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Risk assessment

INFLUENCE OF DIFFERENT TYPES OF SUBSTRATE ON THE RISK OF INJURY IN THE WORKING ENVIRONMENT

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Abstract. During the production of the product, the executant is exposed to the danger of injuries in the working environment. Injuries at work due to slipping are presented as the biggest cause of injuries at work. Injuries caused by slipping, in addition to health complications, require unplanned economic problems such as high hospital costs, medical recovery from injuries, payment of compensation, etc. The paper investigates the influence of the sliding friction coefficient of certain materials on the possibility of injuries at work due to slipping of employees. Based on the obtained research results, a recommendation was given for the selection of materials for making floors in order to reduce injuries in the working environment, i.e. increase the personal safety of employees and reduce the financial costs of the employer.

Keywords: tribology, sliding friction coefficient, slipping, work injuries.

AIMS AND BACKGROUND

Slipping, tripping and falls are the most common causes of workplace injuries in all industries, from heavy industry to office work[1–3]. Previous research has shown that falls occur as a result of personal risk factors and environmental factors[3–10]. Personal factors include gender, age, work experience, work position, level of education, health condition, physical (in)activity, etc. The consequences due to the

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danger of slipping and tripping are various injuries, which can range from minor (bruises and scratches) to severe, serious (bone fractures or head trauma). Injuries caused by slipping, in addition to health complications, require unplanned economic problems such as high hospital costs, medical recovery from injuries, loss of working hours, payment of compensation, etc. In addition to personal factors, environmental factors such as footwear and surface conditions also increase the risk of slipping, tripping and falls[3,11–14]. The main causes of injuries when slipping or tripping in the workplace related to working conditions and the condition of the floors are: spillage of liquid or solid materials, washing and cleaning floors, rain, snow, ice, mud, type of floors, sudden changes in the type of floors, tilts, slopes, protrusions, unevenness or damage to the floors, poor lighting in the workplace, cables and other installations on the floors.

In the design phase of each new workplace, care should be taken to avoid the risk of slipping or tripping when moving in the work area. Potential problems need to be identified and recorded in existing workplaces and the following appropriate corrective measures implemented effectively: surfaces for movement have to be flat, relatively smooth, non-slippery, clean, sufficiently clear and illuminated, especially in critical places such as stairs and passages; mark all changes in the floor level; install anti-slip floor coverings in all critical places; organise training of workers to recognise the dangers of slipping and tripping, as well as to use appropriate, proper protective footwear; quickly clean up spilled water or any other liquid; design the workplace so that cables should not be on the floor; regularly maintain and repair floors; keep your workplace clean and tidy every day; organise the storage and transfer of materials to such a machine to avoid their accumulation in the workplace, and organise the manner of waste disposal and storage in the process of work.

This paper presents the results of research on the influence of the static coefficient of sliding friction of certain materials on the possibility of injuries at work. Based on the obtained results, a recommendation was given for the selection of materials that would, as a preventive measure, lead to a reduction of injuries due to slipping of employees in the workplace.

EXPERIMENTAL

TRIBOLOGICAL FACTORS AND PERSONAL SAFETY

Tribology is one of the sciences that enables the avoidance of losses that can be significantly higher than the savings realised through the price of the product. These losses are estimated through the consumption of replacement parts, inadequately designed parts and parts that have to be replaced before the deadline, machine elements or entire systems that have to be replaced due to inaccuracies resulting from inadequate design. Until recently, when designing tribo-mechanical systems, the opinion was that they should be useful and cost little.

In the process of product design, it is necessary to take into account certain rules and techniques, which are: Analysis of the total operating cycle of the tribo-mechanical system until its removal from use; Do not try to eliminate the accidental cause and predict another accidental cause; Find solutions so that if an accident occurs, the consequences will be as small as possible; It is necessary to consult standards in a particular field, as well as relevant references and experts with experience in this field; The instructions for use should be writtenas clear and precise as possible.

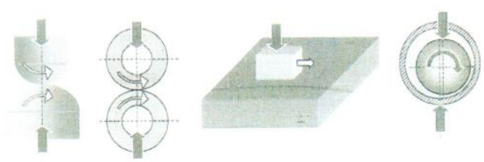

Fig. 1. Contact of ideal triboelements

A theoretical approach to understanding contact is often the ideal case. The contact of ideal triboelements is shown in Fig. 1 (Ref. 15). The contact surface of the triboelements after finishing is never ideally smooth. Numerous irregularities created as a result of roughning and finishing can have different geometric parameters and cause greater or lesser malfunctions of triboelements. Figure 2 (Ref. 16) shows the nominal and real contact surface of the triboelements. The topography of the contact surfaces of triboelements has a significant influence on friction and wear, as well as the service life of tribo-mechanical systems.

