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PERFORMANCE EVALUATION OF PROTECTIVE GLOVES IN PREVENTING HAND LACERATIONS

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Abstract: *In numerous industries, handling objects with sharp edges is a frequent task associated with significant risks of cuts and other injuries. Although they may appear minor, such incidents can have serious consequences, ranging from superficial wounds to deep lacerations or even amputations, ultimately affecting work capacity and quality of life. To prevent these accidents, the use of appropriate protective gloves is essential. This study examines the materials used in the manufacturing of cut-resistant gloves, emphasizing the importance of performance levels in evaluating their effectiveness.*
Keywords: *cut resistance, gloves, risk, sharp edges*, hazards.

1. INTRODUCTION

Regardless of the field of activity, handling objects with sharp edges is a common practice across various industrial sectors and professions, from construction and metallurgy to healthcare and public services. Given that hands play a crucial role in performing most professional tasks, they are exposed to a wide range of risks, including cuts, abrasions, and other mechanical injuries. While superficial injuries, such as scratches or punctures, are frequently encountered and often considered minor, neglecting or improperly treating them can lead to severe complications. Deep cuts on the palm, secondary infections, nerve damage, or even finger amputations may result in temporary or permanent work incapacity, significantly impacting workers' quality of life [1, 2].

As occupational health and safety remain fundamental priorities, the use of protective gloves with enhanced cut resistance is imperative. A thorough understanding of the technical characteristics of these protective equipment items is, therefore, essential in defining optimal selection criteria and ensuring compliance with international standards. This study aims to systematically analyze these aspects, contributing to the improvement of workplace safety.

2. LEGAL PROVISIONS REGARDING THE PROVISION OF PROTECTIVE GLOVES IN THE WORKPLACE

The risk of cutting is a quasi-universal hazard in the economy, occurring whenever hard objects with unrounded edges are handled. Its severity depends on the following factors:

- The angle at the edge of the blades – the smaller it is, the higher the risk of injury;
- The hardness of the objects being handled;
- The average pressing force of the hand, in the case of lightweight objects, which is further amplified by the mass of the objects being manipulated in the case of heavier items;
- The worker's sensitivity.

At the European level, measures aimed at improving worker safety and health are regulated by Framework Directive 89/391/EEC [3], transposed into national legislation through Law No. 319/2006 – the Occupational Safety and Health Law [4]. In accordance with these regulations, employers are required to conduct a risk assessment at the workplace, which involves identifying all hazards arising from or associated with professional activities.

As part of this assessment, employers must identify situations in which there is a risk of hand injuries caused by handling sharp objects or other similar hazards. In cases where the risk cannot be eliminated or reduced to an acceptable level through collective or administrative measures, employers are obligated to provide appropriate protective gloves, taking into account the specific risks identified during the risk assessment. Protective gloves should not be regarded merely as an additional layer of protection but as a fundamental preventive measure against hand injuries.

Thus, according to Directive 89/656/EEC [5], before selecting personal protective equipment (hereinafter referred to as PPE), the employer must evaluate whether the PPE intended for use meets the requirements of Regulation (EU) 2016/425 [6] concerning design and manufacturing. Designed to ensure a high level of protection, the essential health and safety requirements outlined in Regulation (EU) 2016/425 establish safety objectives that must be met in order to eliminate or reduce risks, without mandating specific technical solutions.

Regarding protective gloves against mechanical hazards, these solutions are defined through measurable characteristics in the harmonized European standards EN 420:2003+A1:2009 [7] and EN 388:2016+A1:2018 [8]. These standards provide both testing methods and performance criteria, thereby contributing to the harmonization of safety levels across the market. While EN 420:2003+A1:2009 specifies the general requirements applicable to all gloves, EN 388:2016+A1:2018 includes specific requirements and testing methods for protective gloves designed to withstand mechanical hazards.

Although these standards provide a clear framework for evaluating and certifying protective gloves, continuous advancements in material science necessitate the ongoing revision of performance criteria. Until recently, leather protective gloves were considered adequate for cut resistance; however, the continuous development of technical materials—commonly referred to as "high-performance fibers" [9], [10]—has led to the production of gloves with superior performance levels compared to leather or traditional materials, significantly reducing the risk of severe hand injuries. The emergence of innovative materials with enhanced resistance to mechanical hazards has necessitated the implementation of specific testing methods capable of determining the actual cutting force resistance.

3. CUT PERFORMANCE LEVEL: A KEY FACTOR IN THE PROPER SELECTION OF PROTECTIVE GLOVES

To properly assess the cut resistance of gloves and correlate the performance of the materials used with the actual level of protection provided, standardized methods are required to ensure objective and comparable results. In this context, standard EN 388:2016+A1:2018 defines two essential test methods that determine the degree of protection offered by gloves against cuts.

