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The Effect of the Use of Full Body Harnesses on Their Protective Properties

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A full body harness is a component of personal systems protecting against falls from a height. To ensure users' safety, the harness must retain its protective properties during its whole service period. All the elements of a harness (webbings, threads, metal buckles, etc.) are exposed to destructive factors. Harnesses stored and used for a few years were tested. The paper discusses the most frequent types of damage and their effect on the essential resistance parameters. The effect of atmospheric conditions, sunlight, mechanical damage and dust on the parameters of webbings was tested. Conclusions on the main causes of the loss of the protective properties of harnesses are drawn; periodic checks of the physical conditions and guidelines for estimating acceptable service time are recommended.

personal protective equipment against falls from a height   full body harnesses
natural and artificial ageing   destructive factors

1. INTRODUCTION

A full body harness (FBH) designed in accordance with EN 361:2002 [1] and described by Arteau and Giguere [2] is an essential component of personal protective systems protecting against falls from a height, used at worksites in various sectors of industry. Its most important tasks are

- to connect the user working at a height with anchor points of the worksite;
- to arrest the user's fall from a height;
- to alleviate the effect of a fall arrest by distributing the dynamic forces acting on the user's body to the right body regions;
- to ensure the user's body is in a correct position during the fall arrest;
- to ensure the user is safe and comfortable when waiting for help.

Thus, in critical situations an FBH is crucial for human health and life. To be effective, it must maintain its protective properties throughout its service life.

An FBH consists of webbing; sewing threads; buckles, attachment and adjustment elements made of metal; and accessory elements made of plastic, e.g., belt loops. All these elements are exposed to destructive factors present in the working environment, i.e., atmospheric conditions, sunlight, mechanical and chemical factors. Exposure to these factors can result in harnesses losing their protective properties, which would directly affect the users' safety.

Correct estimation of the service life of an FHB relies on understanding the phenomena that negatively affect protective properties and on making informed decisions during periodic checks on whether they should be withdrawn from service. This paper discusses the problem by presenting research on personal equipment protecting against falls from a height carried out in the Central Institute for Labour Protection – National Research Institute (CIOP-PIB) [3] and UK's Health & Safety Laboratory (HSL) [4].

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TABLE 1. Construction of the Tested Full Body Harnesses (FBH)

	Fall Arrest Attachment						Location of Adjustment Element		
FBH	Front	Back	Other Attachments	Belt for Work Positioning	Seat Strap	Chest Strap	Shoulder Strap	Thigh Strap	Other Elements
A	✓	✓			✓	✓	✓	✓	
B	✓	✓		✓	✓	✓	✓	✓	
C	✓	✓		✓	✓	✓	✓	✓	short lanyard connected with back attachment element
D	✓	✓		✓	✓	✓	✓	✓	shoulder straps made of elastic webbing short lanyard connected with back attachment element
E	✓	✓		✓	✓		✓	✓	short lanyard connected with back attachment element
F		✓	for lifting		✓	✓	✓	✓	
G	✓	✓			✓	✓	✓	✓	
H		✓		✓				✓	short lanyard connected with back attachment element
I	✓	✓		✓	✓		✓	✓	

2. THE USE OF FBH AND ITS PHYSICAL CONDITION

To assess the process of aging of FBHs, researchers from CIOP-PIB analyzed the physical condition of equipment withdrawn from service. It had been withdrawn because the service life recommended by the manufacturer had expired or due to potentially dangerous damage. Table 1 compares the 90 FBHs that were studied (nine types from three largest manufacturers in Poland).

The FBHs had been produced in 1995–2001 and used in 15 companies of various sectors, mainly in construction, power engineering and telecommunication. The harnesses withdrawn from service were inspected for the presence of any changes resulting from their use. Table 2 lists the most common cases of damage and the percentage of all inspected FBHs they were present in, whereas Figure 1 illustrates examples of damage.

TABLE 2. Damage Sustained by Full Body Harnesses (FBHs)

Damage	FBHs (%)
Faded webbing	92
Damaged edges of webbing[1]	20
Damaged surface of webbing[2]	10
Damaged seams connecting webbing	5
Corroded metal elements	3
Dirt ingress (dust)	95
Dirt ingress (paint)	10

Notes. 1—mainly cuts and friction-related defects, 2—mainly friction-related defects where webbing touches metal elements.

Resistance to static load [1, 5] was measured to check how those changes affected the parameters of the mechanical strength of FBHs that had previously been inspected visually. Harnesses were tested on a torso dummy [5]. They were loaded with a static force whose value depended on the direction of its action: (a) 15 kN for the force applied between the lower suspension eye of the dummy and the attachment element of the harness; or (b) 10 kN for the force applied between the upper suspension eye of the dummy and the attachment element of the harness.

Damage sustained by FBHs was studied both during a slow increase in the value of the loading force and during its maintenance phase. A release of the torso dummy meant the test result was negative. Table 3 lists test results and types of damage. Figure 2 presents examples of the effect of load acting on FBHs under static conditions.