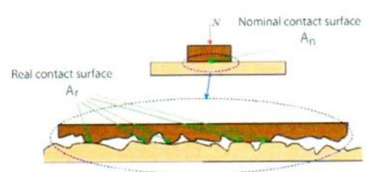

Fig. 2. Nominal and real contact surface

Tribomechanical systems work in conditions of frictional contact and relative movement of their elements. In the zone of frictional contact, complex non-stationary physico-chemical and mechanical processes occur, followed by friction and wear of contact surfaces. Friction and wear of contact surfaces are the main reasons for changes in system structure, energy loss and material loss. As natural processes, friction and wear depend on a large number of different factors including system structure, speed and load, mechanical and chemical properties of materials, lubrication characteristics, aggressiveness of the environment, temperature, topography of contact surfaces, rough and fine machining and others[17–20]. A large number of factors, as well as their complex interrelationship, where often the change of only one parameter causes a chain change of many others, make it difficult to quantify their influences. Areas of action of modern tribology are shown in Fig. 3 (Ref. 15). Minimal friction and minimal wear can be achieved by lubricating the surfaces of the triboelements in contact. Maximum friction and minimum wear occurs if wear-resistant materials are used to make the triboelements. Maximum friction and maximum wear are achieved if materials with increased adhesion are used in joining technologies such as friction welding. Minimal friction and maximum wear occur if consumable materials are used to make the triboelements, such as solid lubricant coatings in sliding contact.

Fig. 3. Areas of action of modern tribology

Having in mind the fact that the product is made and realised to serve man, in addition to the already mentioned requirements that the products should be useful and cost little, there is another aspect, which although was present in the design, today got a new dimension, and that is personal safety. Personal safety is a set of factors about the concept of machining of products, psychological, sociological and legislative factors that contribute to the protection of an individual who is in a direct relationship with the product and together in relation to the environment. Personal safety is a real problem that depends on the properties of the product, the relationship between the product and the user, as well as his/her mental and physical condition. If accidental factors are eliminated, which can lead to a decrease in personal safety, a large share of personal safety has the quality of the product. Protection implies both physical and mental safety.

The products of human labour arise from needs. Seeing the need, a man thinks about what and in what way to satisfy the need. From noticing the need to the finished product is a long and very heavy journey. Finding ways to enhance product quality is especially important for the product development process. During the production of the product, the executor is exposed to the danger of injuries in the working environment. Numerous examples in practice show that tribological problems can occur in any case of movement of two bodies in relation to each other, and therefore a detailed study of these phenomena is necessary.

RESULTS

The quality of the products that employees come into contact with and the quantitative characteristics of the materials from which the products are made significantly affect the personal safety of employees. The experimental determination of the sliding friction coefficient was performed on the device shown in Fig. 4 (Ref. 21). Based on the analysis of possible materials with which employees come into contact, the following substrate materials were selected for this experimental research: ceramics, glass, lacquered wood, laminate, wood, steel, aluminum, copper, carpet, felt, rubber and leather. In all measurement cases the second element of the contact pair is rubber. Based on the experimental plan, the previously mentioned substrate materials were divided into five groups. The sixth group was specially formed, in which there are four different types of tapes. The first group includes the following materials: ceramics 1, ceramics 2, ceramics 3 and glass. Lacquered wood, laminate 1, laminate 2 and wood are materials of triboelements that are classified in the second group. The third group includes steel, aluminum and copper, and the fourth group includes carpet and felt. The fifth group includes triboelements made of rubber and leather. As previously stated, in the sixth group, there are tapes, namely anti-slip tape, damaged anti-slip tape, signaling tape and inscription tape. In all six groups, the static coefficient of friction was determined as a quantification indicator of the characteristics of the materials of triboelements, with which employees come into contact in production halls, offices, corridors, stairs and other accompanying facilities.

Within each group, 20 measurements of the static coefficient of sliding friction were performed. The measurement results as well as the mean and standard deviation of the sliding friction coefficient are shown in Table 1.

Fig. 4. Device for measuring coefficient of sliding friction

Table 1. Measurement results for six groups of substrate materials

Group	Material	μ	μ_{mean}	σ	μ_{group}
I	Ceramics 1	0.24–0.39	0.301	0.0330	0.23–0.57
	Ceramics 2	0.37–0.55	0.448	0.0275	
	Ceramisc 3	0.24–0.44	0.322	0.0312	
	Glass	0.23–0.57	0.486	0.0449	
II	Lacquered wood	0.19–0.32	0.248	0.0279	0.19–0.70
	Laminate 1	0.28–0.57	0.356	0.0461	
	Laminate 2	0.40–0.67	0.545	0.0558	
	Wood	0.48–0.70	0.584	0.0478	
III	Steel	0.55–1.00	0.697	0.0523	0.52–1.00
	Aluminium	0.55–0.92	0.686	0.0677	
	Copper	0.52–0.82	0.646	0.0674	
IV	Carpet	0.48–0.64	0.541	0.0243	0.44–0.64
	Felt	0.44–0.57	0.476	0.0230	
V	Rubber	0.70–1.37	0.890	0.1441	0.60–1.37
	Leather	0.60–0.72	0.652	0.0307	
VI	Anti–slip tape	0.75–0.98	0.803	0.0360	0.35–0.98
	Anti–slip tape damg	0.42–0.52	0.459	0.0208	
	Signaling tape	0.50–0.63	0.585	0.0226	
	Inscription tape	0.36–0.53	0.423	0.0351	

