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EMISSION OF AIRBORNE FIBERS FROM MECHANICALLY IMPACTED NON-ASBESTOS FIBER-CONTAINING MATERIALS: PRELIMINARY RESULTS

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Abstract: The emission rate of fibers released from the new/fresh and used/worn ceramic fiber material, glass wool and man-made mineral fiber material due to mechanical impact was determined experimentally. The emission rate has been defined as a number of fibers emitted per unit mass and unit impaction energy. The averaged emission rate of short fibers ($L \leq 5$ μm) for all studied fresh non-asbestos fiber materials ranged from 2.2 to 20 fibers/(g·J), while the emission of long fibers ($L > 5$ μm) was between 2.2 and 100 fibers/(g·J). The susceptibility of worn fiber-containing materials to emitting fibrous particles due to mechanical impaction was significantly diverse. Emission from glass wool unchanged with the exploitation, while the emission rate of the mineral fiber material increased by a factor of 10^4 compared to new material. The dominating population of emitted fibers from studied materials ranged from 2 to around 8 μm in length.

INTRODUCTION

People in homes, as well as in the work environment, may be exposed to various fibrous aerosols. There are various diseases, including lung cancer, which are caused by inhalation of airborne fibrous dust clouds (e.g.: [7, 14, 15, 20]). Over the past two decades a great deal has been learned about how and why fibers cause pulmonary diseases (e.g.: [1]). There are three essential factors that are required to develop such disease [6]: adequate dose, dimensions of the fibers in the alveolar region, and fiber biopersistence [8]. Other fiber properties, such as presence of iron or other transition metals on fibers, ability of fibers to generate free radicals [5], and the ability of fibers to interact with and alter biologically relevant molecules, as well as the ability of fibers to produce reactive oxygen/nitrogen species (ROS) may also be determinants of fiber toxicity [6], especially among biopersistent fibers. The fundamental property of the fiber toxicity is, that in contrast to chemicals, fibers are believed to cause disease trough a physical/chemical interaction, what means that the health effects depend not only on the type of fiber but also upon

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its diameter and length. Typically, it is assumed that the most hazardous fibers are those longer than 5 μm and of a diameter up to 3–4 μm [22]. It is possible that the physical form of a fiber is even more important than its chemical composition [6, 21].

Since the aerodynamic behavior of airborne fibers depends on the orientation of these fibers in the flow, theories and data valid for spherical particles are not applicable for fibers [16]. Estimation of the exposure to fibrous aerosol requires knowledge about the emission of fibers, their atmospheric and indoor transport, and penetration from outdoor into indoor environment, as well as deposition and resuspension. This knowledge is still very poor. One of the reasons is the lack of a method to inexpensively produce length and diameter mono-dispersive fibers. Only recently Gilbertson *et al.* [3] have developed such a method, which produces straight fibers with controllable lengths, using thin film grown by physical vapor deposition. On the other hand, the health effects of inhalation of fibrous aerosol can concern the huge groups of people becoming very important for some local populations. For example, many buildings in Central Europe are covered with thermal insulation containing asbestos-cement sheets, which weather and corrode. Cement particles, asbestos fibers and agglomerates of both particles and fibers are released from the plate surface and become dispersed in the air [18]. It has been also documented that fibers emitted from the asbestos-cement facades of the buildings migrate into indoor air, significantly elevating the concentration of fibrous aerosol in the flats [10–13]. These airborne asbestos fibers can create a health risk, including a lung cancer risk. However, because the carcinogenic properties of asbestos are most probably due to its fiber geometry, also other fibers with the same characteristics may be carcinogenic [21]. This hypothesis can have very important implications in the future, because in the last five years in a number of buildings in many countries, including Poland, the asbestos-cement sheets have been replaced by different isolating materials, mainly glass wool and other synthetic fibers. In fact, synthetic vitreous fibers (SVS), also called man-made mineral fibers [9], have been used extensively in residential and industrial settings for more than one century. They are used primarily for thermal and acoustical isolation, liquid and gas filtration, industrial textiles, and for reinforcing other materials. SVS include a very broad variety of inorganic fibrous substances with an amorphous (vitreous, i.e., non-crystalline) molecular structure. Traditionally, they have been arbitrarily divided into three general categories based on composition and application [4]: fiberglass (including glass wool and the thicker glass filament), mineral wool (rock, stone and slag wool), and refractory ceramic fibers. However, in the last few years, these three categories have become antiquated; the categories are useless for a number of new "hybrid" SVS formulations and are irrelevant for hazard classification [4]. The commercial production of these materials became especially important when the adverse health effects associated with asbestos prompted the search for a substitute material.

