape of which is determined by the rotation of arbitrary generators. In this method, the reinforcing material (thread, tape, harness or fabric) is laid along a given trajectory on a rotating mandrel, which carries the internal geometry of the product. Almost any continuous reinforcing material is suitable for winding. Special mechanisms that move at a speed synchronized with the rotation of the mandrel control the winding angle and the location of the reinforcing material. It can be wrapped around the mandrel in the form of adjacent strips or according to some repeating pattern until the surface of the mandrel is completely covered. Successive layers are applied at the same or at different winding angles until the desired thickness is reached. The winding angle can vary from very small - longitudinal to large – circumferential, i.e. about 90° relative to the mandrel axis, including any spiral angles in this interval. The main materials for the matrix are epoxy and polyester resins and polymers of vinyl esters. Epoxy resins are more often used for winding carbon fiber products, whereas unsaturated polyester resins are used for winding fiberglass products. Polyamide resins are used to produce heat-resistant products.

Winding methods can be classified:

- according to the method of combining the binder and filler;
- according to the reinforcement laying pattern;
- on the device of winding equipment.

According to the method of combination, "dry" and "wet" winding are distinguished. In the "wet" winding method, resin is applied to the reinforcing fibrous material during the winding itself.

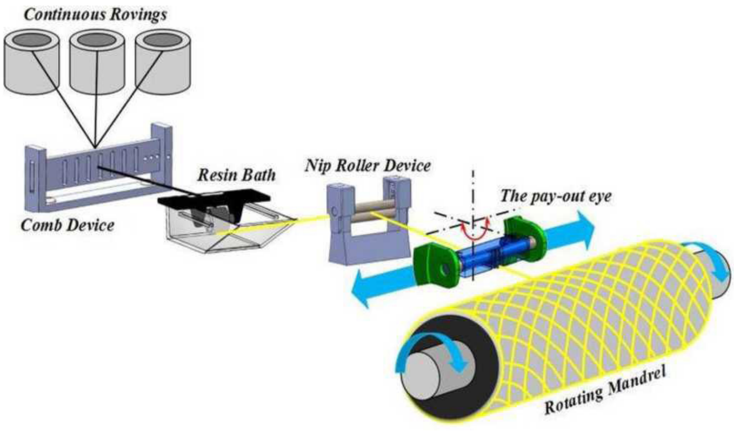

Figure 1 – Process of winding the filament

Filament winding processes can be used for the manufacture of hollow cylindrical composite structures. In the process of winding the thread, stretched continuous bundles of fibers are passed through a resin bath before winding onto a rotating mandrel in various orientations controlled by the fiber feed mechanism. Filament winding is a computer-controlled manufacturing technology that provides a high strength-to-weight ratio and uniformity of composite parts. The process of winding the filament is schematically shown in Fig. 1 (Aktaş et al., 2019).

The equipment for this winding technology consists of the following components: a glass roving feed section; a binder preparation unit: a mixture of polyester resin - a catalyst or another type of binder; a bath with a binder - catalyzed polyester resin or another type of resin through which the roving threads pass and are wetted; a winding section with rotation shafts, the size of which determines the diameter the final product; controls of the winding equipment.

In the case of "wet" winding, a lower tension force is required for the reinforcement, which allows the use of equipment of lower power and mandrels of lower rigidity. "Wet" winding provides better formability of products, therefore it is mainly used in the manufacture of large-sized shells of complex configuration and high-pressure vessels.

"Dry" winding is based on the use of semi-finished products. It ensures a uniform content of the binder specified in the manufacture of semi-finished products, and, consequently, the stability of the strength properties of the products. The coefficient of friction with "dry" winding is almost two times higher than with "wet", which makes it possible to form more complex shapes in this way. When using the "dry" method, the production culture increases and productivity increases. However, with this method, it is necessary to ensure a significant tension of the reinforcement. In, mathematical models and algorithms have been developed to determine the optimal number of simultaneously wound fiber evenness in a given layer. In addition, this study considers the optimal dry winding of the curved parts of the frames.

