Zeszyty Naukowe SGSP 2021
2021, Nr 79, s. 7–30
ISSN: 0239-5223

DOI: 10.5604/01.3001.0015.2886

CAPT. MICHAŁ CECELSKI, MA
Graduate student of the Main School of Fire Service
e-mail: michal.cecelski@gmail.com
ORCID: 0000-0002-4368-9683

MAJ. BARBARA SZYKUŁA-PIEC, PHD
The Main School of Fire Service
e-mail: bpiec@sgsp.edu.pl
ORCID: 0000-0002-4533-232X

COL. ROBERT PIEC, PHD, ENG.
The Main School of Fire Service
e-mail: rpiec@sgsp.edu.pl
ORCID: 0000-0002-5234-5639

INFLUENCE OF BIOLOGICAL FACTORS ON THE STRENGTH OF STATIC ROPE USED BY FIREFIGHTERS IN RESCUE OPERATIONS

ABSTRACT

After conducting a document review, Authors found no reports concerning the influence of biological factors, such as blood, mould and dirt on the durability of rescue ropes. This study aims to answer the question of whether and how selected biological factors affect static rope 10.5, which is frequently used by firefighters in rescue operations.

In the first stage of the research, focal studies were conducted among fifteen members of the Specialist High-Rescue Group in Plock (Poland), which aimed to determine the state of knowledge about the impact of biological factors on the strength of rope. The results indicated that the group had knowledge as to the impact of physical and chemical factors on the rope; however, a lack of information on the impact of biological factors was identified. In the second stage, the force necessary to break static rope having been (contaminated) with selected biological agents was measured. To achieve this, a 100-m section of a new rope was divided into 63 sections, which were then exposed to impurities. The first endurance measurement was taken after 9 months and thesecond one after 12 months.

Findings: contamination with biological agents has an impact on static rope strength, and knowledge about this impact is negligible and not included in any instructions on the use of rope.

KEYWORDS

altitude rescue, climbing ropes, rope strength, biological factors, firefighters, fire rescue

Received: 10.06.2021; Reviewed: 23.08.2021; Accepted: 01.09.2021

WPŁYW CZYNNIKÓW BIOLOGICZNYCH NA WYTRZYMAŁOŚĆ LINY STATYCZNEJ UŻYWANEJ PRZEZ STRAŻAKÓW W AKCJACH RATOWNICZYCH

ABSTRAKT

Po przeprowadzeniu przeglądu dokumentów autorzy nie znaleźli doniesień dotyczących wpływu czynników biologicznych, takich jak krew, pleśń i brud na trwałość lin ratowniczych. Celem pracy jest odpowiedź na pytanie, czy i jak wybrane czynniki biologiczne wpływają na linę statyczną 10,5, która jest często używana przez strażaków w akcjach ratowniczych.

W pierwszym etapie badań przeprowadzono badania fokusowe wśród piętnastu członków Specjalistycznej Grupy Ratownictwa Wysokościowego w Płocku (Polska), których celem było określenie stanu wiedzy na temat wpływu czynników biologicznych na wytrzymałość liny. Wyniki badań wykazały, że grupa posiada wiedzę na temat wpływu czynników fizycznych i chemicznych na linę, natomiast stwierdzono brak informacji na temat wpływu czynników biologicznych. W drugim etapie dokonano pomiaru siły niezbędnej do zerwania liny statycznej skażonej wybranymi czynnikami biologicznymi. W tym celu 100-metrowy odcinek nowej liny podzielono na 63 odcinki, które następnie poddano działaniu zanieczyszczeń. Pierwszy pomiar wytrzymałości wykonano po 9 miesiącach, a drugi po 12 miesiącach.

Wnioski: skażenie czynnikami biologicznymi ma wpływ na wytrzymałość statyczną liny, a wiedza na temat tego wpływu jest znikoma i nie jest uwzględniana w żadnych instrukcjach użytkowania lin.

SŁOWA KLUCZOWE

ratownictwo wysokościowe, liny wspinaczkowe, wytrzymałość lin, czynniki biologiczne, strażacy, ratownictwo pożarowe

Przyjęty: 10.06.2021; Zrecenzowany: 23.08.2021; Zatwierdzony: 01.09.2021

Abbreviations:

NFPA – National Fire Protection Association
FGI – Focus Group Interview
UV – Ultraviolet
SR1 – static rope stored under normal conditions – first trial
SR2 – static rope stored under normal conditions – second trial
SR3 – static rope stored under normal conditions – third trial
DDR – dirty dry rope
DDR_1 – dirty dry rope stored under normal conditions
DWR – dirty wet rope
DWR_1 – dirty wet rope stored under normal conditions
DWR_2 – dirty wet rope – drought
MR – mouldy rope
MR_1 – mouldy rope stored under normal conditions
BR – bloody rope
BR_1 – bloody rope stored under normal conditions
SR – static rope stored under normal conditions

SR1 – static rope stored under normal conditions – first trial
SR2 – static rope stored under normal conditions – second trial
SR3 – static rope stored under normal conditions – third trial
T1 – first trial
T2 – second trial
T3 – third trial
IFSC – International Federation of Sport Climbing

1. INTRODUCTION

In their review of available documents, including those from the National Fire Protection Association (NFPA) [5,6,7], Authors were unable to find any reports concerning the influence of biological factors such as blood, mould and dirt on the durability of rescue ropes.

The literature only describes the deterioration of the rope strength due to the sun, temperature, water and chemicals [1, 2, 8, 15, 16].