It should be noted that fiber-containing materials become dangerous only when the microscopic fibers are emitted from these materials into air. Such phenomenon appears if fiber-containing materials become friable (crumbling), for example due to the atmospheric weather, or if building maintenance, repair, renovation or other activities (vibration

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and vandalism) disturb these materials. Therefore, it can be concluded that the important factor that generates, or considerably increases, the emission of fibers from these fiber-containing materials used in buildings is the mechanical impact. Also in the industry the health risk of workers exposed to fiber-containing materials is directly related to the condition of these materials and their property to emit airborne fibers due to a mechanical contact (impact or/and vibration).

In the last decade some papers describing in qualitative way the process of fibers emission have been published. For example, the release of asbestos fibers from the brake pads of overhead industrial cranes has been described by Spencer *et al.* [17]. USEPA prepared the memorandum on the testing carpet, being the asbestos reservoir [19]. Crossman *et al.* [2] reported the quantification of fiber releases for various floor tile removal methods. They documented that fibers are released when floor tile is broken and/or abraded during removal procedures. They established that fiber levels vary with the aggressiveness of the procedures but they did not study the emission rate. After the pioneering work of Spurny [18] on the release of asbestos fibers from weathered and corroded asbestos-cement products, recently the emission of fibers from asbestos-cement plates due to the mechanical impact has been determined experimentally [11]. However, till now the phenomenon of the mechanically generated emission of fibers from fiber-containing non-asbestos materials has not been satisfactorily recognized.

The aim of this work was to determine the emission rate of fibers released from the new/fresh and used/worn ceramic fiber material, glass wool and man-made mineral fiber material due to the mechanical impaction.

EXPERIMENTAL

A simple experimental set-up has been developed to measure the emission of fibers from the selected materials. The samples of studied materials having a surface area between 0.02 and 0.03 m^2 were placed inside the AURA 2000 M.A.C. Cabinet adapted for the fiber emission experiments. Masses of the samples ranged from about 7 g to 58 g. During the experiments the ventilation system as well as UV lamps was switched off. The basic principle of the experiments was as follows: the falling weight (10 iron balls of 19 g each, or one iron weight of 450 g) generated the emission of fibers from the samples of fiber-containing materials. Since the falling height was 23 cm, the impaction energy was 0.4 J and 1.0 J respectively. Such low impact energy values were selected to simulate both: vibrations of the fiber-containing building facades caused by the turbulence of wind, and weak mechanical impacts made by workers during the renovation of the thermal isolation of buildings and industrial devices. Additional reason was to keep the same conditions like in the previous study of the emission of fibers from the asbestos materials [11]. The increasing concentration of fibers in the cabinet volume was measured by the Laser Fiber Monitor (MIE, Inc., Billerica, MA). The method used in this monitor is based on the electric field-induced alignment and oscillation of particles, combined with light scattering, resulting in the highly selective detection of individual fibers, even in the presence

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of a population of predominantly non-fibrous particles. After each experiment the cabinet was cleaned using the ventilation system with HEPA filter. During all experiments the air temperature and humidity inside the cabinet were almost constant, maintained at the level 24–25°C and 30–31%, respectively.

This set-up had been previously successfully used for the study of fibers emission from mechanically impacted asbestos-cement sheets [11]. Therefore, its detailed description, including the photograph of the Laser Fiber Monitor connected with the cabinet, can be found in this paper.