After the winding is completed, the binder is cured. It is carried out in thermal chambers at an appropriate temperature (for example, in the case of epoxy resins at 395 or 450 K); the curing time is usually 1–2 hours; during the curing process, it is desirable to continue rotating the mandrel. Then the mandrel is removed from the product using a special machine. The final finishing of the product is carried out: stripping, processing of its ends, etc.

Structures wound on the surfaces of rotation can be obtained in the form of smooth cylinders, pipes or tubes with a diameter of several centimeters to several tens of centimeters.

The appearance of the resulting boiler is shown in Figure 2.

Figure 2 – Fiberglass tank boiler obtained by winding

The study (Gari et al., 2022) reflects finite element modeling used to assess stresses and damages of a composite pressure vessel. The sequence of layers, the thickness and the angle of winding of the fiber were considered. The relationship between these variables and the maximum load-bearing capacity of a structure wrapped in composite material to withstand rupture pressure was evaluated

The paper discusses some issues related to the process of obtaining a composite. The study of the influence of the technological process on the properties of the composite, especially in the statistical aspect, is an extremely time-consuming task. Therefore, it is not always possible and even advisable to study the influence of these factors in various types of stress state of the material (Mlýnek et al., 2022).

In accordance with the coordination of rotational motion and axial displacement, three main winding schemes can be obtained. These are flat, spiral and ring windings (Anders et al., 1987) see Fig. 3. The choice of the winding method for the manufactured part is made in accordance with the shape of the part and the orientation of the threads. In cases where the angle of inclination of the fibers is less than 5 ° with respect to the longitudinal axis, the method of flat winding is used. Spiral winding is used when winding fibers that range from 5° to 80° relative to the longitudinal axis. The fibers are wound in the positive and negative directions as an alternative to the mandrel surface. Each completed spiral pattern covering the entire surface of the mandrel leads to the formation of two layers of composite material (Aktaş et al., 2019). Screw windings can be applied through the ends of the part. Ring windings are a different form of spiral windings, and the angle of inclination of the fiber is almost 90 degrees relative to the axis of rotation of the mandrel. As a rule, the winding of the hoop can only be performed on non-circular surfaces, such as cylindrical or flat sections.

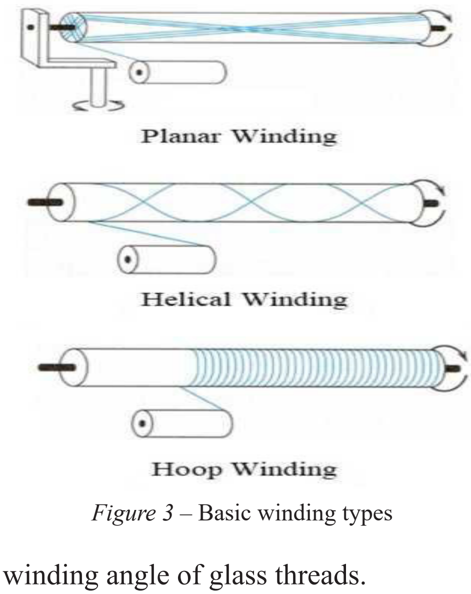

Figure 3 – Basic winding types

Determination of the winding angle of glass threads.

One of the main tasks that arise when creating high-strength shells is to determine the optimal winding angle. Currently, the issue of manufacturing a high-strength cylindrical shell designed to work under uniform internal pressure has been most fully investigated. At the same time, it is believed that the surface of the shell is formed by a grid of absolutely flexible threads that are not interconnected (Gavrilov et al., 2017; Frank Shen, 1995; Sathishkumar et al., 2014; Alves et al., 2022; Voropai, 2017).