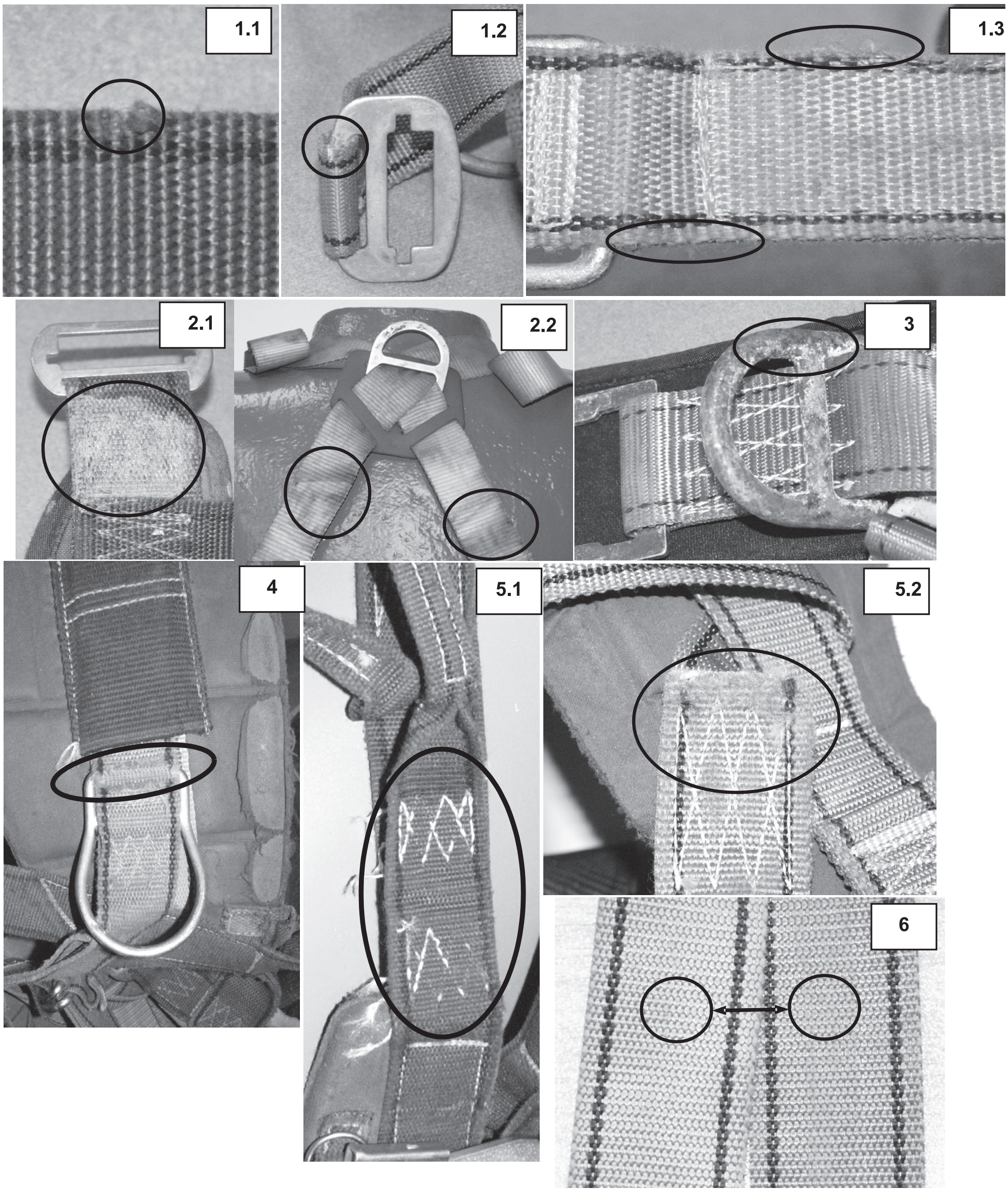

Figure 1. Examples of damage sustained by full body harnesses withdrawn from service. *Notes.* 1.1, 1.2, 1.3—cuts and friction-related defects of the edges of webbing; 2.1—dirt ingress (paint); 2.2—dirt ingress (dust); 3—corrosion of metal elements; 4—friction-related defects of the surface of webbing; 5.1, 5.2—damage of the seams; 6—faded webbing.

TABLE 3. Damage Sustained by Full Body Harnesses Loaded in Static Conditions

Damage	Cases (%)
Seams connecting segments of the webbing break; torso dummy released	10
Attachment or adjustment elements cut webbing; torso dummy released	7
Attachment or adjustment elements break; torso dummy released	4
Seams connecting segments of the webbing partially break; torso dummy not released	30
Other damaged elements (back support for work positioning, secondary straps, etc.)	25