This study, with its initial research, will contribute to knowledge to this area. There is no doubt that all activities related to altitude rescue and fire service units work could not take place if the rescuers did not have the basic equipment, and namely ropes.

The Life Safety Rope Performance Requirements and associated equipment used to support emergency services personnel and civilians during rescue, firefighting or other emergency operations and training can be found in the NFPA 1983 documents. Prior to this, there was no recognised standard for rope rescue and this document helped to standardise many issues in this area. The fire service received a catalogue of helpful information [9]. Climbing ropes are the most important element of the lifeguard's equipment; they provide protection for the lifeguard and they are used to reach the victims, as well as to transport and evacuate them. Altitude activities are also impossible without the use of climbing ropes, and it should be emphasised that no equipment or techniques can replace this basic connector. The ropes must meet numerous requirements regarding strength, length, diameter and other parameters that allow their safe usage during operations. The correct storage of ropes is essential to preserving their durability. It is generally known that ropes should not be stored in direct sunlight or exposed to wet or damp conditions, but kept away from possible contamination by dirt and grid and vehicle exhaust and battery fumes. According to the accepted practice, ropes and webbings shall be stored in a clean, dry, well-ventilated place, away from direct sunlight and heat sources [5]. Ropes shall avoid direct contact with the floor, never be stored on dirt or concrete floors without ventilation underneath nor placed in areas used to store acids or alkalis.

In other words, the documents include information stating that static ropes should always be kept clean and dry; however, there is no risk of non-compliance described in these recommendations.

The instructions concerning storage are clear but do not mention the risk of tainting the ropes with blood, mould, or ordinary biological dirt.

According to specialist literature, materials from which the rope is made can be divided into the following:

- natural fibres,
- steel wire, and
- plastics.

Natural-fibre ropes are no longer used in rescue operations due to their low strength and durability. Steel ropes are mainly used in pulling devices such as a car winch or hand winch mounted on a rescue tripod.

Due to their high resistance to breaking and the possibility of usage in various conditions, ropes made of artificial fibres are currently the most popular ropes used in fire service units.

2. STRUCTURE AND PROPERTIES OF PLASTIC ROPES

Polyamide, polyester and aramid materials of Kevlar [4] are used to make plastic ropes. Ropes of this type outperform ropes made of other materials in terms of strength and durability [3]. Ropes made of plastic have different structures, which include among others the following:

- bolted,
- core-braided, and
- core ropes with strands arranged in parallel.

The most important part of the rope is its core, which is made of approximately 50,000 single and unbroken, properly braided fibres as shown in Fig. 1. They are located in the middle of the rope and transfer all loads that act on the rope. The outer part of the rope is braided. The braid does not carry heavy loads, and its strength has a negligible effect on the strength of the entire rope. It is designed to protect the inner fibres of the core against the adverse effects of mechanical damage and dirt penetration. In summary, the main task of the braid is to stop potentially harmful factors and to protect the core against faster wear of the material due to the slope or clamping devices operating on the rope. Without the protection of the braid, the devices would cause direct destruction of the core.

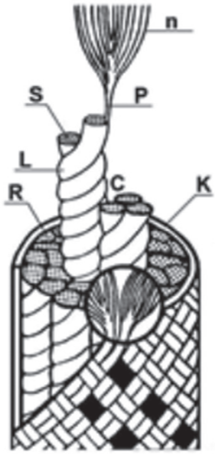

Fig. 1. Structure of a core rope
n – single threads, P – streak of strand, S – strand, L – line, C – central part of the core, R – core, K – plait
Source: [11]

A BUD type A model (name of rope) core rope with parallel laid strands, made of polyamide, with a diameter of 10.5 mm was selected for strength tests. This rope is commonly used by firefighters in Specialist High Altitude Rescue Group in Plock.

Additional information indicated by the manufacturer specifications includes the following:

- 24 kN strength,
- static elongation of 3.1%,
- core sheath representing 36.4% of the total rope,
- weight of 65 g/m, and
- 12 bursts possible.

The rope also has CE 0120 and UIAA certificates [12]. Each rope tested must be marked by the manufacturer as shown in Fig. 2. The markings on the rope determine its purpose and properties. Each rope is assigned with its individual number and production date.

Fig. 2. Marking of the tested rope
Source: own materials

The service life of this type of rope ranges from one to a maximum of 15 years. The storage time for the rope in conditions specified by the manufacturer may be 5 years before the first use, without affecting the future service life. The more often the rope is used, the shorter its service life is. With daily and intensive use, the rope should be withdrawn after a year.

These recommendations provided by the producers are vague because a non-destructive test that measures the amount of residual strength in a rope does not yet exist; however, these recommendations were recognised by the Security Committee of the German Alpine Society in the person of Pit Schubert. The deadline for decommissioning the rope should be set by the rope user who regularly controls its wear and knows the conditions under which it has been used. The decision to use a rope relies on good judgements in three aspects:

- visual,
- tactile, and
- rope log history.

It is difficult to state specifically when a rope should be withdrawn from use. The Standard Guide for Inspection of Nylon, Polyester, or Nylon/Polyester Blend, or Both Kernmantle Rope (ASTM F1740-96) and NFPA 1858 recommend the retirement of any rope that is greater than 10 years old from the date of manufacture, regardless of history and usage. As has already been indicated, a complete inspection of new rope includes both a visual and tactile inspection, which is possible only with experience in working with ropes [13].

These elements relate to human perception and depend on knowledge and experience. The knowledge is useful when it is obtained through scientific method and backed by experts.