Figure 1 illustrates the main part of the experimental set-up, located inside the cabinet. It can be seen the photographed sample of mineral fiber material after the mechanical impaction by the iron balls (which can be also observed near the sample) and on the sample surface as well. Over the sample is seen the box for the balls. These balls could drop down through the hole, located in the bottom of the box, and opened from the outside of the cabinet.

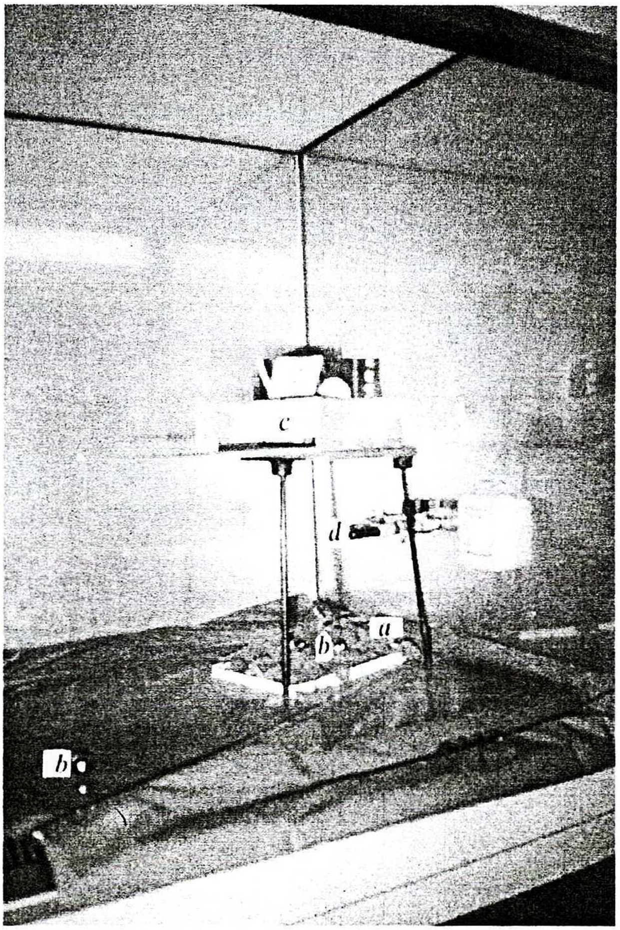

Fig. 1. Photograph of the main part of the experimental set-up inside the cabinet
a – the sample of a mineral fiber material, b – the iron balls, c – the box with iron balls d – the tube connected with the Laser Fiber Monitor (located outside the cabinet)

The emission rate is defined in this study as a number of fibers emitted from the unit mass of investigated material due to the impaction of unit impaction energy. This factor was calculated using the following equations:

$$\epsilon_{m} = \Delta C_{max} \cdot V/(m \cdot E) \tag{1}$$

where:

ϵ_{m} [1/(g·J)] – is the mass emission factor (using the traditional units [fibers/(g·J)]),
ΔC_{max} [fibers/m^3] – is the highest increase in the measured concentration of fibers inside the cabinet after impaction of 10 balls or one iron weight,
V [m^3] – is the volume of the cabinet,
m [g] – is the mass of the sample,
E [J] – is the impaction energy.

The emission rate has been determined for the following, new/fresh and used man-made fiber-containing materials: glass wool, ceramic fibers and man-made mineral fibers. The length distributions of the emitted fibers have been also investigated.

The new/fresh samples were the production residuals while all samples of the used/worn fiber-containing materials were prepared from the materials previously used as a thermal isolating medium. The glass wool has been used for about 20 years as a thermal wrapper of the hot water pipe-line crossing over the ground. Other materials have been used in the industrial plants.