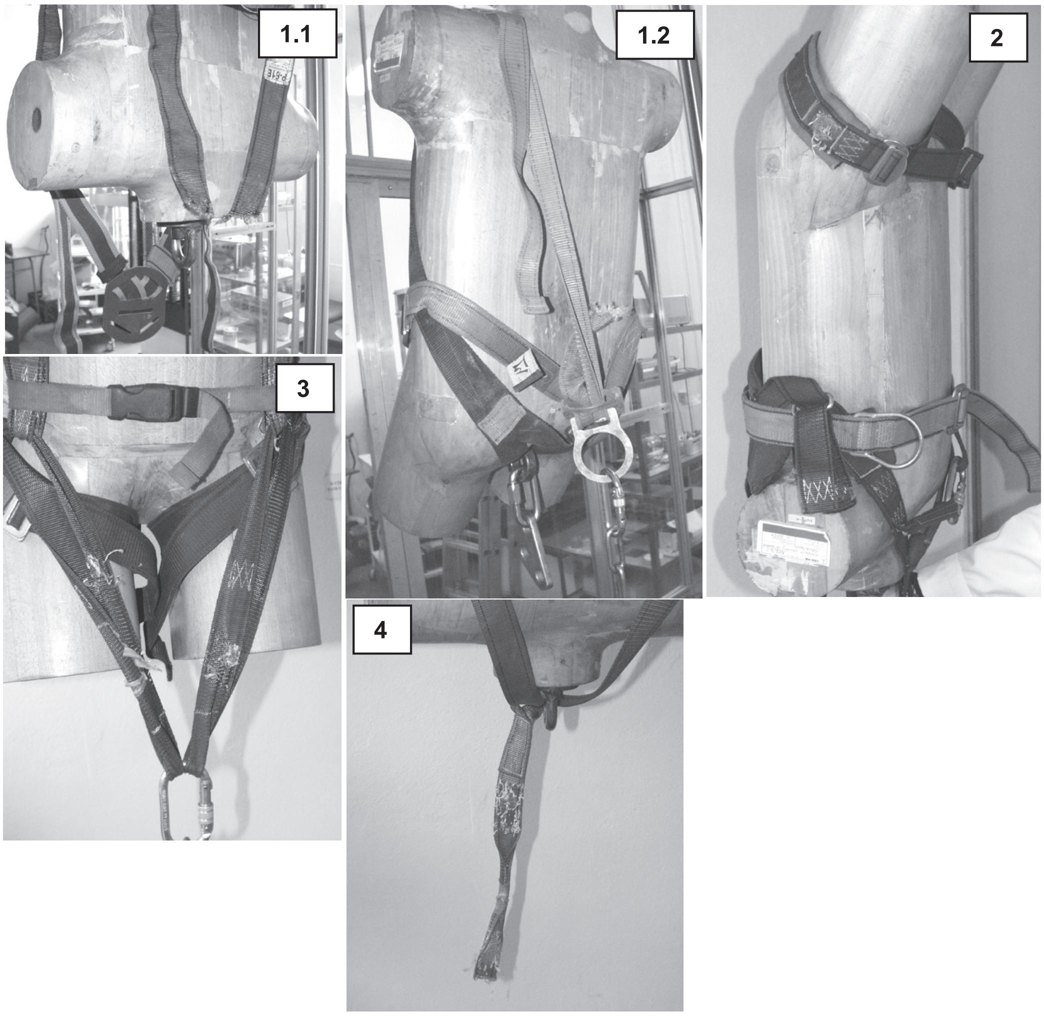

Figure 2. Examples of damage sustained by full body harnesses: results of static strength tests. *Notes.* 1.1, 1.2—broken shoulder straps next to back fall arrest attachment element; 2—torn seam of the thigh strap; 3—damage sustained by the seams of front attachment loops; 4—broken seams of flexible connector.

The following observations were made:

- The torso dummy was released most frequently when the oldest harnesses were used and those regarded as the most damaged during subjective visual inspection of their physical condition.
- Similar types of damage (in the same construction points) were found in harnesses of the same type, used in the same industry for the same time. This means each harness design has construction points especially sensitive to aging.
- Dummies were most frequently released because
  - seams connecting segments of the webbing broke;
  - attachment elements, adjustment elements or buckles cut the webbing.

The tests demonstrated that some FHBs lost their protective properties during their use to the extent that they did not comply any more with the requirements of Standard No. EN 361:2002 [1].

3. THE USE OF FBH AND THE STRENGTH OF WEBBING

For a more comprehensive assessment of the physical condition of FBHs withdrawn from service, the strength of their webbing was tested. They involved collection of webbing segments from the shoulder straps. The webbing samples

TABLE 4. Results of Strength Tests of Webbing From Full Body Harnesses (FBHs) Withdrawn From Service

FBH (Year*)	Extent of Damage	F_{MZ} (kN)	$\bar{F}_{MZ0}$(kN)
A (1999)	2	22.1, 21.8, 21.5	25.1
	3	18.2, 20.7, 20.1, 12.3, 12.8, 11.9	
B (2000)	3	7.6, 11.1, 7.5, 7.0, 7.1	22.0
C (2000)	3	17.6, 21.5, 18.6, 17.6, 19.4	24.9
D (1995)	1	26.6, 25.4, 24.3	27.6
	2	24.8, 23.9, 23.4	
D (1996)	1	25.8, 25.7, 24.2	
	2	24.5, 25.1, 23.9	
D (1998)	2	22.1, 21.2, 21.4	
D (2000)	2	20.5, 21.3, 22.0	
	3	18.9, 19.3, 19.0	
E (2000)	3	16.9, 18.5, 19.5	23.3
F (2000)	3	19.3, 18.8, 17.9	23.4

Notes. A, B, C, D, E, F—see Table 1; *—year when FBH was manufactured; 1—no friction-related wear or cuts, no stains, 2—intermediate physical condition, 3—damaged edges and surface, heavy stains; F_{MZ}—maximum value of tensile force before a break; $\bar{F}_{MZ0}$—mean value of tensile force for new webbing.

had the right length to be placed in the holder jaws of a Zwick ZS-100 (Germany) universal testing machine and there were no seams which could affect their strength. The prepared samples of six types of webbing came from the same group of harnesses which was described in the previous section.

Segments of webbing were cut from FHBs. The harnesses were classified into three categories on the basis of a subjective visual assessment of the extent of damage. Table 4 presents information on the maximum value of tensile force before a break F_{MZ}. These values are compared with the mean values of the force $\bar{F}_{MZ}$ for new webbing produced in respective years. These data were obtained from the manufacturers of FBHs. The following conclusions can be drawn from a comparison of those values with the results of tests:

- in all cases of textile webbing, a few years of use led to a significant decrease in mechanical strength. For B webbing (see Table 4), $\bar{F}_{MZ}$ decreased by 62.7%;
- more significant decrease in $\bar{F}_{MZ}$ correlated with more significant damage assessed visually;
- there was no significant correlation between a decrease in $\bar{F}_{MZ}$ and the year when webbing was produced.

