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PROBLEMS WITH MODELLING THE STRENGTH PROPERTIES OF SAILING VESSELS RIGGING ROPES

This article presents the basic parameters of soft ropes: natural fibre ropes, soft wire ropes and synthetic fibre ropes used for running rigging. There are only several materials still used for the production of natural fibre ropes, including cotton, jute, hemp, sisal and manila hemp. The most commonly used soft wire ropes are twisted pair ropes; for smaller diameters there is a 6x19M – FC rope and for larger diameters – 6x37M – FC. There are several types of materials of varied properties and used in different combinations that are utilised for the production of synthetic fibre ropes. Therefore, the parameters of ropes used for the running rigging of staysails, i.e. halyards, downhauls, sheets and tack lines are discussed. Ultra high molecular weight polyethylene (UHMWPE) called dyneema and spectra, or polyester (PES) called diolen, dacron and trevira are most often used for this type of rigging. The problems with modelling the strength properties of synthetic fibre ropes are related with their complex geometry and structure. Multilayered models and the Continuum model are the basic models determining the strength properties of synthetic fibre ropes.

Keywords: *running rigging, sailing vessel, natural fibre ropes, soft wire ropes, synthetic fibre ropes.*

INTRODUCTION

This article presents the basic parameters of soft ropes: natural fibre ropes, soft wire ropes and synthetic fibre ropes used for running rigging. Soft ropes differ from each other not only in terms of colours and diameters, but most of all – their physical parameters. The aim of these ropes is to transmit the force between two points in order to balance the forces affecting the masts and sails of a vessel. That is why their high breaking strength is the most important criterion for their use. Tensile force should be exerted on soft ropes as little as possible, as it is a variable burden due to the specificity of the rope operation and it causes the rope to extend.

Sailing gear is a set of elements of a sailing vessel equipment that makes it possible to use wind energy for propulsion. Sailing gear consists of masts, sails, rigging and minor gear [21].

Masts (Fig. 1) are used for lifting, spreading and manoeuvring sails. Standing masts are attached to the hull of a sailing vessel using standing rigging that does not change its position during sails manoeuvring. Running masts are elements that ate attached to a standing mast using joints [10].

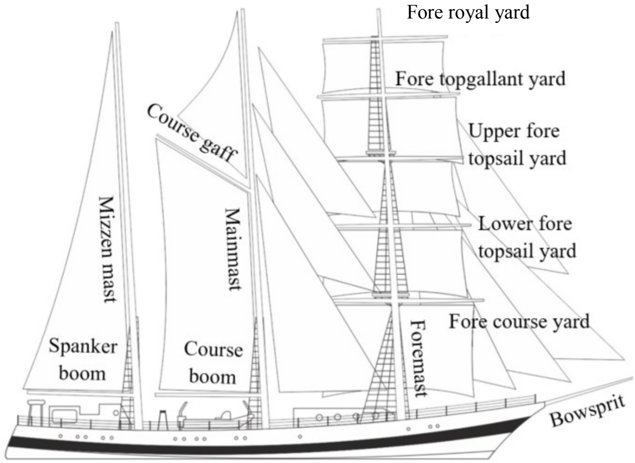

Fig. 1. Masts [29]

Sails (Fig. 2) are made from a sheet of fabric that assumes an aerodynamic shape as a result of the impact of wind, that depends on the cut and the attachment method. In order to generate the maximum aerodynamic force propelling the vessel, the shape of a sail must be set, i.e. its profile and twist, together with the sail trim angle depending on the course, wind force and conditions of interaction with other sails. Main sails, i.e. mast sails, square sails, fore staysails and mast staysails can be differentiated [10].

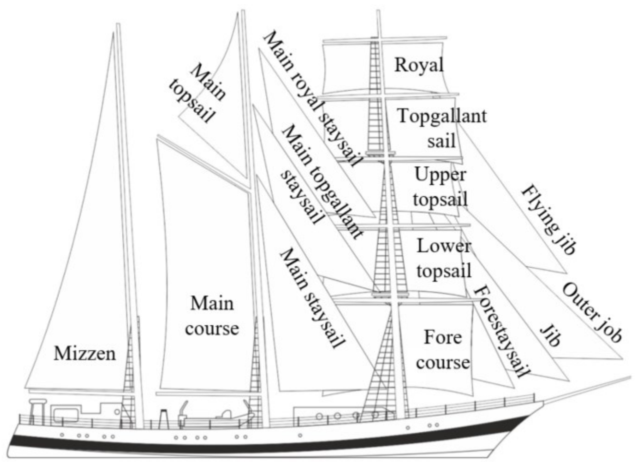

Fig. 2. Sails [29]

Rigging includes rigid elements and tension elements. The rigging of a sailing vessel is divided into standing and running rigging, depending on the functions it performs. Standing rigging ensures the necessary stiffness and strength of masts, combining with them to form a lattice structure. Standing rigging includes, above all, shrouds, stays, jackstays and footropes. Running rigging consists of ropes and blocks used for lifting and lowering the elements of gear and manoeuvring sails, as well as regulating their shape, which is why running rigging is most often used on staysails (Fig. 3). Several types of soft ropes are used with running rigging: natural fibre ropes, soft wire ropes or synthetic fibre ropes [10]. Soft ropes can be divided into: static ropes that are extended only to a minor degree as a result of a load and dynamic that extend to a greater degree as a result of a large load. Only static ropes are used on sailing vessels.

