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The effects of humidity and temperature on the lanyards performance

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Abstract. The lanyard is a component of personal fall protection systems which is connecting the body holding device at a reliable anchorage point. To ensure user's safety, the lanyard must retain its protective properties during the whole service period. Because of the diversity of working environments that) the lanyards are used in, they tend to be often more affected by risk factors than any other component of the system. This study discusses the most frequent types of risk factors (such as humidity and heat) and their effect on the breaking strength of different types of lanyards. The results of the study show that each additional risk factor significantly decreases the mechanical strength of the lanyards which can lead to the creation of unfavorable conditions in the event of a fall. Conclusions on the main causes of the loss of the protective properties of lanyards are drawn and on the need for evaluation criterion according to which should be decided whether to continue or not the use of the lanyards.

1 Introduction

The activities carried out at height are present in most sectors of activity, whether it is construction, demolition, maintenance or firefighting. Because of the specificity of the activities carried out at height and workstations' configuration, there are situations in which the risk of falling from a height cannot be eliminated by organizational measures or collective protection measures. Therefore the only measure to protect workers is the provision and use of an appropriate personal fall protection system [1].

Even if they are designed to provide protection against a single risk, the components of the system, being made mostly of textile materials, are subject to the action of physical hazards (such as: unfavorable temperature environment, hanging, cutting, abrasion, contact occasionally with flame, radiant heat, hot surfaces, molten metal splashes, hot liquids, etc.) and chemicals [2 -4].

Unlike other components of the system, which can either be integrated into a garment (such as the body support device), or which can be placed at distance (such as anchor points) from the action of other dangerous factors, the lanyards are frequently exposed to the action of existing hazards in the working environment. Exposure to risk factors can

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result in lanyards losing their protective properties, which would directly affect the user's safety.

The objectives of this work consist in the development of testing methods in order to understand the factors that negatively affect the protective properties of the lanyard and which will be the basis for establishing criteria regarding the removal from use.

2 Critical analysis of the existing test methods

Having a very important role in maintaining the health and safety of users and being responsible for ensuring the connection between the body's support device (harnesses) and the anchorage point, the placing on the market of these components is regulated by Regulation (EU) 2016/425. In this regard, only the lanyards that meet the applicable essential health and safety requirements (hereinafter-abbreviated EHSR) may be placed on the market i.e. are recognized to ensure the best compromise between the effectiveness of protection and the degree of use.

As EHSR define the results to be achieved or the hazards to be removed without mentioning the technical solutions to be adopted to achieve this, they can often be found in the harmonized standards [5] or in various technical specifications.

Now, at European level, the harmonized standards that contain technical specifications to ensure traceability between the protection features and the EHSR that the lanyards must meet are:

- EN 354:2010 –contains the requirements to be met by the lanyards used as connecting elements or components in the systems of restraint, positioning at work, rope access, fall arrest and rescue [6];
- EN 358:2018 – includes the requirements to be met by the lanyards used as elements (fastened non-removable to the belt) or components (lanyards with length adjustment device) intended for positioning or limitation during work; [7]
- EN 1891:1998 – includes the requirements that must be met by the lanyards that can be used as components in systems for work positioning, restraint, rope access and rescue [8].

In addition to design, materials, terminations and ergonomic requirements, the lanyards that are made in accordance with one of the above standards shall also meet static and dynamic strength requirements, which aim at its ability to withstand all demands on which can be exposed throughout the entire service life.

Since the static resistance is the characteristic that establishes the relationships between the external forces and the stresses that appear at the level of the elements from which they are made, it will be used in the study. In order to establish a value against which a product subjected to thermal degradation methods can be considered compliant, in the following the existing values in the standards mentioned above will be analyzed, for connection means with processed terminations (see table 1).

Table 1. Static resistance.

Standard	Imposed value, kN	Conditions for determining the static resistance
EN 354:2010	22	Sample storage for at least 24 hours at (23 ± 5) ^{0}C and humidity (65 ± 5) %, followed by immersion in fresh water for at least 1 hour at (23 ± 5) ^{0}C, accompanied by conditioning at least 4 h at a temperature of -4 ^{0}C. Store for at least 24 hours at (23 ± 5) ^{0}C and humidity (65 ± 5) %, then place in a cold room for at least 2 hours at (- 30 ± 2) ^{0}C, if the manufacturer declares that the lanyard can be used at a temperature below -30 ^{0}C [6].

Standard	Imposed value, kN	Conditions for determining the static resistance
EN 358:2018	15	No conditioning [7], [13]
EN 1891:1998	15	Conditioning for at least 24 hours at a humidity of 10%, followed by storage at a temperature of (20 ± 2) ^{0}C and a humidity of (65 ± 5) % for at least 72 h. The tests must be performed at a temperature of (23 ± 5) ^{0}C [8].