3. RESEARCH METHODOLOGY

It is important from the point of view of the safety of rescue operations to identify knowledge that is appropriately focused on the examined issues. For this purpose, in the first stage of the research, focus groups have been established among fifteen members of the Specialist High-Rescue Group in Plock, which aimed to show the state of knowledge concerning the impact of biological factors on the strength of static rope.

The focus group interview (FGI) is a good qualitative research method to obtain a wider picture as addenda of technical tests. The discussion led by a moderator (one member of the research team) in a group of intentionally selected people is an important tool for validating the assumptions of research.

As it has already been discussed, it is especially important for the assessment of ropes to be based on both touch and sight, along with their relations to subjective skills. Knowledge needs to be based on the results of technical tests, because they have a strong impact on the cognitive attitudes of users and therefore, on practical activities.

In the second stage of this research, the force necessary to break a static rope contaminated with selected biological agents was measured. When preparing the ropes for testing, a new 100 m rope was divided into 63 sections. Considering the thickness of the cut using a thermal rope cutter, each section had the length of 155 mm, as shown in Fig. 3.

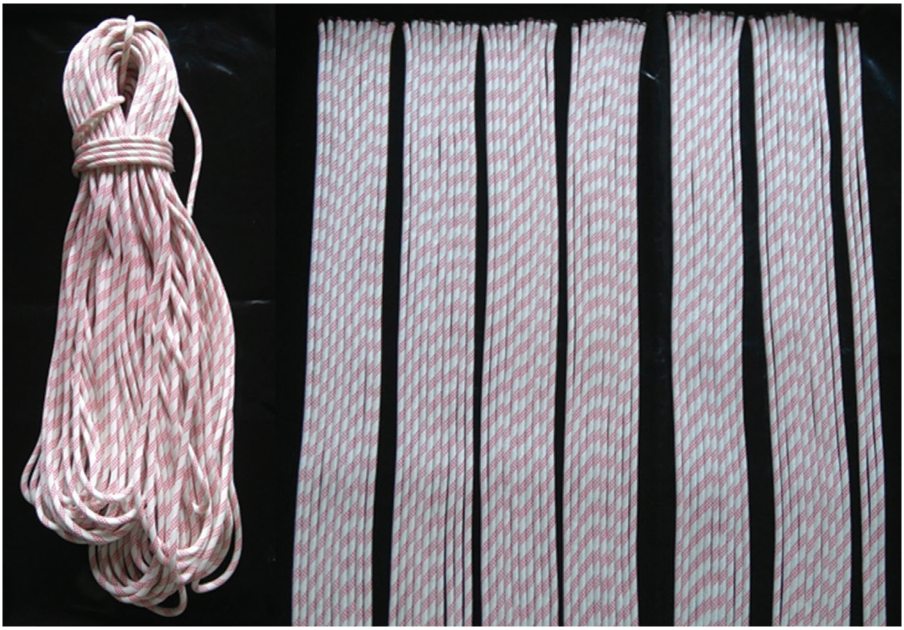

Fig. 3. Edelweiss BUD rope before and after dividing into sections
Source: own materials

The prepared rope sections were placed in containers with selected contaminants. Each sample contained six fragments. Three sections were tested in each measurement. The first endurance measurement was taken after 9 months, the second after 12 months. The ropes were placed in the containers without prior knotting.

The contaminants used for the tests were selected based on observations and popular opinions of users, and were guided by the lack of information as to risks associated with selected contaminants in the instructions provided by the manufacturer. The instructions from each polyamide manufacturer contain hazard guidelines including reasons for their posing a hazard:

- the rope must not be in contact with chemicals, because the chemical compounds destroy polyamide bonds,
- the rope cannot be subjected to high temperatures, because it melts quickly, and
- the rope should not be exposed to excessive UV radiation, because it destroys polyamides [12].

The instructions often include information stating that static ropes should always be clean and dry; however, there is no described risk of non-compliance with these recommendations.

The first contaminant selected was dry soil, which was marked in the tests with the abbreviation DDR (dirty dry rope). Various putrefaction processes occur in the ground, which contains bacteria; this may be perceived as a perfect contribution to the study of biological factors and their effect on rope strength. The soil was placed in a plastic container along with six sections of rope. The container was protected from access of other substances and moisture. The sections remained in the container without interruption until measurements were made.

The next contaminant was moist soil, marked DWR (dirty wet rope). The rope sections were stored in an airtight container with moist soil. Throughout the study, water was regularly added to the sample to accelerate the development of biological agents and to cause their deeper penetration into the rope core. The same type of dirt was also tested under normal conditions. The specimen marked DWR1 (dirty wet rope stored under normal conditions) was soiled with moist soil and then placed in a separate climbing bag. This experiment was intended to examine how heavy dirt affects rope that is not cleaned by the user. In addition, one more factor along with the moist soil contamination was tested. Another rope, contaminated with soil, was allowed to dry at a higher temperature without being cleaned and was stored in this condition. This rope was marked with the abbreviation DWR2 (drought). This was to check whether biological factors affect the properties of the rope in dry soil.

The next contaminant was mould. No information was found as to the effect of mould on rope strength either from the manufacturers or from guidebooks. Only PN-EN 1891: 1998 included a short statement that ropes made of polyamide and polyester are resistant to mould [8]. Rope stored under conditions that allow mould to grow is marked with the abbreviation MR (mouldy rope). To create mould, moist bread was left at room temperature. Twelve rope sections were placed in a large jar to which enough bread was added to cover all the rope sections with mould. A small amount of water was added to the jar, and the lid was tightly closed to cut off the air supply. After a few days, mould growth was visible. Once the mould had covered all the rope sections, six sections were removed and placed, without prior cleaning, into a separate climbing bag. This sample was designated as a mouldy rope stored under normal conditions

(MR1). Also in this case, this was intended to verify extreme conditions that are close to normal. The mould in the jar developed throughout the study. On the other hand, the mould growth on the rope in the climbing bag was almost stopped, although it could still be smelled.