Figure 5 shows the static coefficient of sliding friction for ceramics 1, ceramics 2, ceramics 3 and glass. The static coefficient of sliding friction for materials classified in this group is in the range [0.22–0.57]. The static coefficient of sliding friction for the second group of materials is given in Fig. 6. The lowest static coefficient of sliding friction was obtained for lacquered wood $\mu = 0.19$, and the highest is for wood $\mu = 0.7$. Figure 7 shows the coefficient of sliding friction for the third group of materials from which the triboelements are made and is in the range [0.46–1.0]. Figure 8 shows the static coefficient of sliding friction for the fourth group of materials. The highest coefficient of sliding friction was obtained for carpet $\mu = 0.64$ and the lowest for felt $\mu = 0.44$. Figure 9 shows the static coefficient of sliding friction obtained for the fifth group of materials. For material's from this group, a static coefficient of sliding friction in the range [0.59–1.38] was obtained. Within the sixth group of materials, the lowest coefficient of sliding friction was obtained for the tape with inscriptions $\mu = 0.36$, the highest for the anti-slip tape $\mu = 0.98$ (Fig. 10).

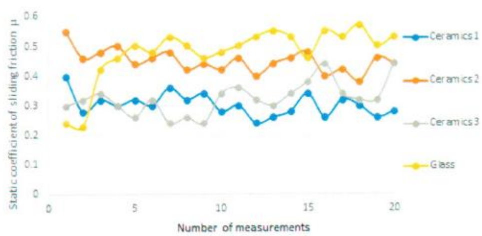

Fig. 5. Static coefficient of sliding friction (first group of substrate material)

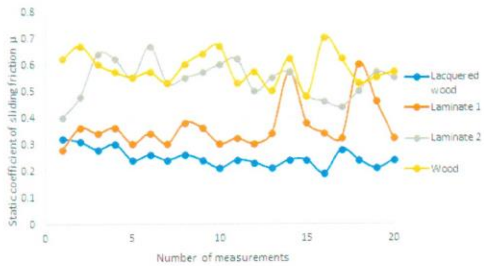

Fig. 6. Static coefficient of sliding friction (second group of substrate material)

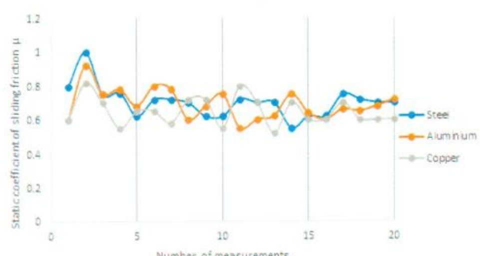

Fig. 7. Static coefficient of sliding friction (third group of substrate material)

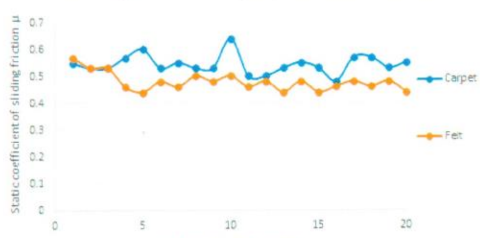

Fig. 8. Static coefficient of sliding friction (fourth group of substrate material)

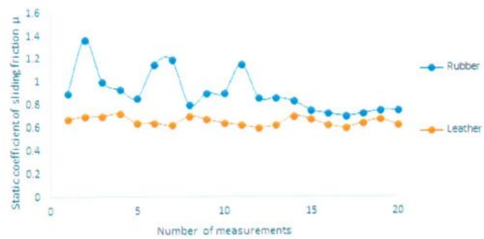

Fig. 9. Static coefficient of sliding friction (fifth group of substrate material)

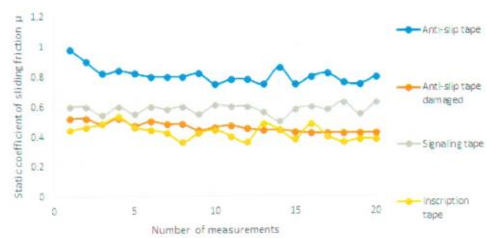

Fig. 10. Static coefficient of sliding friction (sixth group of substrate material)

The mean of static coefficient of sliding friction for all six groups of substrate material is shown in Figs 11–16.