There are various conditions for the optimality of reinforcement schemes: equal strength of the threads, minimum deformation, maximum critical load, etc. We will consider the shell optimal, in which the reinforcing elements are directed along the trajectories of the main stresses and are destroyed simultaneously at the calculated load value (Amani et al., 2017; Yu et al., 2017; ISO 14692, 2017). For the analytical recording of this criterion, a cylindrical shell consisting of a large number of layers of glass fiber connected by a binder is considered. It is assumed that the glass tape is laid at an angle (φ to the forming shell (Fig. 4). The angle φ can take different values up to 90°. The shell structure is considered symmetrical, i.e. it is assumed that a layer wound at an angle of $+\varphi_i$,(*i* =1,2, ...*k)* corresponds to a symmetrical layer laid at an angle of - φ_i

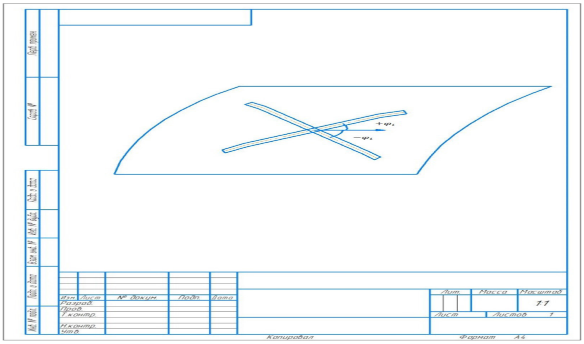

Figure 4 – Layout of reinforcing elements on the shell surface

Let $2n_i$ be the number of layers wound at angles $+\varphi_i$ and $-\varphi_i$; and δ_i;; is the thickness of the elementary layer. The glass tape is characterized by four elastic constants $E_1; E_2; G_{12}; \nu_1$ and (related by the ratio E_1, ν_1), which represent the elastic modulus when the tape is stretched in two directions, the shear modulus and the Poisson's ratio, respectively.

The condition of optimality of the structure of a cylindrical shell loaded with internal pressure and axial force will be written in the form of the following system of algebraic equations

$$\sum_{i=1}^{k} n_i \left[E_1(1+\nu_2)(1-3\cos^2\varphi_i) + E_2(1+\nu_1)(1-3\sin^2\varphi_I)\right] = 0 \qquad (1)$$

Let the construction consist of $2n_1$longitudinal layers and $2n_2$annular layers; if we put φ_1 = 0 and φ_2 = 90° in equality (1), then we get

$$\frac{2n_2}{2n_1} = \frac{2E_1(1+\nu_2) - E_2(1+\nu_1)}{E_1(1+\nu_2) - 2E_2(1+\nu_1)} \qquad (2)$$

From here

$$2n_1 = \frac{n}{3} \cdot \frac{E_1(1+\nu_2) - 2E_2(1+\nu_1)}{E_1(1+\nu_2) - E_2(1+\nu_1)}, \quad (3)$$

$$2n_2 = \frac{n}{3} \cdot \frac{2E_1(1+\nu_2) - 2E_2(1+\nu_1)}{E_1(1+\nu_2) - E_2(1+\nu_1)} \quad (4)$$

where $n = 2(n_1 + n_2)$ is the total number of layers.

When $E_1 = E_2$ and $\nu_1 = \nu_2$, the shell turns out to be isotropic and the concept of optimal structure loses its meaning. It follows from the recorded ratios that the class of structures under consideration cannot be made of a material with an arbitrary ratio of modules E_1 and E_2. Since $n_1 \geq 0$, $n_2 \geq 0$, then in the case of $E_1(1+\nu_2) > E_2(1+\nu_2)$ there is an inequality

$$E_1(1+\nu_2) > 2E_2(1+\nu_1) \quad (5)$$

Let the shell consist of $2n_1$ longitudinal layers and $2n_2$ spiral layers with a winding angle φ, then from the ratio (1) for $\varphi_1 = 0$ and $\varphi_2 = \varphi$, it follows

$$\frac{2n_1}{2n_2} = \frac{E_1(1+\nu_2)(1-3\cos^2\varphi) + E_2(1+\nu_1)(1-3\sin^2\varphi)}{2E_1(1+\nu_2) - E_2(1+\nu_1)}. \quad (6)$$