The last contaminant was blood. As with mould, there is no information concerning this type of contamination. The material for this study was obtained from meat processing plants. The blood came from pigs and was unprocessed, without the addition of any other substances. The blood was placed in a jar shown in Fig. 4, along with six rope sections. The blood sample was marked with the abbreviation BR (bloody rope). The jar was tightly closed and placed with the remaining samples. The next six fragments were stained with enough blood for it to seep into the rope core. Next, these sections were placed in a separate climbing bag and stored under normal conditions. The last sample received the designation BR1.

Fig. 4. Examples of DDR, DWR, and BR[1] samples placed in dirt
Source: own materials

All samples were stored in the same place. The samples placed in the climbing bags were at a temperature of approximately 23°C and air humidity of 65%, in a shaded place, free from any undesirable external factors. These

1 Abbreviations: the LBS, LBW, and LZ on Fig. 4 comply with national nomenclature; Authors mean DDR, DWR, and BR, respectively.

were assumed normal conditions as indicated by the rope producers and PN-EN 1891:1998. The rope was not cleaned before being placed into the bag. The objective was to represent a situation in which rope user does not follow the manufacturer's instructions regarding proper cleaning.

On the other hand, samples under the conditions that were supposed to have the strongest negative impact on the rope's strength were at a temperature above 25°C. The elevated temperature was intended to accelerate the development of biological agents. All samples were cleaned of dirt before their measurement to maintain hygiene in the laboratory where the measurements were made.

All ropes were tested on a machine in the mechanics laboratory of the Main School of Fire Service shown in Fig. 5. The testing machine, commonly known as a ripper, is designed for static and dynamic strength measurements of various materials, such as wood, metal, building materials, and plastics. This type of device is able to perform tensile, compression, crushing or twisting tests.

Fig. 5. Ripper in the Laboratory of Mechanics and Strength of Materials in the Main School of Fire Service
Source: own materials

The literature sources only describe weakening. The device uses a CL15 sensor, with a measuring range of 50 kN, accuracy classes: 0.1, force amplifier CL10.

The drum grips specified in NFPA 1983 are used as the standard for rope strength testing; it refers to the Cordage Institute's international standard CI1801. Authors wanted to recreate the actual condition during the rescue operation, so in the test the rope ends were tied in a knot in figure 8, despite the negative effect of knots on the ropes.

The sample being tested was stretched by the descending trolley until the rope was completely broken. The computer showed the current elongation of the sample in mm, measurement time in s, and force in kN. The measurement results were automatically saved in a spreadsheet.

4. FINDINGS

The results of the focal study have shown that firefighters are aware of the dangers associated with chemical substances and high temperatures and know principles of storing and maintaining static ropes. A special group who use these ropes and work mainly with high-altitude rescue operations without being in contact with other activities such as speleology or mountain climbing participated in focus group interviews. The interviewed firefighters were found not to have any knowledge of the influence of the examined biological factors on the ropes, at the same time acknowledged that it is an important topic. Blood is potentially a frequent factor, especially during rescue actions.

The first rope strength measurement was made in February 2018 after the purchase of the rope. Since it came into the possession of the research team, the rope was stored under normal conditions in a climbing bag shown in Fig. 6. The rope supplier has stated that until the sale, the product was stored in accordance with the manufacturer's instructions. A clean rope, free of dirt and stored under appropriate conditions, was marked with the abbreviation SR (static rope).

The first endurance tests were aimed at determining the reference value for the remaining measurements. The octal node, commonly known as the eighth node, was used for the measurements. The results of the first test are presented in Fig. 7 Graph 1. The average rope strength of three samples was 16.715 kN, and the rope strength decreased by a maximum of 32.67% and by an average of 30.5%.

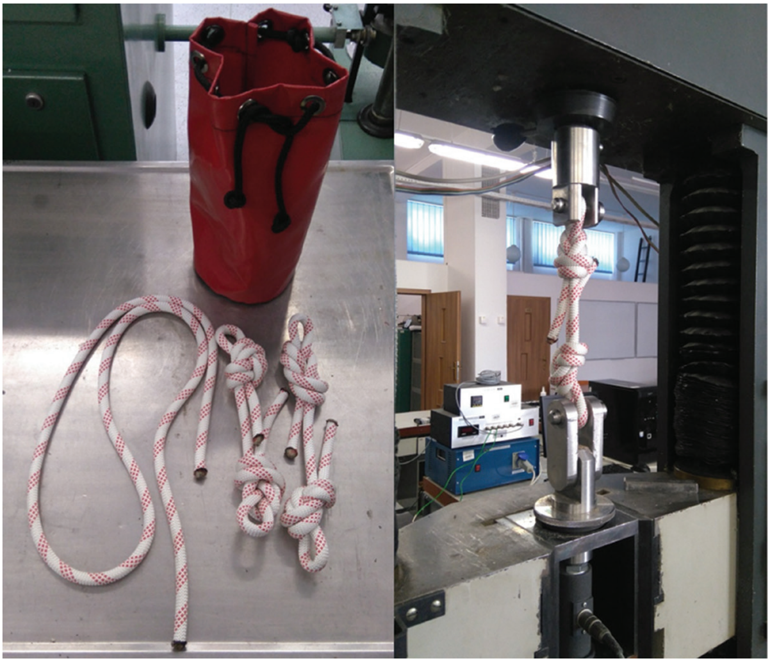

Fig. 6. Photo of the tested rope (SR) before the endurance test
Source: own materials