RESULTS AND DISCUSSION

Table 1 shows the averaged values of the mass emission factor ϵ_{m} for 3 types of fiber-containing materials, fresh and used/worn: glass wool, ceramic fibers and man-made mineral fibers. It can be seen that the mechanically induced emission of long ($L > 5$ μm) and short ($L \leq 5$ μm) fibers from the new/fresh materials is the lowest for the man-made mineral fibers. It should be noted that the emission factor of short fibers for all fresh materials is between 2 and 20 fibers/(g·J) while the emission rate of long fibers shows more significant differences and ranged from 2 fibers/(g·J) for material containing man-made mineral fibers through 69 fibers/(g·J) for glass wool, up to 100 fibers/(g·J) for ceramic fiber material.

Table 1. The mass-oriented emission rate of long ($L > 5$ μm) and short ($L \leq 5$ μm) airborne fibers released from three kinds of fiber-containing materials due to the mechanical impact

Numbers of samples studied	Material	ϵ_{m} [1/(g·J)]*	
		$L > 5$ μm	$L \leq 5$ μm
Glass wool			
4	new (fresh)	$6.9 \cdot 10$	$2.0 \cdot 10$
4	old (used)	$4.5 \cdot 10$	$2.2 \cdot 10$
Ceramic fiber			
5	new (fresh)	$1.0 \cdot 10^2$	$1.3 \cdot 10$
7	old (used)	$3.0 \cdot 10^3$	$2.4 \cdot 10^2$
Man-made mineral fibers			
3	new (fresh)	2.2	2.2
4	old (used)	$7.0 \cdot 10^4$	$5.7 \cdot 10^4$

*in traditional units [f/(g·J)]

It is interesting that the increase of the emission factor of used fiber-containing material highly depends on the type of material. The analysis of the Table 1 indicates that the mass-oriented emission factor of the used mineral fiber material is ten thousand times higher comparing with fresh material while the emission rate of glass wool does not change with long term exploitation. The used ceramic fiber material has the emission factor ten times higher than the emission rate of the fresh material.

Figures 2–4 show the length distributions of airborne fibers emitted during the mechanical impaction. These length distributions have been averaged for the data obtained from both the new and old (used) materials. Although these distributions differ from each other, it can be found that every distribution seems to be two-modal with a first peak appearing for short fibers (L ≤ 5 μm) and the second one observed in the 5–8 μm length range. In this context it is important to note that the length distribution of airborne fibers emitted from asbestos-cement sheets is one-modal, having a peak concentration level in the 4–5 μm length range [11].

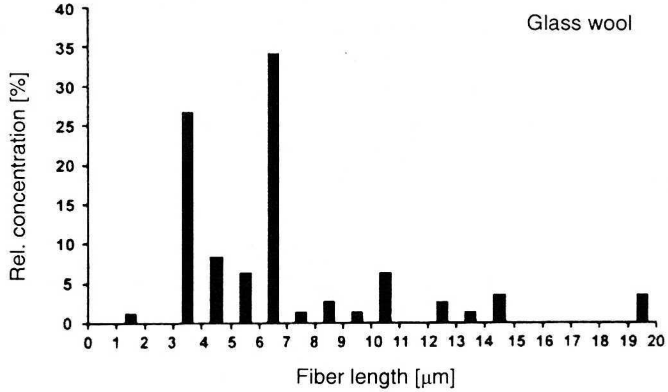

Fig. 2. Length distribution of the fibrous aerosol generated from the glass wool by the mechanical impaction

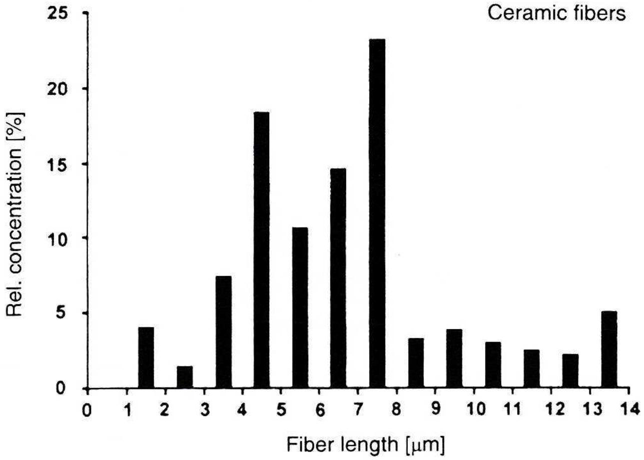

Fig. 3. Length distribution of the fibrous aerosol generated from the ceramic fiber-containing material by the mechanical impaction