The first method used to determine cut resistance is the Couptest method. This method evaluates the behavior of the material when subjected to a constant cutting force by using a circular blade that performs both rotational and linear movements over the tested specimen. The test is conducted under a static force of 5 N (the average pressing force encountered during most handling operations), thereby determining the level of protection provided by a material when exposed to this force (see Figure 1).

Fig. 1. Couptest Apparatus

According to this method, cut resistance is expressed through an index, whose value represents the ratio between the number of cycles required for a blade to cut through a specimen taken from the glove's palm and the number of cycles required for the blade to cut through a reference fabric. Table 1 presents the performance level classification based on the cut index value. As observed in Table 1, the performance level increases as the cut index value rises.

Table 1

Performance Levels of Cut Resistance According to the "Couptest Method"

Level	Level 1	Level 2	Level 3	Level 4	Level 5
Cut Index	1.2	2.5	5.0	10.0	20.0

The results of the trials conducted on various types of materials indicated that, although this testing method appears suitable for most materials (leather, textiles), it may be inadequate for assessing cut resistance in certain types of fabrics, particularly those made from "high-performance fibers" that have the potential to dull the blade during testing. Moreover, the method does not allow for a direct correlation with workplace risk levels but rather enables only a ranking of material performance under the same standardized testing conditions (same blade, same applied force).

The second method, TDM, is described in EN ISO 13997 and involves determining cut resistance using a straight blade (see Figure 2) that applies a variable (dynamic) cutting force to the tested material.

Fig. 2. TDM Apparatus

In this case, the test result is expressed as the force (in Newtons) required for the blade to penetrate the material over a cut length of 20 mm. The performance level is represented by a letter, ranging from A to F, where F indicates the highest level of resistance. Table 2 summarizes the cutting force values corresponding to each performance level.

Table 2

Performance Levels for Materials Tested According to EN ISO 13997

Level	Level A	Level B	Level C	Level D	Level E	Level F
Cut Resistance (N)	2	5	10	15	22	30

Given that the results obtained through these methods form the basis for evaluating cut resistance, their application to a diverse range of samples is essential to obtain a clear assessment of the performance of different types of protective gloves.

In addition to providing a more accurate simulation of real exposure conditions (straight blade), this method enables a performance classification based on risk level, using applied force as a reference criterion. A direct comparison of the two methods cannot be performed.

4. SELECTION OF SAMPLES AND TESTING PROCEDURE

To conduct a comparative evaluation of the performance of cut-resistant protective gloves, samples were selected to encompass significant variations in the materials used in the palm area, which is the most exposed to cutting risks. The selection included gloves made from traditional materials, such as leather and textiles, as well as gloves manufactured from high-performance fibers, such as Kevlar and composite materials. The differences among the samples extended beyond material composition to include structural variations, ranging from single-layer designs to laminated or multi-layered configurations. To ensure an accurate and objective assessment of the effectiveness of the selected gloves, each sample was tested using both standardized methods. The test results obtained for these samples are summarized in Table 3.

Table 3

Experimental Data on Cut Resistance Performance

Sample Code	Tested Product	Palm Material	Index (Couptest)	Cutting Force (TDM), N
X1		Knit of polyester, coated with natural rubber	1.6	1.4
X2		Knit of nylon, coated with polyurethane	2.12	1.6

Sample Code	Tested Product	Palm Material	Index (Couptest)	Cutting Force (TDM), N
X3		Bovine leather	1.29	2.8
X4		Knit of polyamide on the exterior and cotton on the interior	3.78	2.9
X5		Two layers of bovine suede leather	2.66	5.1
X6		Bovine suede leather + bovine leather with natural pressed surface	2.53	5.0
X7		Two-layer laminated fabric: 100% PES + coated textile material 100% PES + fleece knit 100% PES	6.3	10.1
X8		Plain knit fabric made of para-aramid yarn	8.50	12.8
X9		KEVLAR-type fabric (para-aramid yarn), twill weave	17.12	15.4

The experimental data presented in the table reflect the performance of each tested glove type, providing a comparative basis for analyzing cut resistance.

5. INTERPRETATION AND DETAILED ANALYSIS OF RESULTS

The analysis of the obtained data highlights that there is no correlation between the performance levels obtained through the two testing methods. Furthermore, the experimental test results provide a clear insight into the level of protection offered by the different types of gloves analyzed, showcasing varied performance depending on the materials used. Comparing the data obtained through the Couptest and TDM methods allows for a more nuanced evaluation of each material type and its effectiveness in cut protection.

As observed from the results presented in the table, conventional gloves made solely from standard knitted fabrics with a specific mass below 150 g/m², even when coated with PVC or natural rubber, exhibit minimal cut resistance using the classical method and generally fail to withstand the minimum cutting force of 2 N established by the TDM method.

On the other hand, gloves made from natural leather (X3) or textiles coated with polyurethane (X2) and rubber (X1) demonstrated limited cut protection, achieving low values in both testing methods.