4. LONG-TERM STORAGE AND THE PROTECTIVE PROPERTIES OF FBH

When analyzing the aging process of FBHs, a question was raised whether aging occurs also during storage of protective equipment and if so, how rapidly it progresses. To answer this question three types of harness produced in 1992–1995 were tested in 2007 [3]. These harnesses had been stored in their original packaging, in accordance with their manufacturers' recommendations.

To assess their physical condition, 20 FBHs were inspected; their resistance to static load was tested in accordance with Standards No. EN 361:2002 [1] and EN 364:1992 [5]. As a result of this assessment, the following observations were made:

- The only effect noticed on inspection was stiffening of the rubber loops safeguarding the free ends of shoulder and thigh straps of harnesses produced in 1992. In some cases

these elements broke during adjustment. This problem was not encountered in equipment produced in later years, when the loops were made of polyamide.
- The torso dummy was not released in any test of resistance to static load, which meant the test result was negative.
- The damage of the harness observed as a result of loading, e.g., small breaks of the seams, did not affect resistance to static load of the whole construction.

It can thus be concluded that long-term storage of FBHs made of polyamide or polyester webbing did not affect their protective properties.

5. FACTORS AFFECTING PROTECTIVE PROPERTIES

The question which factors of the working environment contributed to the loss of protective properties of FBHs (and of their elements) withdrawn from service followed the tests. According to Baszczyński, Jachowicz and Jabłońska [3], and Wilson, Parkin and Robinson [4] they were mostly (a) atmospheric factors (e.g., sunlight, temperature changes and humidity); (b) mechanical factors (e.g., contact with a sharp or rough surface); and (c) dust pollution.

This research did not cover the effect of factors the manufacturer warned against, e.g., open flame, molten metal splashes and aggressive chemicals.

5.1. Atmospheric Factors

Wilson et al. reported a study of the joint effect of all atmospheric factors (sunlight, rain, snow, temperature and humidity) on the mechanical parameters of webbing [4]. Nine types of polyamide and polyester webbing used in equipment protecting against falls from a height were tested. Webbing was exposed to natural atmospheric factors on a special stand for 2, 4 or 6 months between May and November. After exposure, it was subjected to strength tests, involving, among others, determination of the force $\overline{F}_{MZ}$.

The test showed that even 2-month exposure to atmospheric factors resulted in a noticeable decrease in the strength of webbing: the force $\overline{F}_{MZ}$ decreased by 1.1–28.8%. Together with longer exposure, this tendency increased and after 6-month exposure the force $\overline{F}_{MZ}$ decreased by as much as 6.8–30.7%. Considering the observed tendency of changes in $\overline{F}_{MZ}$, it should be expected that longer exposure would lead to a further decrease in strength, which could be dangerous for the user.

5.2. Sunlight

Tests of polyamide and polyester textiles proved their sensitivity to the effects of sunlight, both within the visible and ultraviolet (UV) spectra [6, 7, 8, 9, 10, 11, 12, 13]. To test this effect on webbing used in personal equipment protecting against falls from a height, HSL conducted an experiment involving exposure of webbing to non-UV sunlight [4]. Samples of webbing were placed in cases made of glass with suitable light filtration properties. Ventilators in those cases eliminated the effect of local heating by sunlight. Like in previous experiments, the samples of webbing were then tested for the maximum value of the force $\overline{F}_{MZ}$. The results showed that after 6-month exposure, the force decreased by 0.13–10.55%.

Textiles used in FHBs were also assessed for resistance to sunlight within the full spectrum range (including UV) and with an extended UV range ($\lambda < 290$ nm). Equipment that was used to do this made it possible to obtain a higher intensity of radiation than under natural conditions [3, 4].

In CIOP-PIB, samples of webbing were irradiated with Xenotest-450 (Germany) and a piece of equipment with an XBO® 450 W/4 (Osram, Switzerland) lamp which is used for accelerated aging of protective helmets [14, 15]. The spectrum characteristics of Xenotest-450 correspond to those of natural sunlight. As far as the irradiation effects are concerned, 2.4 h of exposure to radiation in this equipment correspond to exposure of the sample to one-day average insolation (~13 h).