By analyzing the conditions for determining the static resistance, it can be seen that at the level of these standards were not analyzed the requirements regarding the maintenance of the protection characteristics under the action of thermal factors (fire, contact heat, radiant heat), risk factors that cannot be absent from workstations where welding procedures or fire-fighting activities are carried out.

Furthermore, the lack of requirements for monitoring the mechanical strength of thermally degraded lanyards lead to both non-compliance with the EHSR on solidity (1.3.2) and EHSR on "PPE exposed to wear"/aging (2.4) [5], as well as to create a false impression on the lifespan of these PPE under real conditions of use.

In view of the above and the fact that the lanyards made in accordance with EN 354:2010 can be used in both prevention and fall arrest systems, the analysis of the results obtained for the degraded lanyards has been evaluated in correlation with the value imposed by this standard, respectively maintaining the force of 22 kN for a period of 3 minutes.

3 Establishment of the degradation method and test protocol

3.1 Degradation method

Degradation methods have been established considering both the fact that most work that is carried out at height takes place outdoors and that the thermal exposure generally occurs during welding or fire-fighting processes, when PPE may occasionally come into contact with flame, with different hot surfaces, or may be exposed to the radiant heat [2], emitted by various incandescent objects. As there are situations in which workers may carry out various intervention work in environments with high humidity or varying temperatures, the selected samples were subjected to a conditioning cycle followed by thermal degradation. The methods used were established to be similar to those from standard's specific to other PPE worn at work together with PPE against falling from a height during welding or firefighting activities.

The degradation methods of the selected lanyards were:

- **Conditioning A**, assimilated method according to 5.3.3/EN 443:2008 [9], i.e., the samples were subjected to the following cycle: 1 h at (-30 ± 2) ^{0}C, followed by 1 h exposure at (60 ± 2) ^{0}C, immersion in water for 15 min at a temperature of (10 ± 2) ^{0}C, 1 h at a temperature of (60 ± 2) ^{0}C, 24 h at a standardized temperature of (20 ± 2) ^{0}C and standardized relative humidity of (65 ± 5) %.
- **Conditioning B**, method specific to the lanyards, according to point 5.2/EN 354: 2010 [6], i.e. the samples were subjected to the following cycle: 24 h at a temperature of (23 ± 5) ^{0}C and a humidity of (65 ± 5) %, followed by immersion in fresh water for at least 1 h at (23 ± 5) ^{0}C, accompanied by conditioning for at least 4 h at a temperature of (-4 + 0/-2) ^{0}C, 24 h at standardized temperature of (20 ± 2) ^{0}C and standardized relative humidity of (65 ± 5) %.
- **Exposure to flame** for 10 s: The method consisted of exposing the samples to the flame of a burner specified in EN ISO 15025:2017 [10] for 10 s. The burner flame was placed

in the horizontal standby position and was set to (25 ± 2) mm, the distance being measured from the burner end to the extreme point of the yellow part of the flame. During the test the burner was positioned perpendicular to the test sample at a distance of (17 ± 1) mm measured between the end of the burner and the surface of the lanyards (see Figure 1).

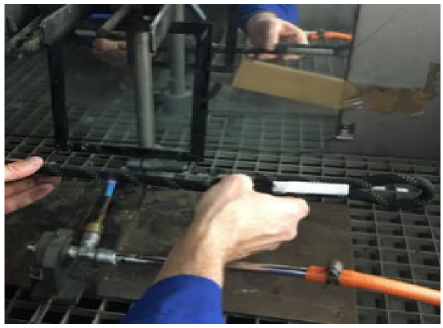


Fig. 1. Flame exposure system.

- **Exposure to contact heat** for 60 s at 300 ^{0}C. The equipment used was as described in section 8.7/EN ISO 20344:2011 [11] (see Figure 2).

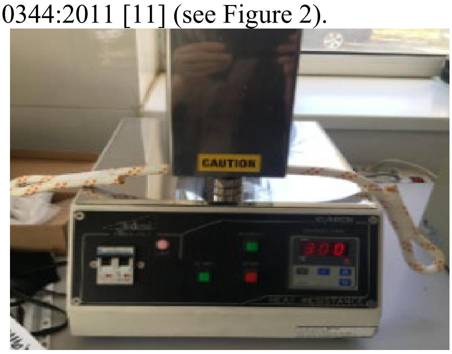


Fig. 2. Apparatus for testing contact heat resistance

- **Exposure to radiant heat** for 18 s at a heat flux of 40 kW/m^2. The equipment used was the one mentioned in EN ISO 6942: 2002 [12] (see Figure 3).