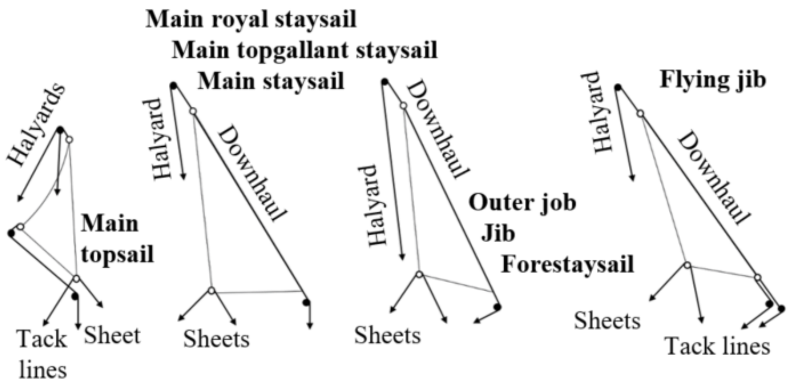

Fig. 3. Running rigging on staysails [29]

Halyards are used for hoisting sails. Downhauls are ropes used for lowering sails. Sheets are used for controlling lower corners of a sail. Tack lines are ropes used for stretching lower corners of sails downwards and towards the bow [21].

Minor gear includes, above all, mobile parts and equipment used for connecting, stretching, hauling masts, sails and rigging, as well as protecting them against chafing, etc. Some of these parts are also used for works that are not directly related with sailing gear [10].

1. NATURAL FIBRE ROPES

From the very beginning of the history of navigation, ropes have been an essential element of sailing vessels equipment. Plant fibres available in a given region of the world or leather and tendons of animals were used for making them. Since the 17th century the development of sea transport related with geographical discoveries has unified the materials used for manufacturing ship ropes and since the beginning of the 20th century there are only several materials still used for the production of natural fibre ropes, including cotton, jute, hemp, sisal and manila hemp.

Natural fibre ropes have varied parameters. Manila hemp ropes are very strong, elastic and relatively resistant to moisture and seawater, however, they sink quickly.

Sisal ropes are strong, elastic, resistant to weather conditions, as well as chemical and organic substances, but they are less resistant to moisture than manila hemp ropes and they swell and become rigid in contact with water. Hemp ropes are not very extensible, they are resistant to friction and weather conditions, however, they swell and become rigid in contact with moisture. Jute ropes are soft to the touch, elastic and do not harden in water, but they are not as strong as hemp ropes. Cotton ropes do not become rigid after absorbing water, they are very elastic and smooth, however, they are also weak and absorb much moisture and water, which results in their swelling and rotting [16, 25, 26].

Ropes made of natural fibres may perform different functions. Manila hemp ropes are made of banana leaves. They are used for mooring lines and anchor lines, their colour is glossy light yellow. Sisal ropes are made of agave fibres and are used for towing and mooring. Their colour is matte white. Hemp ropes are grey, they are used for bolt-ropes, halyards and ropes used for repair works. Jute ropes are widely used in soft rigging, and their colour is matte brown. Cotton ropes are white and are mostly used as sheet ropes [16, 25, 26].

The largest disadvantage of using natural fibre ropes is their low strength (Fig. 4). Manila hemp is the strongest natural fibre and its extension is around 20% [25, 26]. In general, the extension of natural fibre ropes is difficult to assess, since it changes under the impact of moisture.

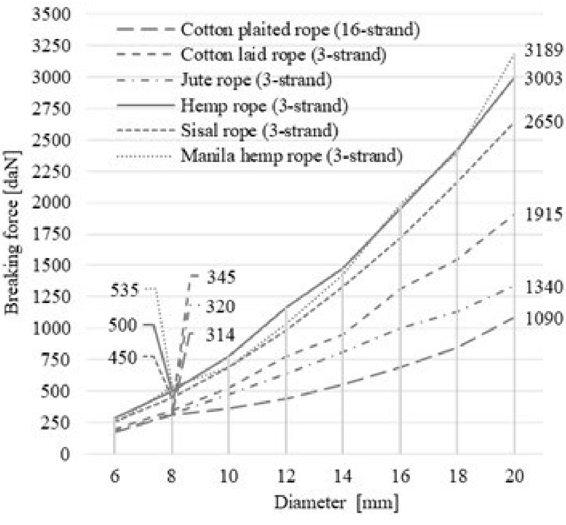

Fig. 4. Comparison of natural fibre ropes strength [25, 26]

The structure of a natural fibre rope has a significant impact on its strength [23]. The value of the breaking force of a laid cotton rope is almost twice as high as the breaking force of a plaited cotton rope for a diameter of 20 mm. Laid ropes (Fig. 5) are most often made using three strands (form A) or four strands (form B).

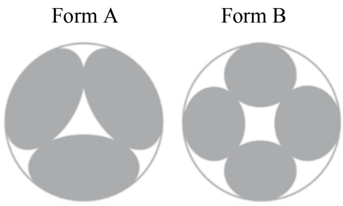

Fig. 5. Laid rope [23]

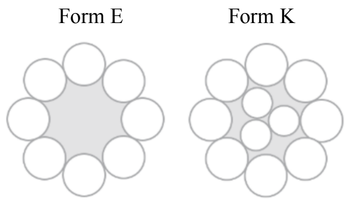

Fig. 6. Plaited rope [23]

The structure of plaited ropes in the case of natural fibre ropes is only used with cotton fibres (Fig. 6). They are made without a core (form E) or with a core (form K). Plaited ropes differ from each other in terms of the number of strands. There are 8-, 16-, 24- and 48-strand ropes. Different forms of plaiting are used [23].

The diameter of a natural fibre rope depends on the form that was used for making it (Fig. 7). The availability of a given rope diameter depends on the manufacturer. The diameter selection depends on the requirements that it must meet.