Hence, if $n = 2(n_1 + n_2)$, it follows that

$$2n_1 = \frac{n}{3\sin^2\varphi} \cdot \frac{E_1(1+\nu_2)(1-3\cos^2\varphi) + E_2(1+\nu_1)(1-3\sin^2\varphi)}{E_1(1+\nu_2) - E_2(1+\nu_1)}; \quad (7)$$

$$2n_2 = \frac{n}{3\sin^2\varphi} \cdot \frac{E_1(1+\nu_2) + E_2(1+\nu_1)}{E_1(1+\nu_2) - E_2(1+\nu_1)}. \quad (8)$$

It follows from the condition $2n_1 > 0$ that the construction in question exists at winding angles determined by the inequality

$$\sin^2\varphi \geq \frac{2E_1(1+\nu_2) + E_2(1+\nu_1)}{3[E_1(1+\nu_2) - E_2(1+\nu_1)]}. \quad (9)$$

Let the shell consist of $2n_1$ spiral layers with a winding angle φ and $2n_2$ annular layers. Let in equation (1) $\varphi_1 = \varphi$ and $\varphi_2 = 90°$; then

$$\frac{2n_1}{2n_2} = \frac{E_1(1+\nu_2)(3\cos^2\varphi - 1) + E_2(1+\nu_1)(3\sin^2\varphi - 1)}{2E_1(1+\nu_2) - 2E_2(1+\nu_1)} \quad (10)$$

or

$$2n_1 = \frac{n}{3\cos^2\varphi} \cdot \frac{E_1(1+\nu_2) + 2E_2(1+\nu_1)}{E_1(1+\nu_2) - E_2(1+\nu_1)}; \quad (11)$$

$$2n_2 = \frac{n}{3\cos^2\varphi} \cdot \frac{E_1(1+\nu_2)(3\cos^2\varphi - 1) + E_2(1+\nu_1)(3\sin^2\varphi - 1)}{E_1(1+\nu_2) - E_2(1+\nu_1)} \quad (12)$$

where is still $n = 2(n_1 + n_2)$.

The condition of existence of the considered construction has the form

$$\sin^2\varphi \le \frac{2E_1(1+\nu_2)-E_2(1+\nu_1)}{3[E_1(1+\nu_2)-E_2(1+\nu_1)]}. \quad (13)$$

Results and discussion

Thus, there are two ranges of winding angle values. One of them corresponds to structures wound in a spiral with longitudinal, and in the other - with annular reinforcement. The angle value φ separating these two ranges of values is optimal for a shell consisting of spiral layers. Indeed, from equality (1) in this case it follows:

$$\sin^2\varphi_0 = \frac{2E_1(1+\nu_2)-E_2(1+\nu_1)}{3[E_1(1+\nu_2)-E_2(1+\nu_1)]} \quad (14)$$

Above, some of the most commonly used winding schemes were considered; using the ratio (1), optimal material structures for other possible reinforcement schemes can be determined, for example, spiral winding with different angles, etc.

To illustrate the obtained dependencies, we can consider as an example a cylindrical shell consisting of spiral $\varphi_i = \varphi$ and annular (φ_2 = 90 °C) layers.

Let $2n_1\delta$ = 0,002 m; $2n_2\delta$ =0,003 m; *h*= 0,005 m: *R* = 0,250 m; E_1 = 4,5·10^{4}MPa; E_2 = 1,5· 10^4 MPa; G_{12} = 0,6 · 10^{4}MPa; $\nu_1 = \nu_2 = 0$.

The optimal winding angle of the spiral layer φ_0, according to condition (1), is 46° 54'.

Conclusions

A cylindrical shell consisting of a large number of layers of glass fiber connected by a binding material is considered.

The relations are determined by which optimal material structures can be calculated for other possible reinforcement schemes of the material, for example, winding in a spiral with different angles.

The condition of optimality of the structure of a cylindrical shell loaded with internal pressure and axial force is determined. With the help of this ratio, the optimal winding angle of the glass is determined, which allows to significantly improve the quality of the resulting product.

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