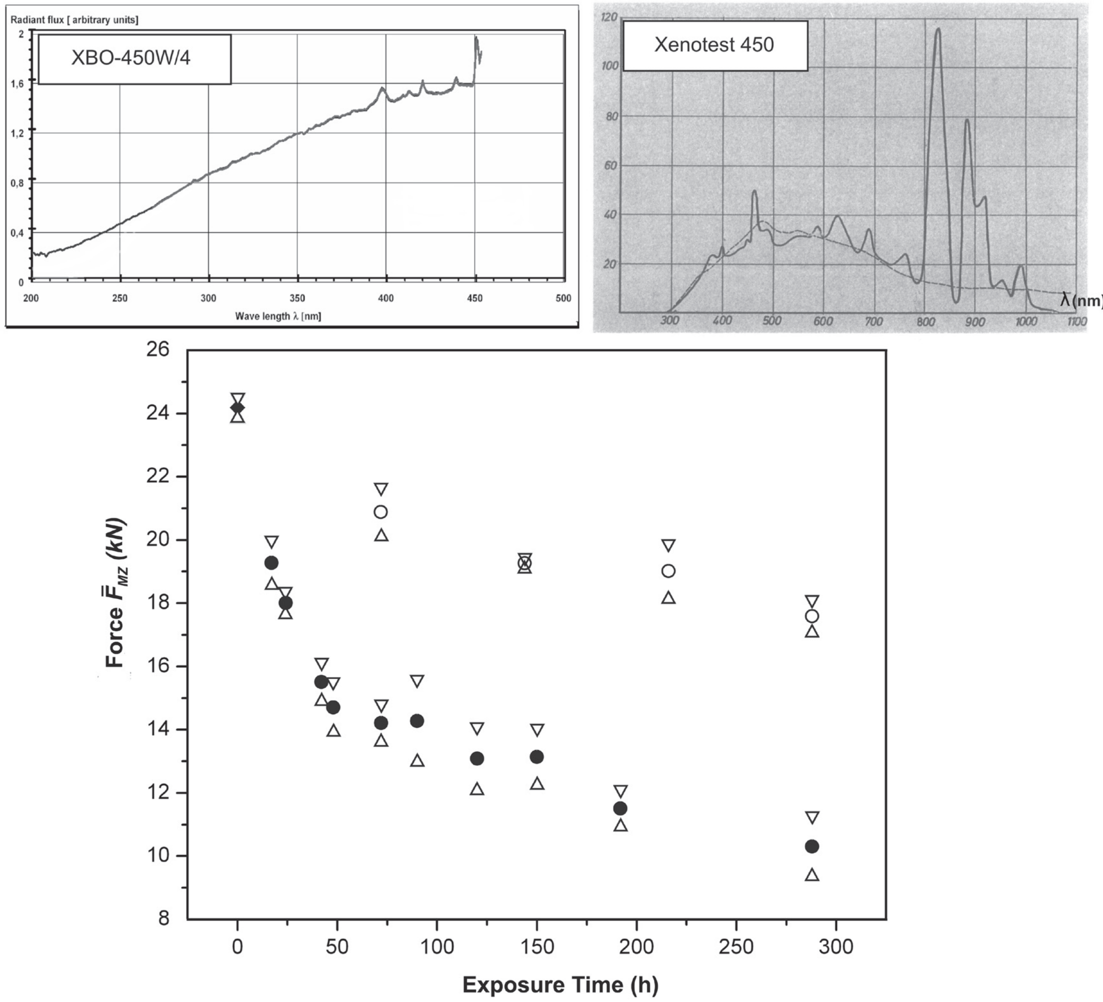

Figure 3. The effect of exposure to radiation from Xenotest-450 (Germany) and equipment with an XBO® 450 W/4 (Osram, Switzerland) lamp on the force $\bar{F}_{MZ}$. *Notes.* $\bar{F}_{MZ}$—mean value of tensile force before a break; 1—characteristics of the equipment with a XBO-450W/4 lamp, 2—characteristics of Xenotest-450; ○— $\bar{F}_{MZ}$ for samples irradiated with the Xenotest-450, ●— $\bar{F}_{MZ}$ for samples irradiated with a XBO-450W/4 lamp, ◆— $\bar{F}_{MZ}$ for samples without irradiation, △— $\bar{F}_{MZ}$ – *SD*; ▽— $\bar{F}_{MZ}$ + *SD*.

The spectrum characteristics of the equipment with an XBO® 450 W/4 lamp are increased by the UV range (λ < 290 nm), which under normal conditions does not reach the earth because of the filtering effect of the atmosphere. Such UV range components occur, e.g., in radiation accompanying electric arc welding. Figure 3 shows some results of strength tests carried out on irradiated samples.

An analysis of the results shows that after time corresponding to ~120-day exposure to sunlight, $\bar{F}_{MZ}$ (in comparison with webbing not exposed to radiation) fell by 26%. Similar tests conducted in HSL with a Sol 2 Cabinet model 0179 from Honle UV (UK) demonstrated that after irradiation corresponding to a real-time time outdoor exposure of the samples of 4 years, $\bar{F}_{MZ}$ decreased by 24.6–80.2% [4].

Irradiation of the samples with the equipment with an XBO-450W/4 lamp caused a significantly more rapid decrease in $\bar{F}_{MZ}$ than irradiation within the range corresponding to natural sunlight (Figure 3). A comparison of curves plotted through the measurement points in Figure 3 demonstrated ~20-fold acceleration of artificial aging of webbing with an XBO-450W/4 lamp. This shows that exposure to sources of UV radiation (e.g., electric arc) can significantly accelerate the loss of protective properties by an FBH.