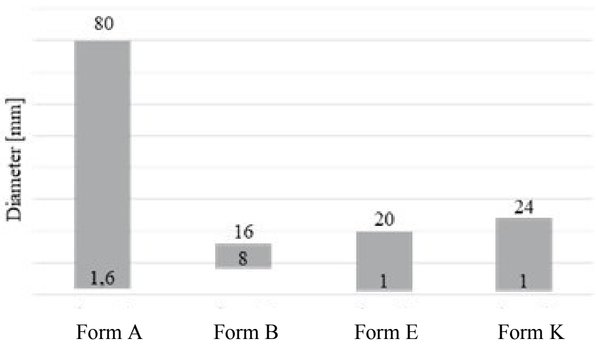

Fig. 7. Ropes diameters [22]

A rope consists of a given number of strands, laid or plaited. A strand consist of fibre, base yarn and twisted yarn (Fig. 8). A single yarn consists of a base and a layer [17].

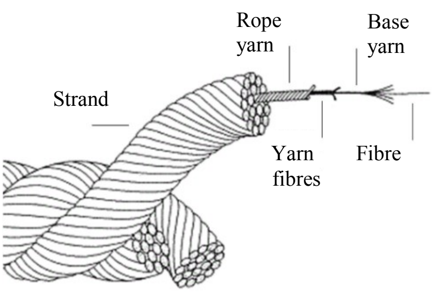

Fig. 8. Strand structure [17]

Natural fibre ropes have been replaced with those made mainly of synthetic fibres or soft wire, however, they are still used for decorative purposes on sailing vessels, despite the fact that their maintenance requires more effort.

2. SOFT WIRE ROPES

Soft wire ropes are used in running rigging only in justified cases. They are mainly used with rollers and a loop or a thimble may be attached to them. They are rarely seen on sailing vessels, mostly because their use requires additional on-board equipment.

Soft wire ropes have a large number of small-diameter wires in the outer layer of the strands, therefore, they are characterised by lower abrasion resistance, while being very elastic. It is assumed that ropes are more elastic with a higher number of strands and rope wires [15, 24].

The most commonly used soft wire ropes are twisted pair ropes; for smaller diameters there is a 6x19M – FC rope and for larger diameters – 6x37M – FC [15]. The surface of this kind of wires either has no coating or is grade B galvanised. A 6x19M – FC rope is a six-strand rope with nineteen wires of the same diameter in each strand, in three layers: one, six, twelve (Fig. 9) [15, 19].

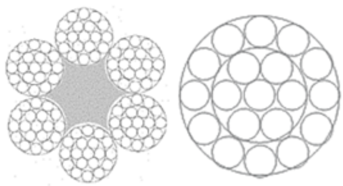

Fig. 9. 6x19M – FC rope [15]

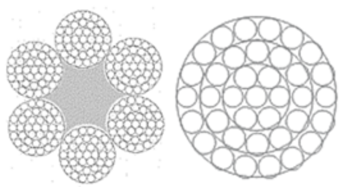

Fig. 10. 6x37M – FC rope [15]

A 6x37M – FC rope is a six-strand rope with thirty-seven wires of the same diameter in each strand, in four layers: one, six, twelve, eighteen (Fig. 10) [15, 19].

FC (Fibre Core) is a core made of natural or synthetic fibre that makes a rope more elastic [13, 19]. A strand consists of a strand wire and a core wire – the central wire of the strand (Fig. 11).

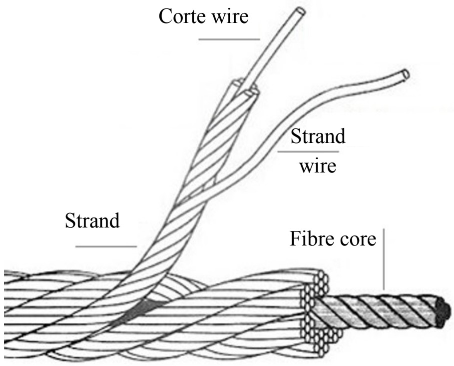

Fig. 11. Soft wire rope [11]

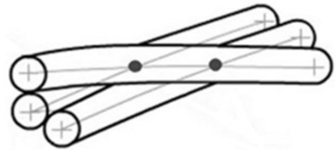

Fig. 12. Rope with cross lay [13]

The M symbol denotes the type of the strand structure, a rope with a point wire contact, i.e. a strand containing more than one layer of wires. All wires in the same strand are of the same length. The wires of overlapping layers of wires cross each other and together make a cross lay. The wires act as beams supported in multiple points (Fig. 12) [15].

Soft wire ropes are laid ropes. There are two basic types of twist: a twisted line rope and a stranded rope. A twisted line rope has two directions of twist: a right-laid (Z strand) or a left-laid (S strand) twist. Stranded ropes have thee directions of twist: ordinary lay, lang lay and alternating. 6x19M – FC and 6x37M – FC ropes are ordinary lay ropes (Fig. 13). The direction of the outer layer wires twist of left-laid ordinary lay ropes (zS) and right-laid ordinary lay ropes (sZ) is opposite to the outer twist of strands in the rope [13, 15, 19, 20].

1x19M (Fig. 14) strands are made in opposite outer and central layer twist directions [20, 27]. 1x37M (Fig. 15) strands are made in opposite outer, central and inner layers twist directions [20, 27].