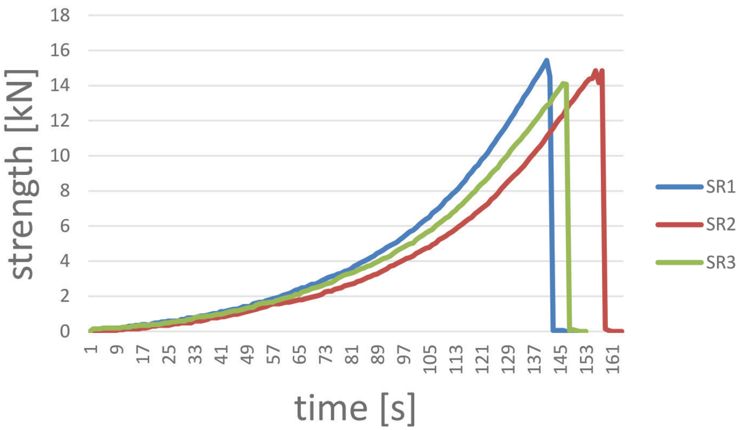

Fig. 7. The first measurement of SR
SR1 – static rope stored under normal conditions – first trial
SR2 – static rope stored under normal conditions – second trial
SR3 – static rope stored under normal conditions – third trial
Source: own materials

After 9 months, further tests were conducted. This time, all the contaminated ropes were tested. The first tested for strength was SR, which was not contaminated with any biological agent. The intention was to determine whether rope stored in the recommended conditions retains its strength properties.

Further tests were performed after another 3 months, i.e. 12 months from the purchase and the beginning of the influence of biological factors on the tested rope. The strength of all samples was tested once again.

5. RESULTS

Of the ten measurements taken on the first date, eight ropes were found to have lost strength after a storage period of nine months.

To evaluate the standard uncertainty, two methods recommended by the Evaluation of measurement data – Guide to the Expression of Uncertainty in Measurement [14] were used: the statistical method (type A), calculated based on three measurements ($n = 3$), and the estimated method (type B), determined based on the accuracy of the measuring instrument.

The type A measurement uncertainty for an individual observation, x, was determined by calculating the experimental standard deviation S using the following formula

$$u_A(x) = \sqrt{S_{\bar{x}}^2} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \qquad \text{Eq 1}$$

The calculation results are presented in Table 1 for each type of rope.

The standard uncertainty of type B was determined based on the measurement accuracy of the device, Δx, using the formula

$$u_B(x) = \frac{\Delta x}{\sqrt{3}} = \sqrt{\frac{(\Delta x)^2}{3}} \qquad \text{Eq 2}$$

The force sensor used has a measuring range up to 50 kN, and the accuracy class is 0.1. The calibration accuracy is

$$\Delta x = \frac{0{,}1 * 50[kN]}{100} = 0{,}05[kN] \qquad \text{Eq 3}$$

The calibration uncertainty is

$$u_B(x) = \frac{\Delta x}{\sqrt{3}} = 0{,}029\ [kN] \qquad \text{Eq 4}$$

Table 1. Measurements, experimental standard deviation and percentage comparison of the average change in strength of tested ropes

Chart number	**Name of the measurement**	**T1 [kN]**	**T2 [kN]**	**T3 [kN]**	**Average measurement result from three samples [kN]**	**Experimental standard deviation**	**SR1**	**SR2**	**SR3**
1	SR1	16.36	16.16	17.63	16.72	0.80			
Research after 9 months									
2	SR2	16.60	14.84	17.38	16.28	1.30	–2.63		
3	DDR	15.43	14.84	14.11	14.79	0.66	–11.5	–9.1	
4	DDR_1	16.16	15.48	15.67	15.77	0.35	–5.65	–3.1	
5	DWR	16.65	16.70	17.14	16.83	0.27	0.68	3.4	
6	DWR_1	16.46	17.33	15.53	16.44	0.90	–1.66	1	
7	DWR_2	16.16	16.80	15.87	16.28	0.47	–2.63	0	
8	MR	13.38	15.23	12.99	13.87	1.20	-17	–15	
9	MR_1	13.38	15.67	15.04	14.70	1.19	–12.1	–9.7	
10	BR	17.33	16.94	17.29	17.19	0.21	2.82	5.6	
11	BR_1	16.70	14.55	16.41	15.89	1.17	–4.97	–2.4	
Research after 12 months									
12	SR3	18.36	18.99	17.87	18.41	0.56	10.13	13.1	
13	DDR	15.72	16.21	16.65	16.19	0.46	–3.12	–0.5	–12
14	DDR_1	16.94	17.48	16.06	16.83	0.71	0.682	3.3	–8.6
15	DWR	14.01	14.60	15.67	14.76	0.84	–11.7	–9.3	–20
16	DWR_1	16.02	17.33	16.50	16.62	0.67	–0.59	2	–9.7
17	DWR_2	15.19	15.87	15.58	15.54	0.34	–7.3	–4.8	–16

cont. Table 1.

