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Comparative Evaluation of Test Methods for Cut Resistance of Protective Gloves According to Polish Standards

Abstract
This paper concerns a comparative evaluation of methods for testing the cut resistance of gloves protecting against mechanical injuries according to PN-EN 388:2006 and PN-EN ISO 13997:2003 standards. The results of preliminary tests indicated that the method applied currently in accordance with the former standard mentioned above is problematic and may yield erroneous results for gloves made of yarns highly resistant to cuts. Therefore the main aim of the study was to perform tests according to both standards and to conclude basis thereon whether the application of the method used for evaluation of protective clothing consistent with PN-EN ISO 13997:2003 would also be possible for testing protective gloves. The other aim of this study was to determine the performance levels for results obtained for gloves according to the test method intended for protective clothing. Cut resistance tests were carried out for twelve different materials obtained from protective gloves and clothing (commercially available) made of fabrics of cut-resistant, high-strength yarns. On the basis of the tests carried out, it was confirmed that the method for testing in accordance with PN-EN 388:2006 is insufficient to assess the key protective parameter, i.e. the cut resistance. The alternative testing method applicable to protective clothing and gloves highly resistant to cuts is that according to PN-EN ISO 13997:2003.

Key words: *protective gloves, cut-resistant, high-strength yarns, standardised test methods.*

Introduction

Bodily injuries occur at work as a result of the presence of various hazardous factors, the elimination or reduction of which is often impossible. Therefore it is necessary for workers to use appropriate personal protective equipment. Injuries to hands constitute a considerable share of the total number of accidents. If no other methods can be applied to eliminate or reduce the risk, protective gloves should be provided. Gloves protecting against mechanical injuries whose effects are bigger than superficial, such as abrasions, cuts and punctures, are classified as category II personal protective equipment acc. to Directive 89/686/EEC [1]. Appropriate harmonised standards are applicable for confirmation of compliance with the requirements of this Directive. The appropriate requirements concerning gloves which can provide protection against cut injuries caused by sharp objects are specified in Standard PN-EN 388:2006 [2]. Gloves protecting against mechanical injuries are more and more frequently manufactured from yarns characterised by very high resistance to cuts (p-aramide, polyethylene or glass fibres) and find application in many industrial sectors (construction, ceramic, metallurgy, machine-building, iron and steel industries, foundries, electronic, motor, furniture industry, glass works, shipbuilding, segregation of waste etc.) [3]. Gloves made of high-strength yarns effectively protect workers during operations involving contact with sharp tools, as well as materials being processed, such as metal sheets or glass panels. It is very important that workers will use only those gloves with confirmed protective properties tested according to appropriate methods with respect to the type of risk. The protective properties of gloves are evaluated by notified bodies taking into account the results of laboratory tests. The basis for evaluation of the cut resistance of protective gloves has been the testing method described in Standard PN-EN 388:2006 , which however seems to be inadequate for gloves made of yarns with very high cut resistance. On the basis of our studies, we established that application of a method according to PN-EN ISO 13997:2003 [4] for testing protective gloves will be suitable.

In order to make the text more readable, the following designations of the standards were accepted:

- PN-EN 388:2006 (EN 388:2003) – standard A,
- PN-EN ISO 13997:2003 (EN ISO 13997:1999, EN ISO 13997:1999/AC2000) – standard B.

The aim of this article is to compare and evaluate both methods.

Methods and materials

Methods

General statements

Cut resistance is a fundamental parameter evaluated in the case of gloves protecting the hands against cut injuries, and its value is taken into consideration when personal protective equipment for specific worksites is selected. Cut resistance is defined as the potential of the material to resist cutting with a sharp blade, which can be determined by means of various test and evaluation methods, depending on the tool which caused the cuts. Cutting the material requires the movement of a cutting element (a blade, knife) exerting appropriate force until the material integrity is disrupted. The higher the force value needed to cut the material, the higher its cut resistance [5]. The basic standard specifying the requirements and methods of testing gloves protecting against mechanical factors including cuts caused by sharp edges, elements and materials is standard A.