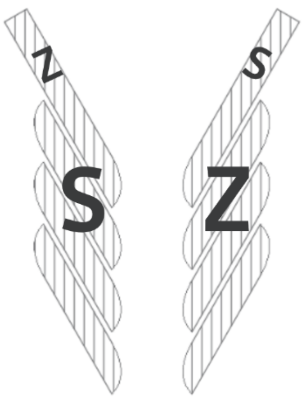

Fig. 13. Laid ropes twist directions [13]

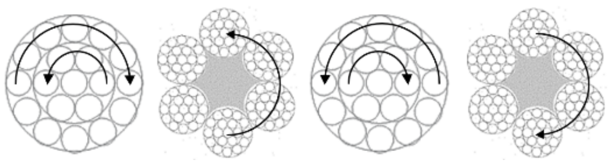

Fig. 14. 1x19M twist direction [15]

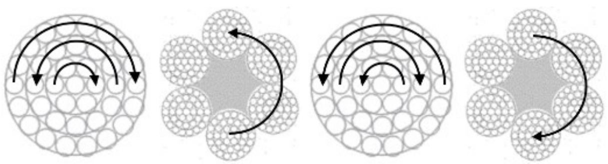

Fig. 15. 1x37M twist direction [15]

Soft wire ropes are made of steel and are protected against corrosion by means of galvanisation. Rope grades may be differentiated, which are groups of ropes with similar mechanical properties and physical characteristics, as well as rope structures, i.e. the particulars and the distribution of the various components of a rope. A rope strength grade, that should determine the rope breaking force, is its most important parameter. The minimum breaking force of soft wire ropes is verified for the strength grades: 1570 N/mm^2 (required tensile strength from 1570 N/mm^2 to 1960 N/mm^2), 1960 N/mm^2 (required tensile strength from 1770 N/mm^2 to 2160 N/mm^2), 2160 N/mm^2 (required tensile strength from 1960 N/mm^2 to 2160 N/mm^2) [18, 19, 20]. The diameter of a soft wire rope depends on the number of strands (Fig. 16) [14].

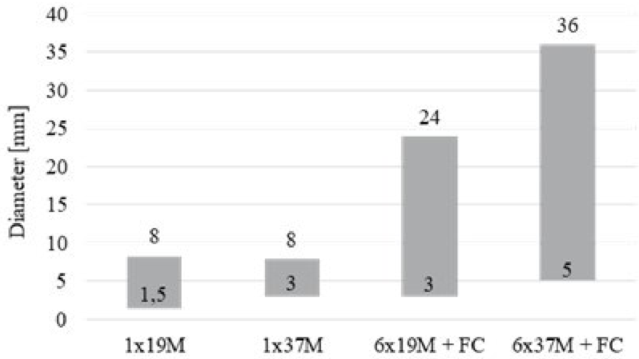

Fig. 16. Ropes diameters [14]

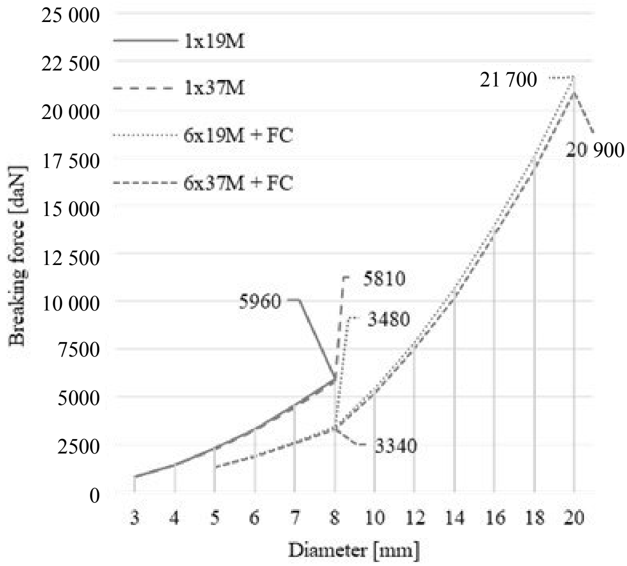

Fig. 17. Comparison of the minimum breaking force of a single strand and an entire rope [15, 24, 27]

Soft wire ropes are much stronger than natural fibre ropes (Fig. 17). The value of the minimum breaking force for the diameter of 8 mm of a single strand is higher than the value of the minimum breaking force for an entire rope of the strength of 1770 N/mm^2 [14, 18].

The following formula is used for determining the extension of soft wire ropes (1) [2]:

$$\text{Elastic Extension} = \frac{W \cdot L}{E \cdot A} \text{ [mm]} \tag{1}$$

where:

- W – category of the applied load [kN],
- L – rope length [mm],
- E – Young's modulus [kN/mm^2],
- A – cross section [mm^2].

The calculations were done for a rope strength grade of 1770 N/mm^2, with a variable strand length and force relevant for the given rope with an 8 mm strand diameter (Fig. 18). A single strand has the extension of 50%, while the extension of the entire rope is 30% [2].

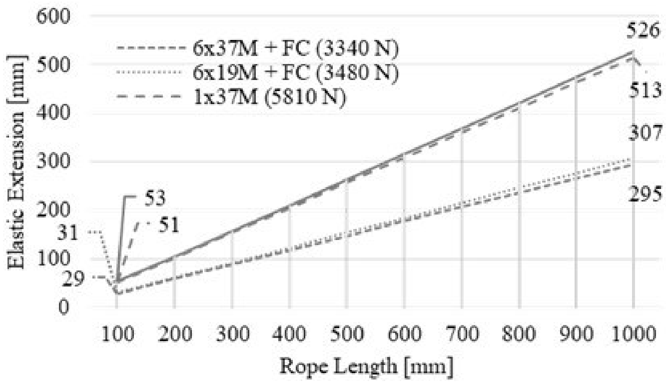

Fig. 18. Elastic Extension [2]

Soft wire ropes, despite being stronger than natural fibre ropes, are not commonly used, because of their greater extension when compared to synthetic fibre ropes.

3. SYNTHETIC FIBRE ROPES

The developing technology of plastics manufacturing in the mid-20th century brought about a revolution in the sailing industry as well. The production of synthetic fibre ropes affected, most of all, the mechanical and the usability properties of ropes.