Chart number	Name of the measurement	T1 [kN]	T2 [kN]	T3 [kN]	Average measurement result from three samples [kN]	Experimental standard deviation	SR1	SR2	SR3
Research after 12 months									
18	MR	14.50	14.50	14.11	14.37	0.23	–14	–11.7	–22
19	MR_1	14.40	14.21	15.63	14.75	0.77	–11.8	–9.4	–20
20	BR	15.92	14.40	15.16	15.16	0.76	–9.3	–6.85	–18
21	BR_1	15.67	13.96	13.77	14.47	1.05	–13.4	–11.1	–21

Sample names of tested ropes:
DDR – dirty dry rope
DDR1 – dirty dry rope stored under normal conditions
DWR – dirty wet rope
DWR1 – rope dirty wet stored under normal conditions
DWR2 – dirty wet rope – drought
MR – mouldy rope
MR1 – mouldy rope stored under normal conditions
BR – bloody rope
BR1 – bloody rope stored under normal conditions
SR – static rope stored under normal conditions
SR1 – static rope stored under normal conditions – first trial
SR2 – static rope stored under normal conditions – second trial
SR3 – static rope stored under normal conditions – third trial
T1, 2, 3 – first, second, third trial
Source: own study based on research

The largest decrease in strength in relation to the new rope (average of 17% in the first test) was recorded for the rope constantly exposed to mould. A slightly better result was recorded for the mouldy rope stored under normal conditions. The rope was not cleaned, and the mould could continue to develop. A decrease of approximately 12% occurred in both tests. The rope stored in dry soil was weaker by 11.8% as compared to the new standard rope. Even the rope that was not subjected to any dirt experienced a decrease in strength of more than 2.5%. Other ropes showed decreases in strength of several percentage points. The most surprising results were obtained from the moist soil rope samples and the sample remaining constantly covered by blood. Both ropes had a higher strength factor than the standard clean rope. The dirty wet rope was found to be stronger by 0.68%, and the bloody rope was stronger by 2.82%. The second measurement produced completely different results. Ropes that were more durable than the clean rope in the first measurement showed a significantly reduced strength in the second measurement.

6. DISCUSSION

Not all results showed a downtrend in strength. Several ropes were noted to have a clear decrease during the first measurement; however, during the second measurement, a greater strength was observed than in the previous test, sometimes even greater than the strength of a clean rope. These ropes included samples DDR, MR, and MR1. A reduction in strength in the second test can be seen in the case of samples DWR, DWR2, BR, and BR1. If the arithmetic mean of the two measurements is taken as the result of the whole test, the results are as follows. All soiled ropes had an average strength that was less than that of the average static rope stored under conditions recommended by the manufacturer. The soiled ropes showed an average reduced strength of 2% to over 15% as compared to that of a clean rope, and a reduced strength of 27% to 41% as compared to the initial rope strength (24 kN). The ropes contaminated with mould showed the worst results, with an average reduced strength of over 20% from the zero test and approximately 40% from the strength declared by the manufacturer. Surprising results were recorded for the blood-contaminated rope; after 9 months, in the first strength test no reduction in strength was recorded, while after a year, the bloody rope, which was still covered by blood, had a significantly reduced strength. However, it should be noted that despite the weakening of the polyamide fibres, the recorded values were within the ranges of rope weakening described in literature as a result of rope tying, i.e. a reduction in strength by 30–50% [2] or 20–40% [1].

The lowest measurement recorded in the study was below 13 kN. This means that the rope could hold 1300 kg. However, it should be noted that these are static loads. In the case of dynamic loads, e.g. a man falling, much greater forces are applied to the rope, and the break could happen much earlier. In addition, it should be noted that in industrial work at heights, ropes are also used to transport heavy elements.

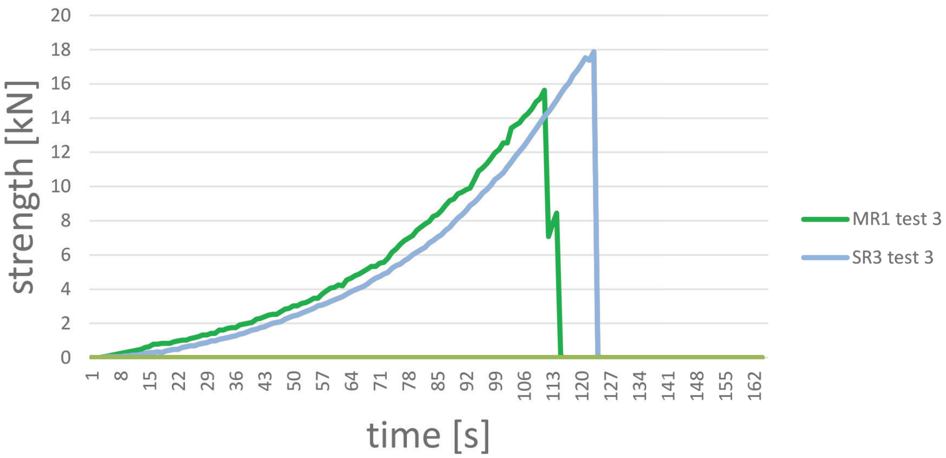

Fig. 8. The disparity in the break point of ropes SR3 and MR after 12 months
SR3 – static rope stored under normal conditions – third trial (after 12 months)
MR1 – mouldy rope stored under normal conditions (after 12 months)
Source: own study based on research

