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Simulation method for assessing the end of service life of gloves used by workers exposed to mineral oils and mechanical factors

Emilia Irzmańska*, Agnieszka Stefko

Central Institute for Labor Protection — National Research Institute, Department of Personal Protective Equipment, 16 Czerniakowska Str., 00-701 Warsaw, Poland

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A B S T R A C T

The paper presents a method for determining the end of service life of all-rubber and polymer-coated gloves protecting against mineral oils and selected mechanical factors. Analysis of variance was conducted to test for differences between ~~the~~ protective parameters (abrasion resistance, cutting resistance, tear resistance, mineral oil permeation resistance) and an ergonomic parameter (bending rigidity) determined for five models of protective gloves following a simulated use procedure. The results show that both protective and ergonomic parameters are affected to the greatest degree by the period of use under conditions of exposure to mineral oil: 2 h, 4 h, and 8 h for polymer-coated gloves and 4 h, 8 h, and 16 h for all-rubber gloves. It has been found that gloves lose their protective properties over time under simulated conditions of use and their performance levels may no longer comply with the relevant standards. Based on the tests conducted, a test protocol has been developed for end-of-service-life evaluation of gloves protecting against mechanical factors and mineral oils.

Relevance to industry: The current system of harmonized standards for testing protective gloves provides information about protection levels only for new products. The proposed protocol for end-of-service-life evaluation of protective gloves exposed to mineral oils and mechanical factors may serve as a useful tool for employers and workers by providing reliable information about the approximate actual period over which gloves may be used safely in the workplace.

1. Introduction

The hands of workers in many industries, and especially in the chemical, petrochemical, machine, metallurgical, and automotive sectors, are often exposed to chemical substances (mineral oils, lubricants) and mechanical factors (abrasion, cutting, tearing). One of the methods of increasing work safety for those persons is the use of appropriate protective gloves that would ensure simultaneous protection against mechanical and chemical hazards. Gloves designed for protection against mineral oils and lubricants should be impermeable and made entirely of oleophobic materials. In situations when the hands come into contact with oily elements of machines or other objects, the protective layer may cover the palmar area alone (including the fingers), with the back of the glove made of knitted fabric (Krzemińska and Irzmańska, 2011).

It should be stressed that chemical protective gloves are part of personal protective equipment and should meet the requirements specified in the relevant standards. Therefore, in the case of both impermeable all-rubber gloves and polymer-coated gloves, it is necessary to verify their protective properties in the laboratory. Along with their protective parameters, it is essential that gloves should have adequate ergonomic properties, suitable for a particular application. Due to the fact that the use of protective gloves during work may cause discomfort in workers, it is important to undertake efforts to eliminate any adverse effects and hazards caused by environmental factors and to improve uncomfortable working conditions. Such efforts include end-of-service-life testing of protective gloves (determining the time after which they lose their protective and ergonomic properties) in order to eliminate the adverse influence of the physical environment on the user during performing work activities (Irzmańska et al., 2013).

Currently, the protective properties of gloves are tested under laboratory conditions (Irzmańska and Dyńska-Kukulska, 2012). Furthermore, only one factor, that is, the breakthrough time of a

* Corresponding author. Fax: +48 042 678 19 15.
E-mail address: emirz@ciop.lodz.pl (E. Irzmańska).