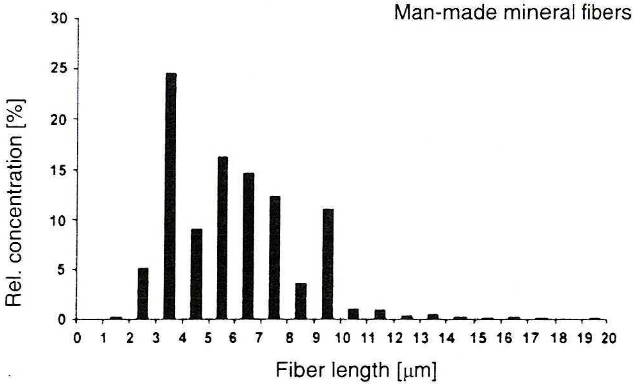

Fig. 4. Length distribution of the fibrous aerosol generated from the man-made mineral fiber-containing material by the mechanical impaction

Finally, it was measured the factor ε'_s, defined as a number of emitted fibers per unit area of the impacted surface of the sample, for some impaction energies: from 0.04 J to 1.44 J. The example result, obtained for the sample of the man-made mineral fiber material, is presented in Figure 5 indicating that in the studied range of impaction energy the relationship between ε'_s and impaction energy E can be described by a linear function.

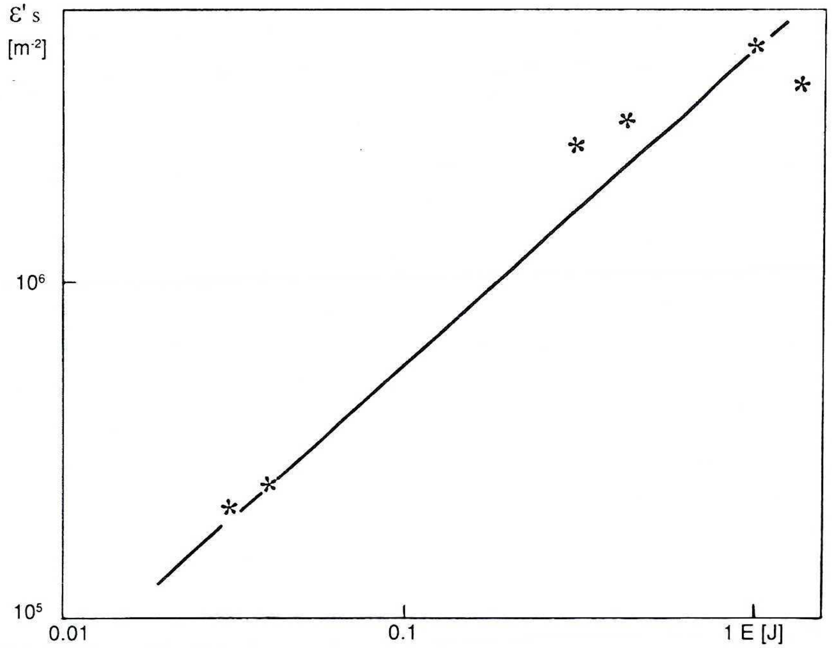

Fig. 5. Fibers emission from the area unit of the man-made mineral fiber-containing material as a function of the impaction energy

Because this paper discusses only the preliminary results of the emission of fibers from some kinds of fiber-containing mechanically impacted materials it was not possible to described how the exploitation conditions and exploitation time influence the emission factor. To find these relationships further studies are needed.