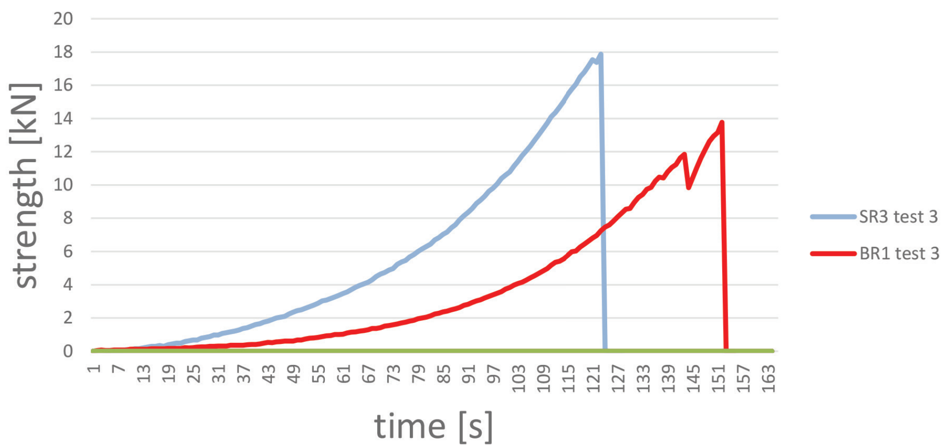

Fig. 9. The disparity in the break point of ropes SR3 and BR after 12 months
SR3 – static rope stored under normal conditions – third trial (after 12 months)
BR1 – bloody rope stored under normal conditions (after 12 months)
Source: own study based on research

Examples demonstrating the strength disparity between ropes stored under normal conditions and ropes with selected biological contaminants have been presented in Fig. 8 and 9.

The first graph (Fig. 8) provides a very clear picture of the faster breakage of rope with mould than that of a clean rope (under static weight). The measurement was carried out after 12 months of absorbing the mould.

The second graph (Fig. 9) shows the breakage of the rope with blood under less static weight than that with the clean rope. The measurement was performed after 12 months of absorbing the blood.

CONCLUSIONS

According to the International Federation of Sport Climbing (IFSC) [10], 25 million people worldwide regularly do mountain climbing. Static ropes used in high altitude works, mountain climbing, speleology and rope parks as well as in high-altitude rescue must have very good strength parameters. Nevertheless, there are many important rules regarding their use, storage, and maintenance that influence the long-term preservation of the output properties of the ropes. In the instructions for use of their product the manufacturers present information on factors that could affect the ropes adversely or situations potentially threatening the lines; these are mainly chemical and thermal factors, while descriptions of the influence of biological factors are lacking.

This work was devoted to testing the static strength of ropes, which are exposed to selected biological contaminants. Two criteria for soil selection were adopted. The first one included the potential biological factors identified in focus studies that may occur during rescue operations involving ropes. The second criterion was the scope of information, or the lack thereof, on hazardous factors for ropes given by the manufacturer. Blood, mould and moisture and wet and dry soil were used for the tests. If a rope becomes contaminated with such factors, the rope owner is left without any information on how to proceed with such a contaminated static rope. Focus studies have shown that users are deprived of the necessary information regarding such contamination and are guided only by conjecture.

The results of the rope strength tests showed that ropes contaminated with biological agents tend to lose their strength. These results are disturbing because the applied biological material affected the rope in a relatively short period of time. As a rule only with very intensive use, the rope is withdrawn from usage after twelve months. Ropes that were contaminated with soil and stored outside a solid biological agent, i.e. under normal conditions, retained the greatest strength. However, the same sections of rope that were stored constantly in soil, both dry and moist, had significantly less strength than those stored in climbing bags. The bloody rope, despite a good result in the first measurements, did not maintain its strength during the second measurement. In this case, the longer blood exposure time significantly reduced the rope's strength. It was found that the rope contaminated with mould was the one that had been most seriously weakened. This is even more dangerous because the PN-EN 1891:1998 standard on static ropes states that mould does not affect polyamide. Consequently, rope users may underestimate the hazards posed by mould.

The implemented studies have shown that soiling with biological agents has a tangible impact on the strength of static rope. The results did not show a significant impairment of rope strength; however, it should be borne in mind that the measured sections were subjected to a static load. Research has shown that providing only brief information in the rope use manual that the rope should be clean and dry is clearly insufficient. The manual should also provide clear information concerning hazards caused by potential biological soiling. These research results indicate that studies should be continued and expanded to determine the effect of biological agents on rope strength.

The researchers did not receive any specific grants from funding agencies in the public, commercial or not-for-profit sectors.

REFERENCES

1. Appelt J., Michalski W., *Materiały szkoleniowe, kurs wspinaczki skalnej*, Warsaw 2009, p. 12.
2. Buchman K., *Wspinaczka linowa. Alpinizm przemysłowy. Materiały instruktażowe*, Ośrodek Doskonalenia Kadr Stowarzyszenia Inżynierów i Techników Mechaników Polskich Wroclaw 2013, p. 5.
3. Gil D., *Specjalistyczny sprzęt pożarniczy*, Szkoła Podoficerska Państwowej Straży Pożarnej, Chapter VII. Sprzęt wysokościowy, 7.2. Liny stosowane w ratownictwie wysokościowym, Bydgoszcz 2007, p. 155.