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chemical substance is evaluated (Perkins, 1987; Berardinelli and Hall, 1985; Man et al., 1987; Gunderson et al., 1989; Nelson et al., 1981; Garrobo, 2001; EN 420:2003+A1:2010; ASTM F1790 – 05; ASTM F1342 – 05; EN 374-3:2005/AC:2006; ASTM F739-85; ASTM F739-07; Mickelsen et al., 1986; Vo et al., 2003). It should be stressed that under actual conditions of use gloves may be affected by a number of other factors, either immediately decreasing their protective properties or accelerating the loss of those properties. These factors are linked to specific workplace conditions and to user–glove interactions. Therefore, of great importance are parameters that are individually determined by the users, such as the temperature and humidity in the space between the glove and the hand, mechanical stress (multiple flexion and abrasion), multiple and varied contact with one or several substances at different concentrations (sweat, dangerous chemicals), etc. There are few publications concerning evaluation of the end of service life of protective gloves subjected to several factors at the same time (Park, 2000; Vahdat, 1992; Ellingsen and Dugstad, 1984). Another work (Irzmańska et al., 2013) proposed a method for testing the end of service life of protective gloves under simulated use conditions. The presented end-of-service-life simulation of protective gloves was founded on a previous survey conducted in 30 workplaces, such as car repair shops and auto service centers. The survey was conducted with a focus on one eight-hour workday. The workers were asked about the time of exposure to and the type of contact with lubricants and mineral oils, as well as how often they changed their protective gloves. Furthermore, the users were asked to subjectively evaluate the loss of glove impermeability. The parameters that should be recreated under simulated conditions were identified based on the results of the survey. To imitate real use conditions as closely as possible, the test temperature was set to that of the human body (approx. 36 °C) and an artificial sweat solution was used. Given the fact that the majority of the respondents worked only in closed spaces, relative air humidity during simulation tests was set to approx. 60%, reflecting the conditions in car repair shops. Due to the simultaneous presence of lubricants, oils, and mechanical factors, it was decided that gloves should be subjected to the simultaneous effects of mechanical factors and oils during simulation tests. Preliminary results were presented for two types of glove materials subjected to the action of a range of factors: mechanical stress (stretching, flexing, and abrasion), chemical substances (mineral oil), and the microclimatic processes occurring in the space between the user's hand and the glove (sweat, temperature, humidity). New gloves, tested both under simulated and real-life conditions of use, revealed a decrease in resistance to cutting, abrasion, tear, and permeation of mineral oils. In another work (Irzmańska et al., 2014), scanning electron microscopy (SEM) was used for evaluation of the surface microstructure of protective gloves following end-of-service-life testing. Particular attention was paid to surface microdefects that arose as a result of the action of external factors, which may accelerate the loss of protective properties by the studied glove materials without the users' realizing it (such microdefects are not organoleptically detectable). The test results showed that the cumulative effect of the studied factors significantly influenced the surface morphology of the protective glove materials, making them less resistant to abrasion, tear, and permeation of oils and lubricants than materials not subjected to such factors.

Laboratory tests conducted in accordance with the standards harmonized with Directive 89/686/EEC are the primary source of information about the protection levels offered by new gloves and may be used, e.g., for comparing commercially available products with a view to selecting the best products for a given workplace (Council Directive 89/656/EEC, 1989). Unfortunately, such tests do not reflect the actual protection levels that the gloves provide to the users. They do not sufficiently account for the impact of external factors and the influence of the user, including the activities he or she performs, on the glove material.

The presented paper is a continuation of our research into determining the end of service life of protective gloves in terms of resistance to mineral oils and mechanical resistance. The objective of the work was to propose a protocol for end-of-service-life evaluation of protective gloves, to analyze the parameters that should be measured when evaluating gloves, and to propose assessment criteria for determining product acceptability.

2. Materials and methods

2.1. Materials

The tests were conducted on five types of gloves protecting against mineral oils and mechanical factors. The gloves can be classified into two broad categories: all-rubber gloves and knitted gloves coated with a polymer layer in the palmar region. The tested gloves were marketed by their manufacturers as products with high chemical resistance to mineral oils and with good mechanical properties. The gloves were also claimed to exhibit anti-slip properties improving the grip of oily elements. The tested protective gloves are characterized in Table 1.

2.2. Methodology

2.2.1. Specimen preparation for end-of-service-life testing of protective gloves

Glove specimens were prepared for end-of-service-life tests using an apparatus that simulated the real-life conditions of use of protective gloves at automotive repair shops, where workers are exposed to mineral oils and mechanical factors. The testing apparatus was described at length in another publication of the authors (Irzmańska et al., 2013). A scheme of the apparatus is given in Fig. 1.

Glove materials were subjected to simulated use for 2 h, 4 h, 8 h, and 16 h. The simulation periods were adopted on the basis of the results of a questionnaire administered to automotive repair shop workers, which were published in another paper by the authors (Irzmańska and Stefko, 2012).

Protective gloves were acclimatized in the laboratory at (23 ± 2)°C and a relative air humidity of (50 ± 5)% for at least 48 h. Subsequently, 110×50 mm specimens were cut out from the grip area of the gloves. Prior to inserting in the apparatus, every specimen was weighed with an accuracy of 1 mg. Following mounting in the apparatus (Fig. 1), each specimen was contaminated with 3 mL of IRM 903 mineral oil (according to ASTM D 471), applied by means of a syringe and spread with a brush. The selected mineral oil consists of a mixture of specially processed fractions derived from naphthenic crude, thanks to which the methodology conforms to the relevant standards (EN 374-3:2005/AC:2006; ASTM F739-85). The reference oil was described in detail in another work by the authors (Irzmańska and Dyńska-Kukulska, 2012).

Following specimen mounting, the testing apparatus was run. During the test, the specimen was continuously wetted with an artificial sweat solution (with an alkaline pH typical of physical exercise), which simulated sweating under conditions of hard work (Irzmańska and Brochocka, 2014). The apparatus was housed in a climatic chamber with a constant temperature of 36 °C and a relative humidity of approximately 60%, which corresponded to the microclimate in the space between the worker's hand and the glove (Oppl, 2001a,b; Evans et al., 2001). Following the prescribed