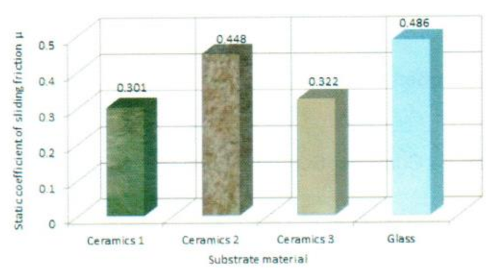

Fig. 11. The mean of static coefficient of sliding friction (first group of substrate material)

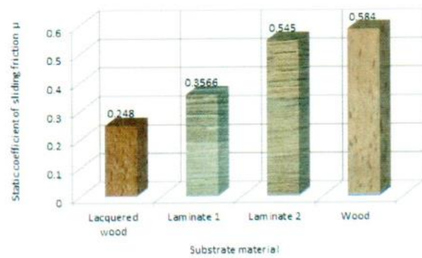

Fig. 12. The mean of static coefficient of sliding friction (second group of substrate material)

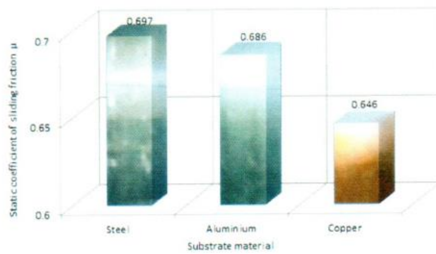

Fig. 13. The mean of static coefficient of sliding friction (third group of substrate material)

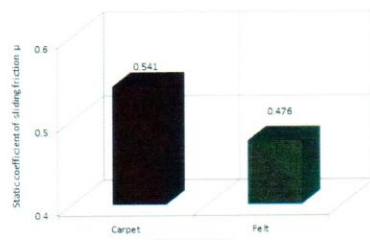

Fig. 14. The mean of static coefficient of sliding friction (fourth group of substrate material)

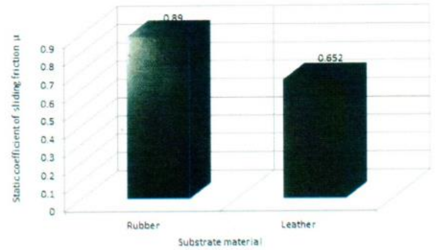

Fig. 15. The mean of static coefficient of sliding friction (fifth group of substrate material)

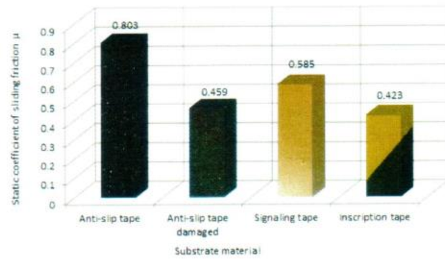

Fig. 16. The mean of static coefficient of sliding friction (sixth group of substrate material)

Having in mind the recommendation of the International standard ISO 20344 which refers to the resistance of the material to slipping and the required minimum value of the coefficient of sliding friction and based on the measurement results obtained in the research in this paper (Table 1) rubber and leather from the fifth group of substrate materials as well as anti-slip tape that is classified in the sixth group of materials are slip-resistant materials because their coefficient of sliding friction is in the range $\mu = [0.6–1.37]$. The mean of static coefficient of sliding friction is 0.89, 0.803 and 0.652 for rubber, anti-slip tape and leather, respectively. Therefore, rubber, leather and anti-slip tape are recommended for flooring in the work environment in order to reduce injuries at work. Substrate materials from the second group are in second place with a slightly higher risk of injury because their coefficient of sliding friction is in the range $\mu = [0.52–1.00]$. The mean of static coefficient of sliding friction is 0.697, 0.686 and 0.646 for steel, aluminium and copper, respectively. The next group with an even higher risk of injury includes laminate 2, wood and carpet. Their coefficient of sliding friction is in the range $\mu = [0.4–0.7]$. The mean of static coefficient of sliding friction is 0.584, 0.545 and 0.541 for wood, laminate 2 and carpet, respectively. All other tested materials belong to the group of very risky materials for the occurrence of injuries in the work environment because their coefficient of sliding friction in all measurements is below the minimum required value of 0.64.

CONCLUSIONS

Slipping is one of the main cause of injuries in the working environment. This paper presents the results of measuring the static coefficient of sliding friction of different substrate materials encountered in the workplace.

Based on the obtained measurement results as well as the International standard ISO 20344 rubber, leather and anti-slip tape are slip-resistant materials because their static coefficient of sliding friction is in the range $\mu = [0.6–1.37]$. Therefore, these materials are recommended for making floors in the working environment in order to reduce injuries at work, as well as the financial costs of the employer incurred as a result of employee injuries.

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