There are several types of materials of varied properties and used in different combinations that are utilised for the production of synthetic fibre ropes. Therefore, the parameters of ropes used for the running rigging of staysails, i.e. halyards, downhauls, sheets and tack lines are discussed. Ultra high molecular weight polyethylene (UHMWPE) called dyneema and spectra, or polyester (PES) called diolen, dacron and trevira are most often used for this type of rigging. [1, 6, 7, 8, 9].

Polyethylene ropes are characterized by very good gliding properties, low abrasibility, significant vibration damping and very good chemical resistance. What is more, they are very resistant to solar radiation. They are characterised by longevity and resistance to significant loads, as well as resistance to bending. They do not absorb moisture. They float in water. They have low flammability [3, 4, 8].

Polyester ropes are very resistant to weather conditions, as well as to abrasion and friction. They are highly resistant to light and have low water absorption. Caution is advised when dealing with chemical agents, as they may significantly weaken the material (and such changes are often not visible to the naked eye). They do not float in water [3, 5, 8].

Extension after breaking is a percentage ratio of a sample length change at the moment of its breaking to the initial length of the sample (Fig. 19). In practice, the longer the section and the larger the load, the greater the rope extension. Therefore, a rope extension increases the closer it gets to its maximum strength. That is why it is not always worth using minimum diameter ropes. What is more, small diameter ropes are often more difficult to operate. The extension of a polyester rope varies depending on the rope structure and the number of strands [8].

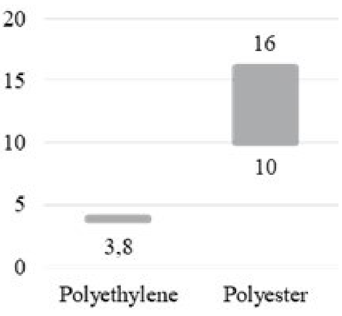

Fig. 19. Extension [%] [8]

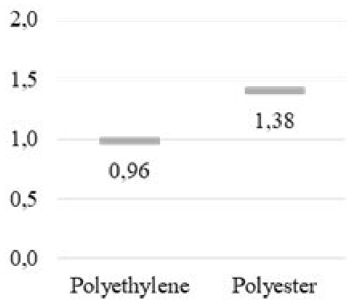

Fig. 20. Specific gravity [g/cm^3] [8]

Specific gravity is the weight per unit volume of an object (Fig. 20). Polyethylene ropes are characterised by a very high ratio of fibres strength to their weight, which is why they are much lighter than polyester ropes [8].

The Young's modulus is the measure of the stiffness of a material (Fig. 21). It defines the relationship between relative linear strain and stress in a material as regards elastic strain. The higher the Young's modulus, the stiffer the rope [6].

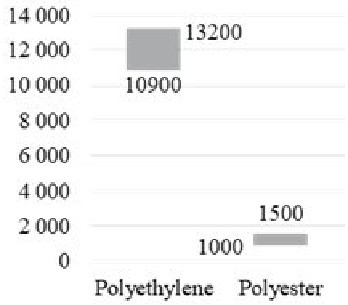

Fig. 21. Young's modulus [daN/mm^2] [6]

Melting point and short-term heat resistance are some of the basic physical properties of synthetic materials (Fig. 22). Melting point is the temperature at which irreversible changes are taking place in a synthetic material. Short-term heat resistance is temperature that does not cause irreversible changes.

Polyethylene has a low melting point and, consequently, proneness to fibre damaging as a result of friction. Ropes are damaged to the greatest degree when they interact with rigging elements. Sailing knots are just as damaging, in particular, rapid bending as a result of them being tied [6].

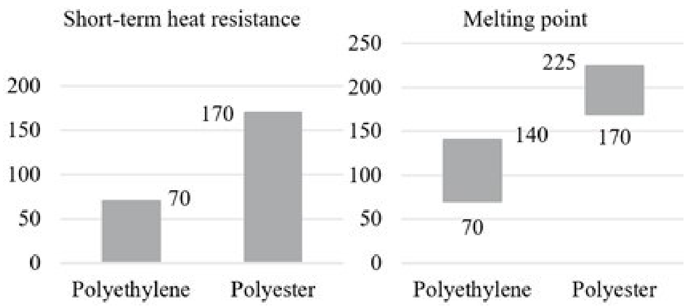

Fig. 22. Permissible temperature [°C] [6]

Lineal density of a thread is the weight per unit of length (weight/10 000 m). Lineal density depends on the diameter of the measured object and its unit is 1/10th of a tex (dtex). The higher the value of lineal density, the thicker the fibre [6].

Tensile strength is expressed in force (daN) affecting the lineal density of a rope (Fig. 23).

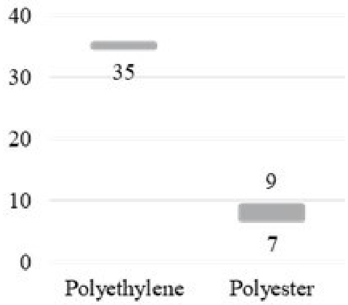

Fig. 23. Tensile strength [daN/dtex] [6]

Polyethylene and polyester ropes differ from each other also in terms of the available diameter ranges (Fig. 24). The available diameters depend on the rope manufacturer [28].

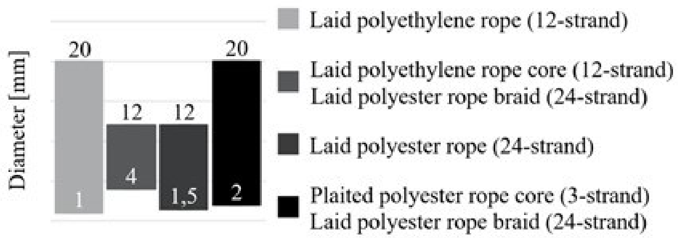

Fig. 24. Diameters [28]

Braided and non-braided ropes are available on the market. A braid protects a rope against weather conditions, high temperature and, consequently, friction, solar radiation and dirt, as well as improves the adherence of the rope in cleats and facilitates the use of the ropes. That is why polyethylene ropes are most commonly used with a polyester braid [28].