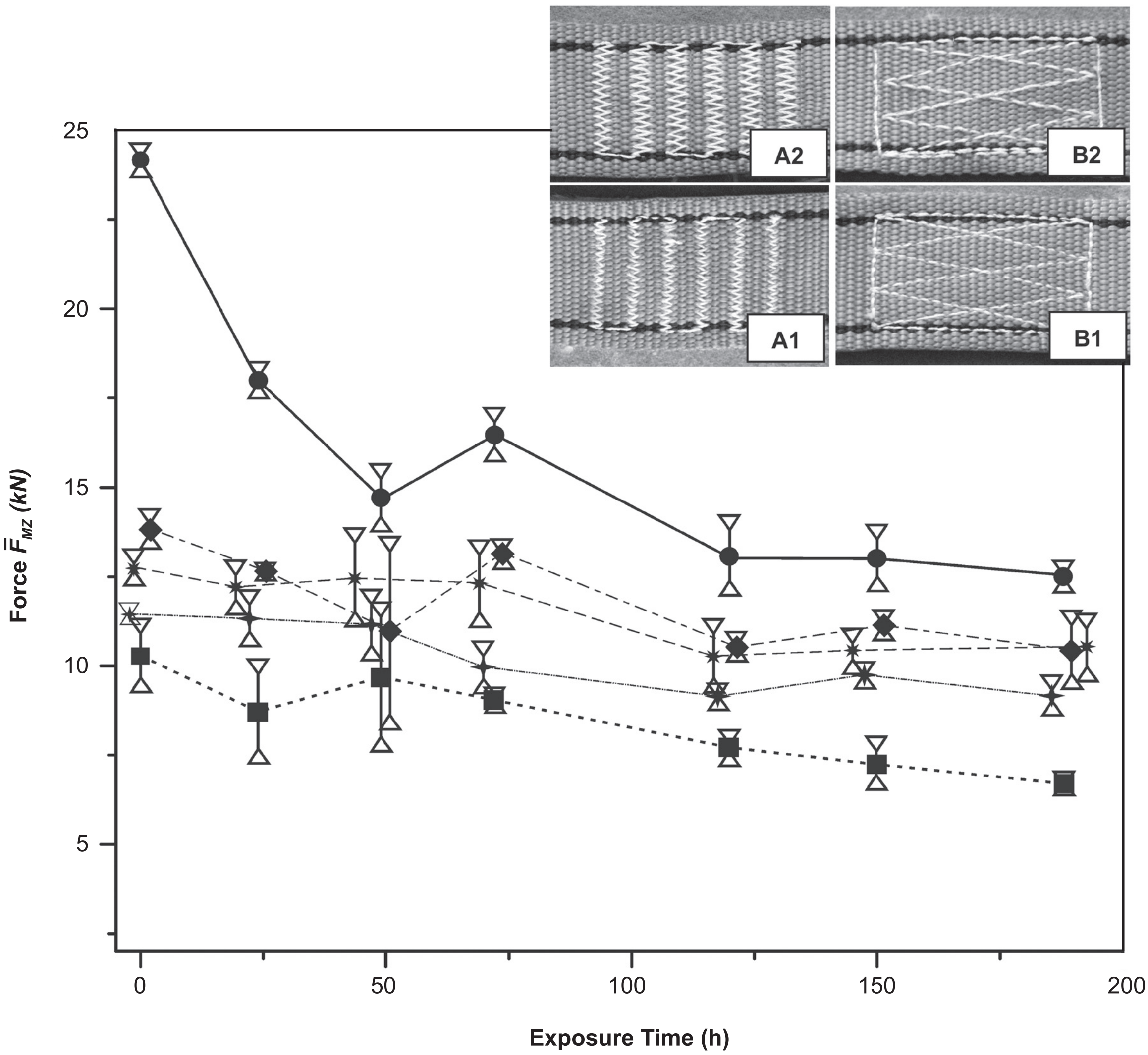

Figure 4. The effect of exposure to radiation emitted by equipment with an XBO® 450 W/4 (Osram, Switzerland) lamp on typical seams used in full body harnesses. *Notes.* $\overline{F}_{MZ}$—mean value of tensile force before a break; ●— $\overline{F}_{MZ}$ for samples without seams, ✶— $\overline{F}_{MZ}$ for samples with A1 seams, ✦— $\overline{F}_{MZ}$ for samples with A2 seams, ◆— $\overline{F}_{MZ}$ for samples with B1 seams, ■— $\overline{F}_{MZ}$ for samples with B2 seams, △— $\overline{F}_{MZ}$ – *SD*; ▽— $\overline{F}_{MZ}$ + *SD*.

Tests of resistance to static load show that damaged seams connecting parts of webbing are the most frequent cause why a harness withdrawn from service is not fit for use. That is why, CIOP-PIB carried out experiments simulating aging of typical seams used to connect webbing in FBHs (Figure 4). Irradiation for 180 h, corresponding to exposure to sunlight for 1 500 days (13 h of insolation per day) caused an average decrease in $\overline{F}_{MZ}$ of ~30%. Figure 4 shows that the decrease in $\overline{F}_{MZ}$ for seams was less marked than for nonsewn webbing. On the other hand, $\overline{F}_{MZ}$ for webbing with seams was lower, which meant a higher risk of damage to the whole construction of an FHB.

5.3. Mechanical Factors

FBHs withdrawn from service had sustained mechanical damage, especially to the edges of webbing where they rubbed against metal buckles. To check the effect of such damage on