Method according to standard A

Cut resistance is determined on the basis of index 'I', which is an abstract number calculated as an arithmetic mean of five 'i' indexes calculated on the basis of the number of blade rotations causing the cutting of the test sample and control specimen (a cotton canvas of standarised parameters) before and after the test carried out on the test sample.

For each type of glove two samples are tested, and for each of them five cuts are carried out.

The test sample and control specimen are mounted without stretching on a special

Figure 1. Blade used in cut resistance tests according to standard A.

Table 1. Performance levels with respect to cut resistance according to standard A [2].

Performance level	Cut resistance expressed as index 'I'
LEVEL 1	1.2
LEVEL 2	2.5
LEVEL 3	5.0
LEVEL 4	10.0
LEVEL 5	20.0

frame, on a rubber pad, with aluminum foil covered with a sheet of filter paper. The blades used for the test (***Figure 1***) are discs with a diameter of 45 ± 0.5 mm, thickness of 3 ± 0.3 mm and with a total cutting angle of 30 - 35°. They are made of tungsten steel with a hardness of 740 - 800 HV [2]. The blade loading amounts to 5 ± 0.05 N, whose sharpness is checked before each test performed on the material sample with a control specimen; and the blades can be used many times.

Index 'I' is calculated for either of the two test samples, and the lower index value is adopted as the result of the test for gloves. Basing on the *'I'* index, the performance level for gloves is indicated. The performance levels for cut resistance are presented in ***Table 1***.

Method according to standard B

The method of cut resistance evaluation consistent with standard B is applicable to both protective gloves and protective clothing and makes it possible to assess resistance to cuts inflicted by sharp edges such as knives, parts of metal sheets, filings, fine chips, glass, sharp tools, and casts [4].

The distance covered by a longitudinal blade up to the moment when the test sample is cut, with various values of force exerted on the blade, is measured. Data obtained from tests with at least three different forces (for each force value five cuts of a test sample are carried out) are used for ploting a graph of the correlation between the cutting distance and values of forces applied. From this graph the force needed to cut through the test sample with a 20 mm blade displacement is determined. The tests are continued (five next cuts) using the force determined from the graph and the average distance is then calculated. If this average value is not included in the range between 18 mm and 22 mm, a further five cuts are carried out. All the results are then used for plotting a new graph of the correlation between the cutting distance and values of forces applied. From this graph the final result of the test is obtained (the force needed to cut through the material sample with a 20 mm blade displacement).

The test sample is mounted directly in the holder in a special apparatus for cut resistance tests, to which the sample is attached by means of double-sided adhesive tape. A conductive material – copper foil – is placed between the sample and holder.

The blades used for tests (***Figure 2***) are rectangular and made of stainless steel of a hardness greater than 45 HRC. The thickness of the blade is 1.0 ± 0.5 mm, and the angle is approximately 22° at the cutting edge. Blades have a cutting edge length greater than 65 mm, and their width is more than 18 mm [4]. The blades move in one direction with a constant velocity of 150 mm/min. The blade sharpness is checked on neoprene material before using it in the cut tests; every twentieth blade in each lot is checked, and the blade can be used only once to make one cut [4].

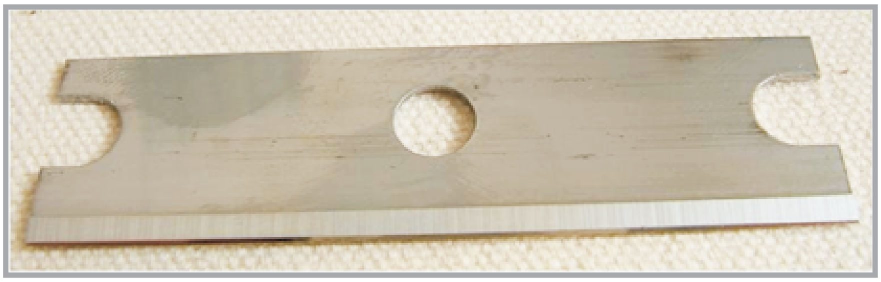

Figure 2. Blade used in cut resistance tests according to standard B.