The structure and form of a rope has a significant impact on its strength (Fig. 25). Polyethylene ropes are usually 12-strand laid ropes. They are most often used with a 24-strand laid polyester braid.

Polyester ropes are available as 24-strand laid ropes without a core or 3-strand plaited ropes with a core. It all depends, however, on the rope manufacturer [8, 28].

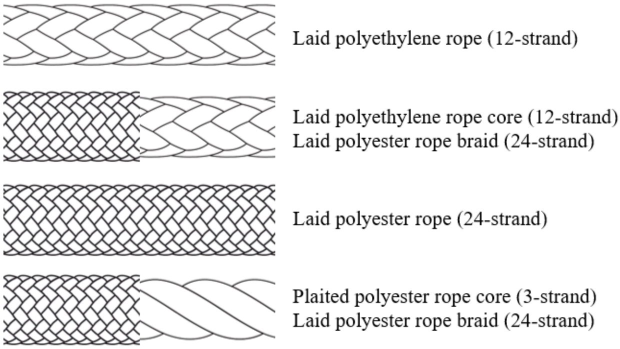

Fig. 25. Structure [8, 28]

Polyethylene is characterized by very high breaking strength (Fig. 26). The strength of a laid rope with a core made of polyethylene (12-strand), with a laid polyester braid (24-strand) significantly decreases when compared to a laid rope made of polyethylene (12-strand). Laid polyester ropes (24-strand) and plaited ropes with a polyester core (3-strand), with a laid polyester braid (24-strand) are much less strong than polyethylene ropes. Polyester ropes have a similar strength [28].

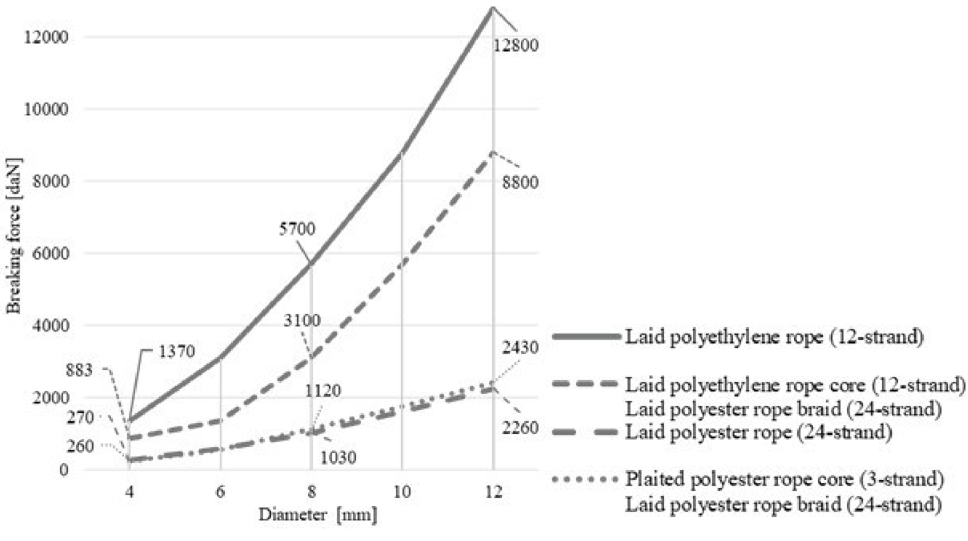

Fig. 26. Comparison of natural synthetic ropes strength [28]

Synthetic fibre ropes are easier to maintain and use, as well as more resistant to moisture and seawater. They must be protected, however, against high temperatures. They may be used for any purpose. They are available in multiple colours which enables their differentiation depending on their function on board. Some types of synthetic fibre ropes are characterized by much greater strength and more limited extension than natural fibre or soft wire ropes.

4. SAILING VESSELS RIGGING ROPES

The aim of sailing vessels rigging ropes is to transmit the force between two points in order to balance the forces affecting the masts and sails of a vessel. That is why their high breaking strength is the most important criterion for their use. Each rope becomes weaker with time. Synthetic fibre ropes are much stronger than natural fibre ropes or soft wire ropes (Fig. 27).

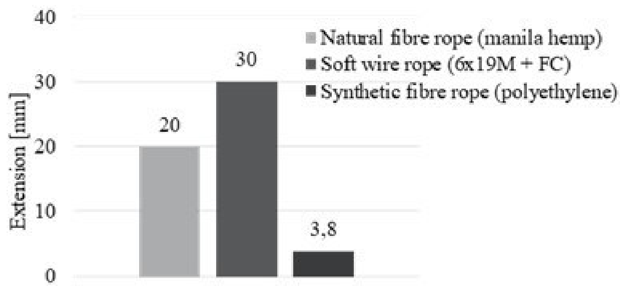

Fig. 27. Ropes strength comparison

Tensile force should be exerted on sailing vessels rigging ropes as little as possible, as it is a variable burden due to the specificity of the rope operation and it causes the rope to extend.

A sail trimmed using blocked ropes should maintain its position with respect to the rest of the rigging also when the wind affecting it drops or increases, which happens even in the case of constant wind due to course changes. The strength of synthetic fibre ropes is much lower than the extension of natural fibre ropes or soft wire ropes (Fig. 28).