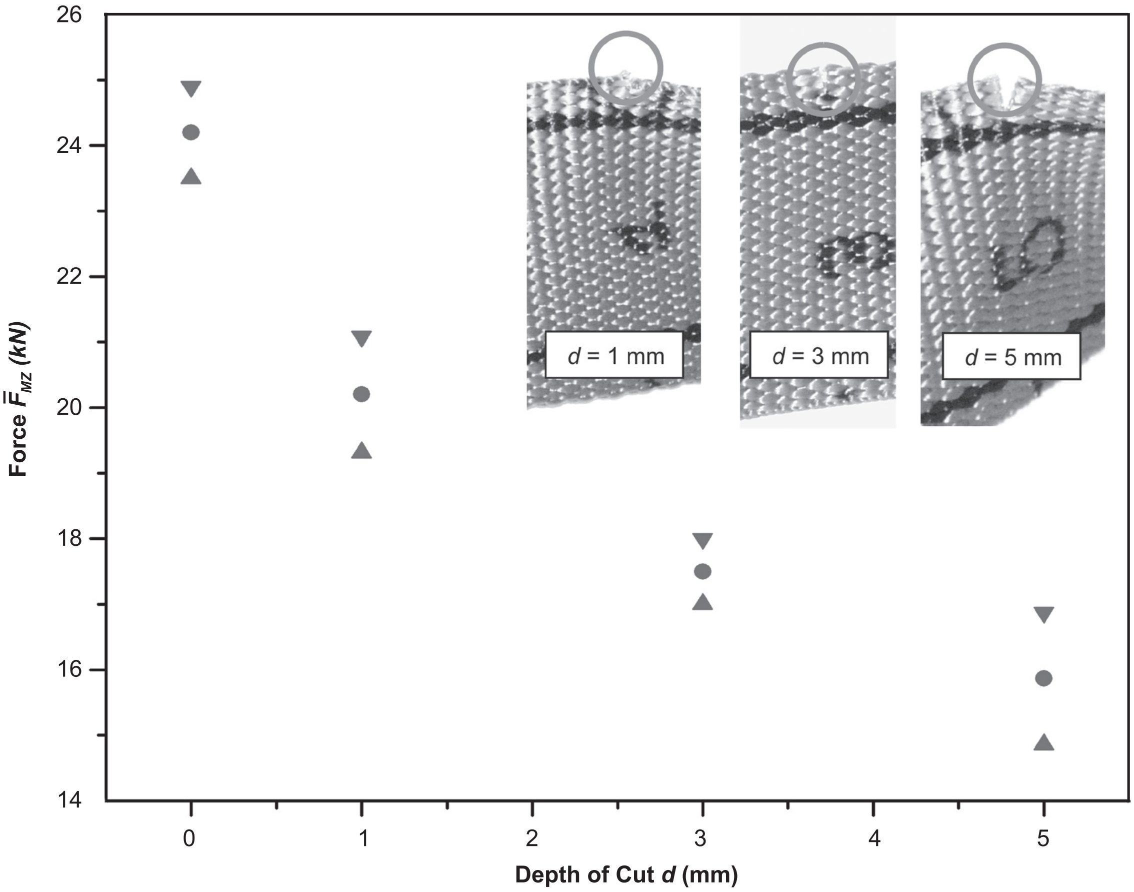

Figure 5. The effect of the depth of the cut of webbing edge on the force $\bar{F}_{MZ}$. *Notes.* $\bar{F}_{MZ}$—mean value of tensile force before a break; ●— $\bar{F}_{MZ}$, △— $\bar{F}_{MZ} - SD$; ▽— $\bar{F}_{MZ} + SD$.

the strength of webbing, cuts 1–5 mm deep were made in webbing used in FBHs. Baszczyński et al.'s [3] and Wilson et al.'s [4] test results were similar. Figure 5 illustrates correlation between $\bar{F}_{MZ}$ and the depth of the cut.

Tests showed that the decrease in the strength of webbing was higher for deeper cuts. For webbing 40 mm wide, the minimum for webbing used in the main straps of an FBH, a cut 5 mm deep (i.e., 12.5% of the width of webbing) resulted in a decrease in $\bar{F}_{MZ}$ of ~33.7%. This means that even an apparently small cut can cause a considerable reduction in the strength of webbing.

5.4. Ingress of Dirt

Strength tests of webbing samples obtained from FBHs withdrawn from service showed that samples considered more damaged because of soiling had lower values of $\bar{F}_{MZ}$. This means that nonchemical soiling affects the strength of webbing. The mechanism of this phenomenon involves the ingress of various types of dust, e.g., grains of sand, into the structure of webbing. As webbing is stretched, grains cause damage to its fibres, thus decreasing strength.

This phenomenon was simulated in a laboratory both in HSL [4] and in CIOP-PIB in tests involving cyclic passage of webbing through a container with builder's sand, followed by measurements of $\bar{F}_{MZ}$. Webbing was transferred with a special roller system [4] in a container so that sand could penetrate its structure along a segment 100 mm long.

In CIOP-PIB's tests, a 5-kg rigid mass was attached to webbing. Thus, when it passed through a container with sand, it was tense all the

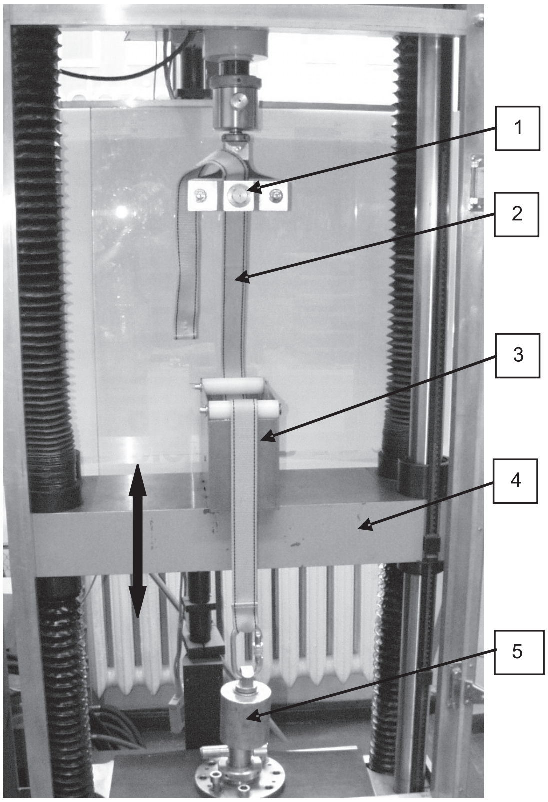

Figure 6. Stand used for ingressing dirt. *Notes.* 1—grip for test webbing, 2—test webbing, 3—container with sand, 4—universal tensile testing machine, 5—5-kg rigid mass.

time. It was moved by a roller system using the cyclic movement of a mobile beam in a Tiratest 2300 (Germany) testing machine (Figure 6).