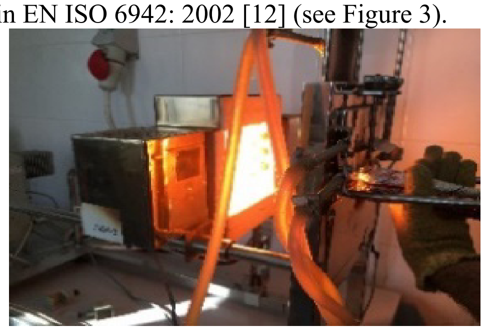


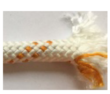
Fig. 3. Apparatus for testing radiant heat resistance

In case of exposure to combinations of conditioning and thermal degradation methods, the samples were conditioned for 24 h at a standardized temperature of (20 ± 2) ^{0}C and to a standardized relative humidity of (65 ± 5) %.

3.2 Test results and analysis

For the study, 8 models of lanyards were used (see Table 2), differentiated by diameter, materials and structure of the mantle and core.

Table 2. Selected samples

Sample code	Photo	Diameter, mm	Material	Structure
1		10	Polyamide (hereinafter-abbreviated PA)	- the mantle has a woven structure of 40 strands taken 2 each (8 khaki, 32 black), - the core consists of 14 twisted strands, each consisting of 3 twisted strands.
2		10.5	PA	- the mantle has a braided structure of 48 strands, taken 2 each (5 black blue threads, 43 blue), - the core consists of 11 strands each consisting of 3 twisted strands.
3		10.5	PA	- the mantle has a braided structure of 64 strands, taken 3 at a time, - the core consists of 11 strands each consisting of 3 twisted strands.
4		10.5	PA	- the mantle has a braided structure of 16 strands, taken 1 each (2 blue threads, 1 red thread, 1 yellow thread, 12 gray threads), - the core consists of 24 strands each consisting of 3 twisted strands.
5		11	PA	- the mantle has a woven structure of 48 strands, taken 2 at a time, - the core consists of 13 strands each consisting of 3 twisted strands.
6		12	PA	- the mantle has a braided structure of 64 strands, taken 4 at a time, - the core consists of 9 strands formed by twisting 3 strands each.
7		12	Polyester (hereinafter-abbreviated PES)	- the mantle has a braided structure of 24 strands, taken 1 each, - the core consists of 3 tubular strands, each formed by weaving 7 strands.
8		12.5	PES/PA	- the mantle has a braided structure of 24 strands, taken 1 each, - the core consists of 4 strands each consisting of 3 twisted strands and is wrapped in an inner mantle consisting of 32 strands taken 4.

A set consisting of the 8 samples of lanyards shown in Table 2 was prepared for each exposure. They were tested at a force of 22 kN for 3 minutes after being successively exposed to one of two conditions A or B, followed by exposure to fire, contact heat, radiant heat and fire, radiant heat and contact heat. Situations where there would be exposure to radiant heat without occasional contact with flame or hot surfaces have not been taken into consideration.

Following the series of tests, it was observed that all lanyards, which were exposed to conditions A and B, regardless of the diameter, structure or nature of the material from which they are made, resisted for 3 minutes when a force of 22 kN was applied.

By performing the series of tests on the sets of samples exposed to conditioning A and B followed only by exposure to flame, as shown in Figures 4 and 5, it was found that regardless of whether the mantle was slightly melted (in the case of samples 1, 2, 3, 4, 5 and 7 exposed to conditioning B) as shown in Figure 4 or a hole with an area of less than approx. 20 mm^2 (in the case of most of the samples exposed to conditioning A) as shown in Figure 5, the connecting means withstood for 3 minutes to the application of a force of 22 kN.

Fig. 4. Samples exposed to B conditioning and flame

Fig. 5. Samples exposed to conditioning A and flame

Regarding the exposure of the sample sets to conditions A and B followed only by exposure to contact heat, it was found that although the mantle of most samples (except samples 6 and 8) was melted in the exposed area (see Figure 6), all lanyards lasts 3 minutes when 22 kN is applied.

Fig. 6. Samples exposed to A conditioning and contact heat

It cannot be said the same about the successive exposure of the lanyards to different thermal risk factors. Tables 3 and 4 show the results recorded on the sample sets exposed to heat shocks A and B followed by successive exposures to radiant heat and contact heat or radiant heat and flame exposure.