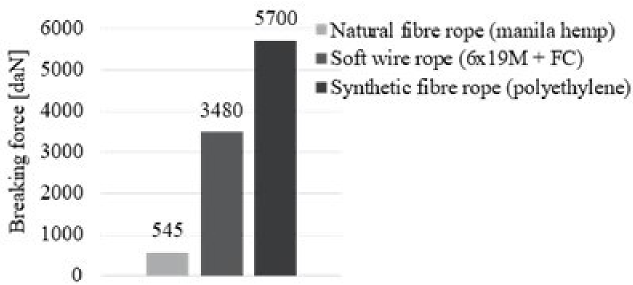

Fig. 28. Ropes extension comparison

5. PROBLEMS WITH ROPES STRENGTH PROPERTIES MODELLING

Synthetic fibre ropes are currently used for the running rigging of sailing vessels. The problems with modelling the strength properties of synthetic fibre ropes are related with their complex geometry and structure.

The geometry of each component is characterized by pitch length P and angle α measured with respect to axis Z of the structure. In such a case the centre line of the component is a spiral curve with radius r (Fig. 29). Pitch length is identical for all components and the radius and twist angle increase from zero to maximum on the outer surface of the structure [12].

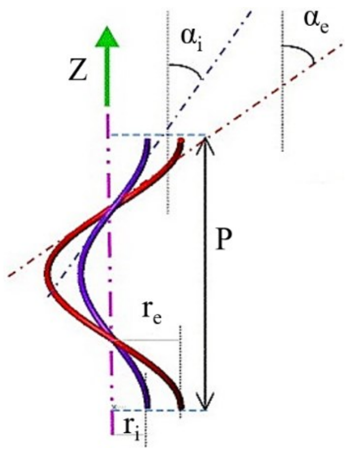

Fig. 29. Component geometry [12]

Cross sections of fibres are elliptical in a plane perpendicular to axis Z [12]. Therefore, angle α_i may be determined for a specific radius r_i (2).

$$\tan\alpha_i = \frac{2\pi r_i}{P} \tag{2}$$

Synthetic fibre ropes are subject to axial loads and the axial behaviour of such structures shows a relation between stress and twist due to the screw-based design of the component [12]. The overall behaviour of the component may then be expressed as (3):

$$\begin{Bmatrix} F_z \\ M_z \end{Bmatrix} = \begin{Bmatrix} k_{\varepsilon\varepsilon} & k_{\varepsilon\theta} \\ k_{\theta\varepsilon} & k_{\theta\theta} \end{Bmatrix} \begin{Bmatrix} u_{z,z} \\ \theta_{z,z} \end{Bmatrix} \tag{3}$$

where:

$u_{z,z}$ – overall axial stress,
$\theta_{z,z}$ – twist angle,
F_z – axial force,
M_z – torque, stiffness matrix components: $k_{\varepsilon\varepsilon}$ (tension), $k_{\theta\theta}$ (twist), $k_{\varepsilon\theta}$ and $k_{\theta\varepsilon}$ (coupling conditions).

Multilayered models and the Continuum model are the basic models determining the strength properties of synthetic fibre ropes [12].

Multilayered models comprise a large number of twisted components. What is more, multilayered models require knowing the rope structural parameters which makes analysis that much more difficult [12].

The Raoof, Hoppe and Leech model is a multilayered model with layered structure geometry. The model comprises components with a round cross section, a core and subsequent layers. Each layer has a spiral structure comprising multiple components with the same pitch length, but a different twist angle. The Raoof, Hoppe and Leech model requires the specification of the following parameters: pitch length, number of layers, components number per layer, component radius, Young's modulus of component [12].

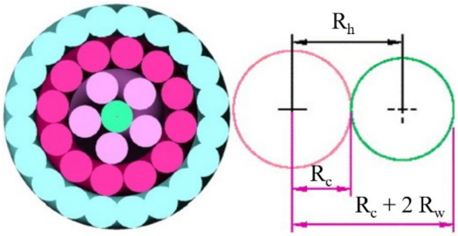

Fig. 30. Raoof, Hoppe and Leech model: R_c – core radius, R_w – radius of a given layer component, R_h – spiral radius [12]

The Leech model (Fig. 31) is a multilayered model with wedge-shaped structure geometry. A packing factor is introduced into each layer in order to account for the presence of empty spaces in a layer. In wedge-shaped geometry the spiral radius is equal to the wedge area centre radius. The Leech model requires the specification of the following parameters: pitch length, number of layers, component number per layer, components radius, component axial stiffness k_c (4), packing factor PF for each layer (5) [30].

$$E_c = k_c / A_c \tag{4}$$

where:

E_c – Young's modulus,
k_c – axial stiffness (component of slope of a strain and force curve),
A_c – component cross section.

$$PF_i = \frac{n_i A_c / \cos\alpha_i}{2\pi r_i W_i} \tag{5}$$

where:

n_i – number of components per layer,
A_C – component cross section,
α_i – a given angle,
r_i – a given radius,
W_i – layer width.

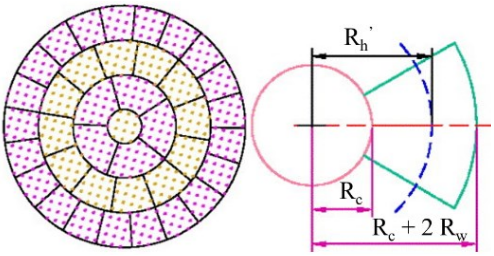

Fig. 31. Leech model: R_c – core radius, R_w – radius of a given layer component, R_h' – spiral radius [12]

The Continuum model was established for the purpose of analysing the overall axial stiffness of a fibrous structure with a large number of twisted components. The Continuum model (Fig. 32) comprises a structure with a central simple core and six spiral components (1+6) [12].