Polyamide webbing 45 and 20 mm wide, used in FBHs described in section 1, was conditioned. Samples were subjected to 5, 20, 50, 100 or 200 cycles of movement in a container with sand. Then, they were tested with a Zwick ZS-100 (Germany) universal testing machine; values of $\bar{F}_{MZ}$ were determined. Figure 7 shows that penetration of the textile structure of webbing by dust weakened it considerably. Five conditioning cycles decreased $\bar{F}_{MZ}$ by 32.1% (45-mm webbing) and 16.2% (20-mm webbing). Increases in the number of cycles over 20 did not cause any further significant decreases in $\bar{F}_{MZ}$. This means that the structure of the textile was saturated with dust and further penetration was impossible. The results obtained in CIOP-PIB, despite the use of different sand, a different method of webbing transmission through the container and different types of webbing, are fully consistent with Wilson et al.'s [4]. Both sets of results confirmed the effect of dust grains on webbing

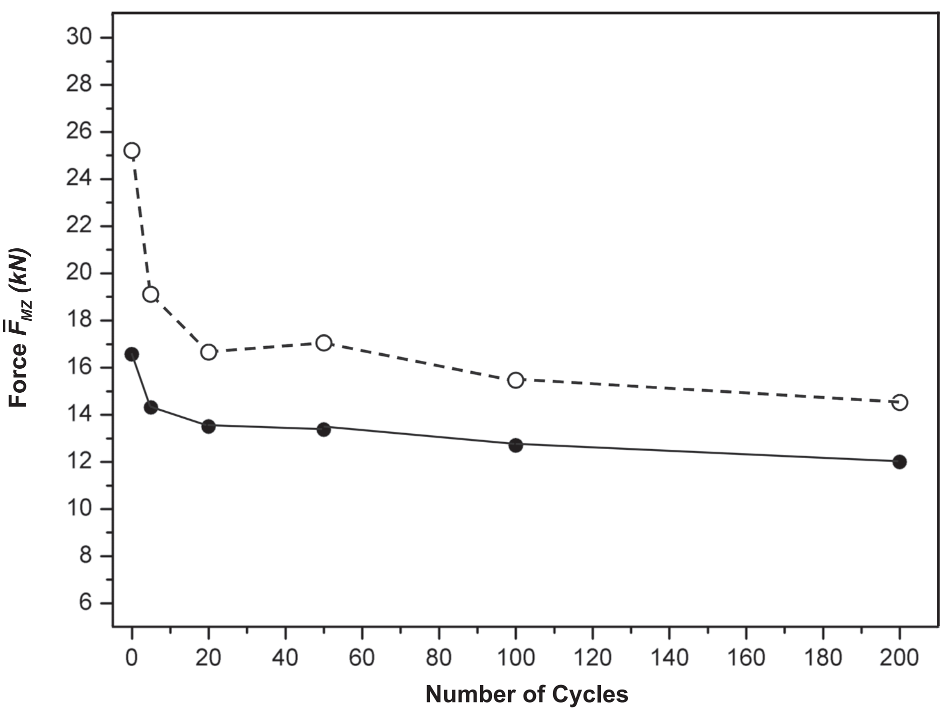

Figure 7. The effect of ingressing dirt on the force $\bar{F}_{MZ}$ *Notes.* $\bar{F}_{MZ}$ —mean value of tensile force before a break; ○— $\bar{F}_{MZ}$ for samples of polyamide webbing 45 mm wide, ●— $\bar{F}_{MZ}$ for samples of polyamide webbing 45 mm wide.

fibres and showed that the ingress of dust into the structure of webbing could significantly affect its resistance, and, consequently, the protective properties of the whole FBH.

6. CONCLUSIONS

The test results discussed in this paper showed that FBHs protecting against fall from a height lose their protective properties during their service life. The main factors causing this process are (a) sunlight, particularly UV radiation; (b) mechanical damage (cuts and friction-related defects of webbing and connecting seams); (c) dust penetrating the structure of webbing.

These factors most commonly impair the strength of the construction of FBHs where webbing is stitched together and where adjustment elements and buckles touch webbing.

The tests demonstrate that in the case of FBHs made of polyamide materials even long-term storage (in a dark place at 20 ± 10 ºC and relative air humidity not exceeding 70%) does not cause significant deterioration of their protective properties. Thus, assuming that harnesses are stored in good conditions, the beginning of usage rather than when they were manufactured can be regarded as the beginning of their service life.

Tests of effects of sunlight filtered through glass stopping its UV components demonstrated that indoor use of FBHs leads to slower loss of their protective properties than that observed in the case of exposure to atmospheric factors.

Tests of harnesses withdrawn from service make it possible to formulate practical guidelines on periodic checks of their physical condition. During such checks, special attention should be paid to (a) fading, which suggests long-term exposure to sunlight; (b) mechanical damage, e.g., cuts and friction-related damage of webbing, broken threads in the seams; (c) heavy staining; (d) corrosion of metal elements.

The loss of protective properties can also be caused by other types of damage, which result from not following manufacturers' instructions. Such damage can be a consequence of contact with open fire, molten metal splashes, aggressive chemicals, etc.

The data presented in the paper also indicate the need to inform users of the estimated service life of FBHs. This time should be specified as acceptable time of usage (starting from when the equipment is approved for use) provided there is no damage that should render an FBH unsafe. It is essential, though, that the types of damage requiring withdrawal from use be described.

The service life time should always be estimated after new materials, e.g., webbing, have been introduced in FBHs, and after changes in the construction of the elements bearing the load during fall arrest. The results of test presented in this paper show that most of all sunlight, including UV radiation, should be considered. The weakest construction points should be tested, e.g., stitched segments of webbing. The problem is being studied in CIOP-PIB, with Baszczyński, Jachowicz and Jabłońska having reported the first results [3].

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