Table 3. Static conditioning resistance "A" followed by degradation

Sample code	**Observations after the application of the force of 22 kN**	
	Conditioning A + Exposure to radiant heat + Exposure to contact heat	Conditioning A + Exposure to radiant heat + Exposure to flame
1	it was broken at 18.04 kN	it was broken at 15.48 kN
2	it was broken at 18.80 kN	it was broken at 18.16 kN
3	it was broken at 18.36 kN	it was broken at 15.58 kN
4	it was broken at 19.54 kN	it was broken at 19.52 kN
5	it was broken at 20.27 kN	it was broken at 18.70 kN
6	it lasted for 3 min.	it lasted for 3 min.

7	it was broken at 20.55 kN	it was broken at 19.32 kN
8	it lasted for 3 min.	it lasted for 3 min.

Table 4. Static conditioning resistance "B" followed by degradation

Sample code	Observations after the application of the force of 22 kN	
	Conditioning B + Exposure to radiant heat + Exposure to contact heat	Conditioning B + Exposure to radiant heat + Exposure to flame
1	it was broken at 16.74 kN	it was broken at 15.10 kN
2	it lasted for 3 min.	it lasted for 3 min.
3	it was broken at 19.08 kN	it was broken at 16.36 kN
4	it was broken at 16.54 kN	it was broken at 14.08 kN
5	it was broken at 19.85 kN	it was broken at 18.64 kN
6	it lasted for 3 min.	it lasted for 3 min.
7	it lasted for 3 min.	it lasted for 3 min.
8	it lasted for 3 min.	it lasted for 3 min.

By analyzing the results recorded in Tables 3 and 4 it can be seen that compared to ropes that were initially exposed to conditioning cycle B and then to successive degradations, ropes that were exposed to conditioning A and then degraded were affected in a greater extent under the action of the dangerous factors to which they have been exposed. Due to this fact it can be concluded that successive exposures to large temperature variations (from -30 ^{0}C to 60 ^{0}C) accompanied by immersions in water, specific to conditioning A and frequently encountered in the case of activities carried out at height, cause changes in the structure of the fibers. As these changes cannot be observed in the case of periodic inspections under the synergistic action of some risk factors they can lead to serious accidents.

Moreover, by analyzing the results obtained, it can be said that the static resistance depends both on the diameter of the rope and on the nature of the material from which they are made. Thus, it can be said that the ropes with a diameter greater than or equal to 12 mm have an increased resistance. Ropes made of PA or combinations of PA with PES seem to withstand thermal factors better than those made entirely of PES.

Moreover, the results of the study show that while each of the degraded lanyards could be successfully used in fall prevention systems, when it comes to their use in fall arrest systems it is necessary to pay more attention to both the diameter , as well as the materials from which they are made.

4 Conclusion

Even if the manufacturing technology for ropes has been in a continuous development during last decade, the results of the study shown that while the lanyards exposed to a single thermal risk factor do not influence their structural resistance too much, it was noticed a significant decrease of the safety characteristics when multiple thermal risk factors were applied simultaneously. Because of this, the manufacturers who release on the market new lanyards should follow all the essential health and safety requirements enforced according to Regulations (UE) 2016/425, including the requirements (1.3.2 and 2.4) that represent the resistance of environmental factors when they are foreseeable.

Considering everything mentioned above and the lack of specific methods of thermal degradation for these products, it is necessary to consider the elaboration of a document that contains:

- common points of static resistance according to existing standards,
- description of the methods used for degradation,
- an evaluation criterion against which should decide whether to continue or not the use of the individual equipment for protection.

In the future, the plan is to track the simulation grade and the reproducibility of thermal degradation methods by correlating the results obtained with the ones that were captured on lanyards that were exposed to the action of environmental factors in the foreseeable conditions of use.

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References

1. Standard EN **363** (2008)
2. G. Song, S. Mandal, R. Rossi, *Thermal Protective Clothing for Firefighters (*ELSEVIER*,* Iowa, 2016)
3. Standard OHSAS **18002** (2009)
4. J. M. Willi, G. P. Horn, Fire Tech **52***,* 1667-1696 (2016)
5. Regulation (EU) **2016/425** (2016)
6. Standard EN **354** (2010)
7. Standard EN **358** (2018)
8. Standard EN **1891**(1998)
9. Standard EN **443** (2008)
10. Standard EN ISO **15025** (2017)
11. Standard EN ISO **20344** (2011)
12. Standard EN ISO **6942** (2002)
13. D. A. Prostakishin, K. V. Zherdev, R. S. Gadzhiev, A. Ya. Barvina, Innov Tech Constr *BUILDINTECH BIT 2021* **1926,** 012044, (2021)