4. Martin D.A., Obstalecki M., Kurath P., Horn G.P., *An Approach for Quantifying Dynamic Properties and Simulated Deployment Loading of Fire Service Escape Rope Systems*, "Experimental Techniques" 2016, Volume 40, Issue 1, pp. 367–379, https://doi.org/10.1007/s40799-016-0041-9.
5. NFPA 1858: Standard for the selection, care and maintenance of rescue ropes and equipment for emergency services.
6. NFPA 1983 The Life Safety Rope Performance Requirements and associated equipment used to support emergency services personnel and civilians during rescue, firefighting, or other emergency operations and training.
7. NFPA 2500: Standards for Operations and Training for Technical Search and Rescue Incidents and Life Safety Rope and Equipment for Emergency Services.
8. PN-EN 1891:1998 Sprzęt ochrony indywidualnej zapobiegający upadkom z wysokości – Liny rdzeniowe w oplocie o małej rozciągliwości, 5 Metody badań, 5.2. Klimatyzowanie, (2002), p. 24.
9. Rope Rescue Colorado Technical Rescue 3301 South Field Street Lakewood, CO 80227.
10. Saula D., Steinmetzb G., Lehmanna W., Schilling A.F., *Determinants for success in climbing: A systematic review*, "Journal of Exercise Science & Fitness" 2019, Volume 17, Issue 3, pp. 91–100, https://doi.org/10.1016/j.jesf.2019.04.002.
11. Stefan W., *Sprzęt i technika w ratownictwie wysokościowym PSP*, CNBOP, Jozefow 2000, p. 15.
12. The catalogue of products, EDELWEISS Professional Equipment, Static ropes, (2013), p. 5.
13. https://www.cmcpro.com/pro-tip-inspecting-life-safety-rope Accessed 10 January 2020.
14. Evaluation of measurement data – Guide to the expression of uncertainty in measurement, JCGM 100:2008 GUM 1995 with minor corrections, https://ncc.nesdis.noaa.gov/documents/documentation/JCGM_100_2008_E.pdf.
15. Berdeen J. and other, *National Tree Climbing Guide*, United States Department of Agriculture, Electronic Edition 2015.
16. Brown A., *The strength of knots in dynamic climbing rope*, Technical Report, 2007/08, http://personal.strath.ac.uk/andrew.mclaren/alasdair_brown_2008.pdf.

MICHAŁ CECELSKI – ukończył licencjat w Państwowej Wyższej Szkole Zawodowej na Instytucie Nauk Ekonomicznych, kierunek ekonomika i organizacja turystyki (2008–2011). Tytuł magistra uzyskał, kończąc Uniwersytet Warszawski na Wydziale Dziennikarstwa i Nauk Politycznych, kierunek bezpieczeństwo wewnętrzne (2012–2014). Tytuł inżyniera, kończąc Szkołę Główną Służby Pożarniczej (2015–2018). Od 2014 r. służby w Komendzie Miejskiej PSP w Płocku, Jednostka Ratowniczo-Gaśnicza nr 3. Od 2015 r. mł. ratownik wysokościowy w Specjalistycznej Grupy Ratownictwa Wysokościowego „PŁOCK 7".

MICHAŁ CECELSKI – Completed his bachelor's degree at the State Higher Vocational School at the Institute of Economics, majoring in Tourism Economics and Organisation (2008-2011). Master's degree, graduating from the University of Warsaw, Faculty of Journalism and Political Science, majoring in Internal Security (2012–2014). Engineer's degree, graduating from the Main School of Fire Service (2015–2018). Since 2014 he has been serving in the City Command of the PSP in Płock, Rescue and Fire Fighting Unit No. 3. Since 2015 he has been a junior height rescuer in the "PŁOCK 7" Specialist Height Rescue Group.

BARBARA SZYKUŁA-PIEC – absolwentka Uniwersytetu Warszawskiego, Wydziału Filozofii i Socjologii, Instytutu Socjologii. Stopień doktora socjologii uzyskała na Uniwersytecie w Białymstoku. Ukończyła studia podyplomowe z zakresu zarządzania kryzysowego i analizy ryzyka. Jest autorką oraz współautorką wielu artykułów, rozdziałów w monografii m.in. o odporności społecznej, potrzebach, kulturze zaufania. Obecnie pełni funkcję Kierownika Zakładu Edukacji Społecznej w Szkole Głównej Służby Pożarniczej.

BARBARA SZYKUŁA-PIEC – A graduate of the University of Warsaw, Faculty of Philosophy and Sociology, Institute of Sociology. She earned her PhD in sociology from the University of Białystok. She completed postgraduate studies in Crisis Management and Risk Analysis. She is the author and co-author of many articles, chapters in monographs on, among others, social resilience, needs, culture of trust. She is currently Head of the Social Education Department at the Main School of Fire Service.

ROBERT PIEC – doktor nauk technicznych w dyscyplinie inżynieria środowiska. Ukończył również studia podyplomowe zarządzenie w stanach zagrożeń w Szkole Głównej Służby Pożarniczej, studia podyplomowe Bazy danych w Wyższej Szkole Informatyki Stosowanej i Zarządzania oraz studia podyplomowe z seminariami doktoranckimi Analiza ryzyka w Akademii Finansów. Jest autorem lub współautorem wielu artykułów, rozdziałów monografii oraz referatów prezentowanych na konferencjach krajowych i zagranicznych. Obecnie jest Dyrektorem Instytutu Bezpieczeństwa Wewnętrznego Szkoły Głównej Służby Pożarniczej.

ROBERT PIEC – Doctor of Technical Sciences in the discipline of Environmental Engineering. He also completed postgraduate studies in Hazard Management at the Main School of Fire Service, postgraduate studies in Data Bases at the College of Applied Computer Science and Management and postgraduate studies with doctoral seminars at the Academy of Finance in Risk Analysis. He has authored or co-authored numerous articles, monograph chapters and papers presented at national and international conferences. Currently he is the Director of the Institute of Internal Security at the Main School of Fire Service.