CONCLUSIONS

Various insulating materials made from natural or artificial fibers are susceptible to emitting fibrous particles generated by impact.

The mass emission rate of short fibers for all new/fresh non-asbestos fiber materials ranges from about 1 to 10 fibers/(g·J) while the emission of long fibers was more diverse; it was about 1 fiber/(g·J) for man-made mineral fibers, 10 fibers/(g·J) for glass wool and about 100 fibers/(g·J) for ceramic fibers.

The susceptibility of worn/used fiber-containing materials to emitting fibrous particles due to a mechanical impaction is significantly diverse:

a) Emission from glass wool did not change after the exploitation.
b) The emission rate of the worn/used ceramic fiber material increased nearly ten times compared to the emission from the new material.
c) The emission rate of the mineral fiber material increased by 10^4 times above the emission level from the new material.

The dominating population of fibers emitted during a mechanical impaction from the examined materials contains fibers from 2 to around 8 µm of length.

The length-distribution of fibers emitted from materials containing man-made fibers is two-modal, with the first maximum appearing for short fibers ($L \leq 5$ µm) and with the second maximum in the range of fibers of 5–8 µm long.

The method of the estimation of the emission rate, described in this work, could be useful in the assessment of the health risk related to human contact with the fiber-containing materials, as well as in the control measurements of the safety level of these materials.

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REFERENCES

[1] Burmeister B., T. Schwerdtle, I. Poser, E. Hoffmann, A. Hartwig, W.U. Müller, A.W. Rettenmeier, N.H. Seemayer, E. Dopp: Effects of asbestos on initiation of DNA damage, induction of DNA-strand breaks, P53-expression and apoptosis in primary, SV40-transformed and malignant human mesothelial cells, Mutation Research, 558, 81–92 (2004).

[2] Crossman R.N. Jr., M.G. Williams Jr., J. Lauderdale, K. Schosek, R.F. Dodson: Quantification of fiber releases for various floor tile removal methods, Appl. Occup. Environ. Hyg., 11, 1113–1124 (1996).

[3] Gilbertson K.E., W.H. Finlay, C.F. Lange, M.J. Brett, D. Vick, Y.S. Cheng: Generation of fibrous aerosols from thin films, Journal of Aerosol Science, 36, 933–937 (2005).

[4] Hesteberg T.W., G.A. Hart: Synthetic vitreous fibers: a review of toxicology research and its impact on hazard classification, Critical Reviews in Toxicology, 31, 1–53 (2001).

[5] Kadiiska M.B., A.J. Ghio, R.P. Mason: ESR investigation of the oxidative damage in lungs caused by asbestos and air pollution particles, Spectrochimica Acta Part A, 60, 1371–1377 (2004).

[6] Maxim L.D., E.E. McConnell: Interspecies comparisons of the toxicity of asbestos and synthetic vitreous fibers: a weight-of-the-evidence approach, Regulatory Toxicology and Pharmacology, 33, 319–342 (2001).

[7] Moolgavkar S.H., J. Turim, R.C. Brown, E.G. Luebeck: Long man-made fibers and lung cancer risk, Regulatory Toxicology and Pharmacology, 33, 138–146 (2001).

[8] National Research Council (NRC): Review of the U.S. Navy's Exposure Standard for Manufactured Vitreous Fibers, National Academy Press, Washington, DC, 1–63 (2000).

[9] Navy Environmental Health Center (NEHC): Man – Made Vitreous Fibers, Navy Environmental Health Center, Norfolk, Virginia (1997).

[10] Pastuszka J.S.: Asbestos fibers in the indoor environment, [in:] Sourcebook on Asbestos Diseases, (G.A. Peters, B.J. Peters, ed.), LEXIS Publishing, Charlottesville, Virginia, 261–280 (1997).

[11] Pastuszka J.S.: Emission of airborne fibers from mechanically impacted asbestos-cement sheets and concentration of fibrous aerosol in the home environment in Upper Silesia, Poland, Journal of Hazardous Materials, 162, 1171–1177 (2009).