Standard B does not define performance levels but contains a suggestion that materials and products should be classified so as to provide various levels of performance.

Materials

Cut resistance tests were carried out for twelve different materials selected from protective gloves and clothing commercially available made of leather (1 sample) and textiles containing yarns characterised by different resistance to cutting. The samples for testing were collected from final products (gloves, clothing). The samples tested were made of materials of different resistance to cutting and characterised by a large range of values of the surface mass and thickness (surface mass from 240 to 900 g/m^2 and thickness from 0.50 to 2.60 mm). An analysis of the influence of textile structural parameters on their resistance to cutting was not the aim of this study. Characteristics of the materials tested are presented in ***Table 6*** together with the test results.

Results and discussion

Preliminary tests

Testing method A is certainly adequate for materials characterised by a lower resistance to cuts, i.e. by a lower level of performance with respect to this parameter (e.g. for leathers, fabrics made from cotton yarn covered by polymer etc.).

However, the results of a number of preliminary tests on different types of glove material indicated that in some cases this test method seems to be insufficient for evaluation of glove resistance to cutting, concerning gloves made from textile fabrics highly resistant to cutting. Quick blunting of the cutting edges of blades and consequently the impossibility of providing reproducible conditions for the experiment poses a key problem during cut resistant evaluation. There were significant differences in the number of rotations of the blade before and after tests with the control specimen. Changing the blade after each of the five cut tests, recommended by the standard, is not a solution. During the test, the cutting edge undergoes rapid degradation in contact with cut-resistant material without cutting it with a simultaneous increase in the number of cycles. A considerable scatter of results, making it impossible to determine an accurate value of the 'I' index, and consequently the real cut resistance of the gloves tested, was observed. As follows from the preliminary experiments, in some cases the apparatus failed to signal any cutting of the sample after many rotations of the cutting blade, whereas the material sample tested demonstrated signs of cutting when checked, presented in ***Table 2***. Even if the tests were conducted with a new blade for each cut within the sequence of cut tests, a considerable scatter of results was observed. The gloves tested were reported to be characterised by at least a level 3 performance against cuts. Such classification was adopted on the basis of the lowest value of index 'i' obtained, which equaled 7.7 (for test sample No 1 – according to ***Table 2***).

Similar problems with testing and interpretation of the results of cut resistance determination for gloves according to standard A are also described in the relevant literature [5 - 7]. Lara and Massé [5, 6] indicated difficulty in testing gloves made of Spectra® yarn. A sample of material collected from gloves made of Spectra® yarn was cut after 558 rotations of the blade. After 50 cycles completed without effective cutting of the sample, the authors checked the sharpness of the cutting blade using a standard material. Before the test on the test sample, the number of blade rotations necessary to cut the control specimen was 0.8, whereas after 50 cycles on the glove sample the number of cycles obtained amounted to 25.5. The results above indicate that the blade loses the sharpness required even before the test sample was cut. According to the recommendations given in standard A, if the number of cutting blade rotations required to cut the control specimen, tested after the test sample, is more than 3, a new blade should be mounted. However, the authors continued the tests using the same blade and checked its sharpness on the control specimen after 200 and 400 cycles, the result being that it had failed to cut the test sample. The results of the experiments demonstrated significant deterioration of the blade sharpness in comparison with that observed after 50 cut test cycles carried out on samples collected from gloves made of Spectra® yarn. Simplified results of tests performed by Lara and Massé are presented in ***Table 3***.