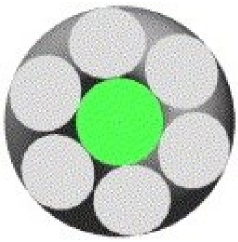

Fig. 32. Continuum model [12]

The Continuum model requires the specification of the following parameters: strand radius, pitch length, Young's modulus of component, global packing factor PF_g (6) [12].

$$PF_g = \left[NA_c \frac{\int_0^{2\pi}\int_0^{r_{eo}} r_0 dr_0 d\theta}{\int_0^{2\pi}\int_0^{r_{eo}} \cos\alpha_0 r_0 dr_0 d\theta} \right] / \left(\pi r_{eo}^2\right) \quad (6)$$

where:

N – total number of the structure components,
A_C – component cross section,
r_{eo} – structure outer diameter,
r_o – radius of any point,
α_o – starting angle,
θ – angle value in a global coordinate system.

The Continuum model is based on a hierarchical structure (Fig. 33). Considering the architecture of a synthetic fibre rope, it comprises two different types of structure: one is a structure with a central simple core and six spiral elements

(1 + 6), while the other is a set of a large number of twisted (multilayered) components. In order to transition from a fibre structure to a rope structure, two subsequent transition models to scale are necessary. The results of a given model at each level may be used as input data for a model at the next level. The use of this approach from the lowest level where mechanical properties are given as input data, to the highest rope level determines the rope properties. On the basis of this strategy, transition models may be used for analysing synthetic fibre ropes with a complex cross section [12].

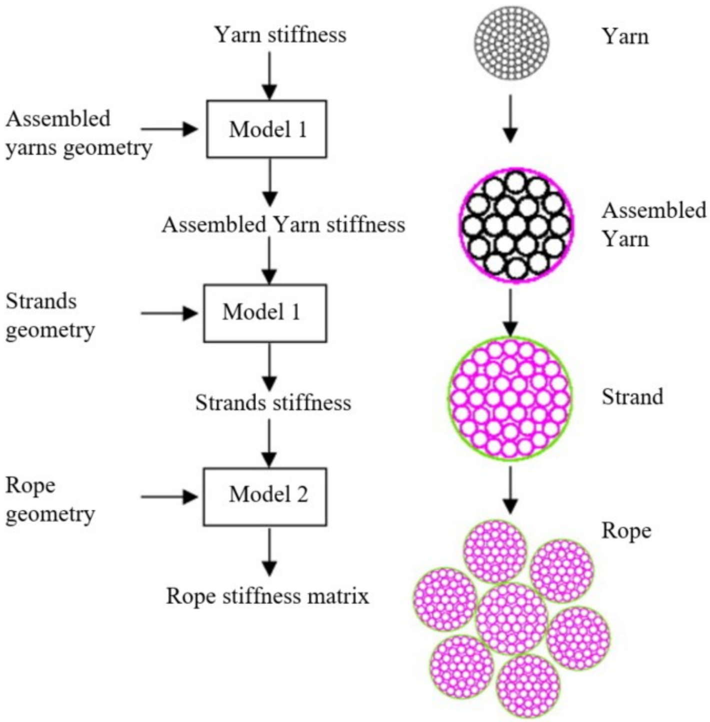

Fig. 33. Hierarchical model: Model 1: for a structure with a large number of components, Model 2: for a 1+6 structure [12]

Contrary to multilayered models, in the Continuum model the analysed structure is shown in the form of a set of coaxial spirals characterized by an outer twist angle and a proper radius. What is more, the model does not require knowing the rope structural parameters. The model accounts for static axial loads, however, it does not account for the effects of friction between fibres. The Continuum model makes it possible to optimise the rope structure [12].

CONCLUSIONS

Some types of synthetic fibre ropes are characterized by much greater strength and much smaller extension than natural fibre or soft wire ropes. Synthetic fibre ropes are currently used for the running rigging of sailing vessels. The problems with modelling the strength properties of synthetic fibre ropes are related with their complex geometry and structure. Multilayered models and the Continuum model are the basic models determining the strength properties of synthetic fibre ropes.

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PROBLEMY MODELOWANIA CECH WYTRZYMAŁOŚCIOWYCH LIN TAKIELUNKU JEDNOSTEK ŻAGLOWYCH

Streszczenie

W niniejszym artykule przedstawiono podstawowe parametry lin miękkich: naturalnych, stalowych miękkich i syntetycznych, wykorzystywanych w olinowaniu ruchomym. Pozostało zaledwie kilka surowców służących do wytwarzania lin z włókien naturalnych, są to m.in.: bawełna, juta, konopie, sizal i manila. Najczęściej stosowanymi linami stalowymi miękkimi są liny dwuzwite, dla średnic mniejszych jest lina typu 6x19M – FC, a dla średnic większych – lina typu 6x37M – FC. Do wytwarzania lin syntetycznych stosuje się kilka rodzajów surowców, charakteryzujących się bardzo zróżnicowanymi właściwościami, dodatkowo występujących w różnych konfiguracjach. W związku z tym przedstawiono parametry lin stosowanych do olinowania ruchomych sztaksli czyli: fałów, kontrafałów, szotów i halsów. Najczęściej do tego typu olinowania wykorzystuje się surowce z polietylenu o ultrawysokiej masie cząsteczkowej (UHMWPE) o nazwie handlowej „dyneema", „spectra" lub poliestru (PES) o nazwie handlowej „diolen", „dacron", „trevira". Problemy modelowania cech wytrzymałościowych lin syntetycznych wiążą się z ich złożoną geometrią oraz strukturą. Modele wielowarstwowe oraz model Continuum stanowią podstawowe modele określające właściwości wytrzymałościowe lin syntetycznych.

Słowa kluczowe: *olinowanie ruchowe, żaglowiec, liny naturalne, liny stalowe miękkie, liny syntetyczne.*