[12] Pastuszka J.S., A. Kabała-Dzik, U.K.T. Paw: A study of fibrous aerosols in the home environment in Sosnowiec, Poland, The Science of the Total Environment, 229, 131–136 (1999).

[13] Pastuszka J., J.A. Sokal, R.L. Górny: Fibrous and particulate pollution of indoor air in Upper Silesia, a highly industrialized Polish region, Preliminary results, [in:] Proceedings of Indoor Air'93, vol. 4, 17–22, Helsinki, Finland (1993).

[14] Peters G.A., B.J. Peters (ed.): Asbestos and Cancer. Sourcebook on Asbestos Diseases: Medical, Preventive and Socio-Economic Aspects, vol. 16, LEXIS Publishing, Charlottesville, Virginia (1997).

[15] Peters G.A., B.J. Peters (ed.): The treatment and prevention of asbestos diseases, Sourcebook on Asbestos Diseases: Medical, Preventive and Socio-Economic Aspects, vol. 15, LEXIS Publishing, Charlottesville, Virginia (1997).

[16] Podgórski A., L. Gradoń: Mechanics of a deformable fibrous aerosol particle: general theory and application to the modelling of air filtration, [in:] Advances in Aerosol Filtration (K. Spurny ed.), Lewis Publishers, Boca Raton, Florida, 193–218 (1998).

[17] Spencer J.W., M.J. Plisko, J.L. Balzer: Asbestos fiber release from the brake pads of overhead industrial cranes, Appl. Occup. Environ. Hyg., 14, 397–402 (1999).

[18] Spurny K.R.: On the release of asbestos fibers from weathered and corroded asbestos cement products, Environmental Research, 48, 100–116 (1989).

[19] United States Environmental Protection Agency (USEPA), Office of Solid Waste and Emergency Response: Memorandum of June 9, 2002 on the subject: Testing Carpet, the Asbestos Reservoir, Washington, D.C. (2001)

[20] Walton W.H.: Airborne dust, [in:] Mineral Filters and Health, CRC Press, Boca Raton, Florida (1991).

[21] World Health Organization (WHO): Air Quality Guidelines for Europe, Second edition, Regional Office, Copenhagen (2000).

[22] World Health Organization (WHO): Asbestos and other natural mineral fibers, [in:] Environmental Health Criteria, No. 53, Geneva (1986).

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EMISJA WŁÓKIEN Z NIEAZBESTOWYCH MATERIAŁÓW WŁÓKNISTYCH GENEROWANA MECHANICZNĄ IMPAKCJĄ: WYNIKI WSTĘPNE

W pracy wyznaczono doświadczalnie wskaźnik emisji włókien wydzielanych z nowych oraz zużytych materiałów włóknistych (włókna ceramiczne, wełna szklana sztuczne włókna mineralne) na skutek mechanicznej impakcji (uderzenia). Wskaźnik emisji zdefiniowano jako ilość włókien emitowanych z jednostki masy na skutek jednostkowej energii uderzenia. Średni wskaźnik emisji krótkich włókien ($L \leq 5$ µm) dla wszystkich badanych nowych/świeżych materiałów nieazbestowych zawierał się w przedziale od 2,2 do 20 włókien/

(g·J), natomiast emisja długich włókien ($L > 5$ μm) wynosiła od 2,2 do 100 włókien/(g·J). Podatność zużytych materiałów włóknistych do emitowania cząstek włóknistych na skutek uderzenia była znacząco zróżnicowana. Emisja z wełny szklanej nie zmieniała się na skutek eksploatacji materiału, podczas gdy wskaźnik emisji z zużytego materiału zawierającego sztuczne włókna mineralne był większy w stosunku do wskaźnika emisji z nowego materiału aż 10^4 razy. Dominującą populację włókien emitowanych z badanych materiałów stanowiły cząstki włókniste o długości od 2 do około 8 μm.