Also tests conducted by researchers from one of the world leaders in manufacturing protective gloves confirm that the test method described in standard A is not adequate for determination of the cut resistance of high-strength materials [7]. The results obtained for textile materials characterised by high resistance to cuts may be overestimated because of the fact that the blunt blade must complete more cutting cycles, and therefore the index expressing the cut resistance of the material will be higher, which may result in the assignment of a falsely higher level of performance against cuts.

Table 2. *Examples of results of preliminary tests of cut resistance for gloves made of yarn highly resistant to cuts according to standard A; *Not calculated because of the fact that the sample was cut but the device failed to signal the cut.*

Measurement number	Index „i"		Index „i"		Index „i" for gloves
	Sample no 1	Sample no 2	Sample no 1	Sample no 2	
1	11.54	23.30	15.7 (calculated on the basis of four test results)	26.6	7.7
2	7.67	57.60			
3	24.18	16.29			
4	19.28	11.58			
5	*	24.10			

Table 3. *Results of cut resistance tests performed on gloves made of Spectra® yarn according to Lara and Massé [5, 6]; * without cutting the sample.*

Measurement Number	Number of blade rotations resulting in cutting of control specimen	Number of blade rotations resulting in cutting of test sample	Number of blade rotations resulting in cutting of control specimen
1	0.8	50*	25.5
2	25.5	50 - 200*	24.4
3	27.3	200 - 400*	27.2
4	27.2	400 - 558	28.1

Table 4. *Comparison of selected performance levels of gloves made of yarns with high cut resistance described in standard A [2].*

Performance level for test results obtained according to Standard A	Value of the cutting force necessary to cut the material tested by 20 mm according to Standard B
4	≥ 13 N
5	≥ 22 N

Table 5. *Proposed classification of performance levels of gloves made of yarns with high cut resistance, compliant with the requirements of standards A and B.*

Performance level for test results obtained according to PN-EN 388:2006 (Standard A)	Value of the cutting force necessary to cut the material tested by 20 mm according to PN-EN ISO 13997:2003 (Standard B)
5	≥ 22 N
4	≥ 13 N
3	≥ 6.5 N
2	≥ 3.3 N
1	≥ 1.6 N

Planed tests

Plenty of tests were carried out for the same samples, first according to standard A and then standard B. The next stage was a comparison of results obtained in the tests according to both standards.

Standard A gives an incomplete reference to the comparison of performance levels with respect to the cut resistance determined by both testing methods: A and B (***Table 4***).

The final stage of the study involved the development of classification A of performance levels with respect to resistance to cuts for gloves made of yarns highly resistant to cutting obtained by both test methods (***Table 5***) including the relation of forces obtained by method B to the performance levels obtained by method A.

According to this procedure, all materials selected were tested and performance levels from 1 to 5 were obtained. All results are presented in ***Table 6*** (see page 102).

It can be observed that for small performance levels the results obtained by both tests (A & B) correlate mutually. On the

*Table 6. Extrapolation of the obtained results to the proposed classification of performance levels for gloves made of yarns highly resistant to cutting, taking into consideration the requirements of standard A and standard B (**Table 5**) [3].*

Test sample number	Type of structure fabric	Type of yarn/ material	Surface mass, g/m²	Thickness, mm	Index 'I' (cut resistance of the material) according to PN-EN 388:2006 (Standard A)	Performance level according to PN-EN 388:2006 (Standard A)	Cutting force in N according to PN-EN ISO 13997:2003 (Standard B)	Proposed performance level classification (Table 5) (Standard B)
1	-	leather	900	1,20	1.6	**1**	2.9	**1**
2	woven with polyacrylnitrile finish	cotton	800	0,70	1.3	**1**	2.4	**1**
3	woven	para-aramide	240	0.80	4.7	**2**	4.9	**2**
4	knitted	type hd kevlar	500	2.00	5.6	**3**	10.2	**3**
5	knitted	glass, polyamide, polyurethane	500	1.40	6.1	**3**	9.5	**3**
6	knitted with natural latex finish	para-aramide	500	2.50	11.2	**4**	13.4	**4**
7	knitted	para-aramide	800	2.40	12.5	**4**	13.7	**4**
8	woven	para-aramide, glass	720	1.80	48.1	**5**	33.1	**5**
9	knitted	para-aramide, glass, cotton	900	2,60	30.1	**5**	17.5	**4**
10	knitted	dyneema®, polyamide, glass	700	1.70	38.0	**5**	17.6	**4**
11	knitted	kevlar, glass, polyamide	500	1.40	37.3	**5**	15.8	**4**
12	woven with silicone and polyurethane finish	basalt	550	0.50	-	**-**	36.2	**5**