In the case of leather gloves, their structure consists of randomly oriented collagen fibers [11], which result in low cut resistance since the fibers do not form a sufficiently dense barrier to prevent material sectioning. On the other hand, gloves made of textiles coated with polyurethane or rubber feature an outer surface that enhances grip but does not significantly contribute to increased cut resistance. Thus, while these gloves may offer some degree of protection against other mechanical risks (e.g., abrasion and puncture resistance), they are not suitable for use in environments with frequent exposure to sharp objects, where the risk of cutting injuries is high. In practice, the use of these gloves is more appropriate for tasks such as general material handling or work that does not involve direct contact with sharp surfaces.

For gloves made of layered materials (X7), which combine synthetic fibers with additional protective layers, test results indicate improved protection compared to traditional materials. The cut index obtained using the Couptest method was significantly higher, and the force required to penetrate the material in the TDM method was greater, demonstrating that these gloves can absorb and distribute applied forces more efficiently.

This increase in performance is attributed to the multilayered structure, which creates an additional physical barrier and slows down the cutting process. By redistributing the applied force across the material, composite gloves can prevent or delay blade penetration [9]. These properties make them suitable for environments with moderate cut risk, such as the automotive industry, metal component assembly, or tasks involving contact with slightly sharp surfaces. The best results were achieved by gloves made of para-aramid fibers (X9) and (X8), which proved to have the highest cut resistance. In the Couptest method, these gloves recorded very high values, and in the TDM method, the forces required to penetrate the material were significantly higher compared to other analyzed categories. This superior level of protection can be explained by the density and molecular structure of the fibers used, which allow for the dispersion of applied force, reducing the likelihood of blade penetration [12]. The exceptional performance of these gloves recommends them for use in industrial environments with high exposure to sharp-edged objects, such as metal processing or operations involving the handling of sheet metal and hard materials.

6. PERSPECTIVES ON THE INTEGRATION OF PROTECTIVE GLOVES IN THE CONTEXT OF INDUSTRY 4.0

In the context of Industry 4.0, the industrial landscape is undergoing a profound transformation, marking a shift from rigid automation to direct collaboration between human operators and collaborative robots (cobots) [13]. This transformation not only redefines production processes but also reshapes the requirements for personal protective equipment (PPE), which must simultaneously ensure safety, dexterity, and technological integration. The integration of cut-resistant protective gloves into human-robot collaborative environments poses significant challenges regarding the balance between safety and the maintenance of dexterity required for precision tasks. The use of multi-layer gloves made from PES (such as those coded X7), while offering superior cut resistance, may impair the fine motor skills necessary for precision operations, such as cobot calibration. Recent research has focused on developing knitted structures that incorporate flexible conductive fibers into their fabric [14], providing users with instant feedback on any surface degradation of the glove. This approach would allow for the preservation of tactile sensitivity—essential for the precise handling of objects—without compromising the glove's mechanical strength. Moreover, current studies show that the integration of tactile sensors [15], [16] enables real-time monitoring of critical parameters such as grip force or temperature. Such technologies are essential in a dynamic industrial environment, where safety and operational efficiency are top priorities.

To support these developments, current standards such as EN 388 and ISO 13997 should be updated to include requirements regarding sensor durability, cybersecurity, and interoperability with IoT systems. Such updates will ensure that protective gloves designed against mechanical hazards remain suitable for the challenges and opportunities brought by Industry 4.0

7. CONCLUSION

The results of the experimental tests confirm the importance of selecting appropriate protective gloves based on the specific risk level of each activity. Gloves made from traditional materials are suitable for activities with minimal exposure to sharp/edged objects, while those made from composite materials offer a balance between protection and flexibility. For high-risk environments, gloves made from Kevlar and para-aramid fibers are the safest option, providing significantly superior protection. Based on these findings, the TDM method proves to be more relevant for classifying protective gloves, as it precisely measures the cutting force required for material penetration.

The selection of suitable gloves should consider both the required level of protection and the ergonomic needs of users, ensuring an optimal balance between safety and comfort in workplaces exposed to cutting hazards.

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Evaluarea performanței mănușilor de protecție în prevenirea leziunilor de tăiere la nivelul mâinilor

În numeroase industrii, manipularea obiectelor cu margini ascuțite este o activitate frecventă, asociată cu riscuri semnificative de tăieturi și alte leziuni. Deși pot părea minore, astfel de incidente pot avea consecințe grave, de la răni superficiale la leziuni profunde sau chiar amputări, afectând capacitatea de muncă și calitatea vieții. Pentru a preveni aceste accidente, utilizarea mănușilor de protecție adecvate este esențială. Acest studiu examinează materialele folosite în fabricarea mănușilor rezistente la tăiere, subliniind importanța nivelurilor de performanță în evaluarea eficacității lor.

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