other hand, considering samples which yield higher 'I' values and cutting force levels, with only one exception, we obtained varied results, which is related in all cases to samples containing glass or basalt fibres. However, in two cases samples containing glass fibres yield comparable results; but it should be emphasised that diffenences in the structure of the gloves were not considered.

The tests failed to determine the real cut performance level according to standard A for one material made of basalt fibre (sample 12) because significant blunting of the blade occurred during the test, which was evidenced by the high number of blade rotations that caused the cut, as well as by the high number of blade rotations needed to cut the control specimen after the test performed on the sample studied. The case of that sample confirms in particular that the method according to standard A is not reliable for tests performed on materials with very high resistance to cutting. Despite the blunting of the blade observed, the 'I' index calculated for 5 cuts of the same sample amounted to 1.6, which corresponded to cut performance level 1 according to standard A. In view of the above, the test results did not allow to obtain reliable information concerning the actual cut resistance of the material. This confirms the earlier finding that the method according to standard A is inadequate for textile materials made of yarns characterised by high resistance to cuts.

In the case of materials we made with the addition of glass fibre yarns, problems were also observed with method A (samples 8, 9, 10 and 11). The blade in contact with these materials was subjected to rapid degradation, not cutting the material, and at the same time increasing the number of cycles performed, which was even higher than 1500, and in another case the sample was not cut through. In the case of these materials a large scatter of results was observed, and even when a lot of tests were performed for the sample, it was not possible to determine the exact value of the 'I' parameter, thereby to determine the real resistance of the gloves to cutting. It was also observed in some cases that the device did not signal cutting of the sample after many rotations of the blade, and after checking, the test sample showed signs of having been cut through. Thus high values of strength parameters for glass and basalt yarns in the materials tested did not allow for an objective testing thereof using method A because of the technical and measuring limits of the equipment.

Method B allows to conduct the test and determine more real values of glove resistance to cutting. The blade is used only one time for one cut and degradation of the blade is not observed during the test, which allows to ensure more uniform conditions during the test. Using test method B for reliable materials made from high-resistance yarns, ie. glass and basalt, it was possible to determine the value of their resistance to cutting.

Taking in mind the above considerations, there appears a need to continue the research with respect to the influence of textile structural parameters on their resistance to cutting.

Conclusions

- Method A is cheaper (the blade is mostly used for several cuts) and simpler (quick measurement) compared with method B (blade used only once) but more complicated concerning the determination of the final result.
- The hitherto standard testing method consistent with standard A applied to protective gloves characterised by very high resistance to cutting may be not reliable enough to establish cut resistance. However, it is a method appropriate for materials characterised by lower resistance to cutting, which cause no blunting of the cutting edges.
- The alternative testing method according to standard B applied to protective gloves (and clothing) highly resistant to cutting (e.g. made with the use of para-aramide and polyethylene yarn

and especially glass and basalt fibres) is suitable and more objective for assessment of cut resistance.

- Method B is recommended for evaluation and classification of the performance levels of protective gloves made of yarns very highly resistant to cutting and may be useful for the selection of materials designated for designing protective gloves and clothing. The authors propose to accept the relationship between the forces obtained by method B and the performance levels characteristic for method A.
- In the future, research should be performed in order to analyse the influence of the structure of protective gloves and clothing on their cut resistance.

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