Critical Evaluation of Individual Hearing Protectors of Workers in Civil Construction

Fernando B. Mainier[1], Larissa F. Dantas[2], Daniel O. G. de Souza[3]

[1]Escola de Engenharia, Universidade Federal Fluminense, Niterói, RJ, Brazil: fmainier@uol.com.br
[2]FIOCRUZ e Universidade Federal Fluminense, Niterói, RJ, Brazil: larissafdantas@gmail.com
[3]Petrobras, Petróleo Brasileiro, RJ, Brazil: daniel.petrobras@gmail.com.br

Abstract — *The hearing protection of workers is of great concern to occupational health and safety professionals because of the irreversible damage caused by prolonged exposure to noise. This work seeks to determine whether the hearing protection equipment used in the construction industry today is adequate, considering that, in addition to the intense noise, other risk factors are present in the typical environment of a construction site. For this, a survey was conducted on how workers in the industry recognise and prevent exposure to noise and how they use hearing protection. Subsequently, laboratory experiments were used to study, how the main contaminants interact with the material of which this equipment is composed. In laboratory tests, both foam and silicone plugs gained weight when exposed to contaminants typically found in construction. This fact evidenced the need for training regarding the hygiene of hearing protectors. Regarding the performance of the foam earplugs in the tests, it was verified that, even though they went through the cleaning process, the equipment also increased in mass. This fact demonstrates that cleaning helps but does not eliminate the contamination of the hearing protection devices (HPD). Finally, it was concluded that the both types of earplugs are efficient in relation to noise attenuation and protection of the hearing of the workers. However, the way they are used and cleaned can influence the contamination of these protectors and the research detected both a lack of information from the manufacturers and little or no training of the workers.*

Keywords — civil construction, work safety, hearing protection equipment, hearing protection.

I. INTRODUCTION

The construction industry in Brazil has been modernising the tools and methods used to carry out its processes. New execution times and quality parameters, as well as the need to optimise costs, have required the emergence of new and more modern tools, but they are no less noisy than their predecessors.

To eliminate or minimise worker exposure to noise, a number of measures can be implemented by employers. Engineering controls, such as enclosing noisy machines and implementing acoustic barriers in the environment are expensive and often unfeasible during the production process. In other words, the use of individual protection equipment is still the main means used to minimise the damage to health caused by noise.

Different types of hearing protection devices (HPD) are available on the market. Earmuffs and plugs, disposable or not, can be found at industry-specific stores varying in price, quality, and protection capability. The choice of HPD is fundamental to the success of hearing protection for construction workers. The scenario found in works in Brazil usually involves high temperatures, use of volatile chemicals such as paints and solvents, and certainly involves high levels of suspended particles.

Figure 1, below, shows a flagrant breach of health and safety procedures at civil works, where workers are subject to noise and dust but do not use the obligatory ear protection during these operations.

Fig. 1: Construction workers not wearing ear protectors

This work aims to analyse whether the hearing protection devices used in the civil construction industry today are adequate, considering that, in addition to the intense noise, other risk factors are present in the typical environment of a construction site. In order to answer this question, it is first necessary to study the working environment and the people who work in it. To do so, it is necessary to identify how construction workers recognise and prevent exposure to noise and to study, in practice, how the main contaminants interact with the material of which this equipment is composed.

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II. CONTEXTUALISATION

2.1 Noise in construction

The construction industry, according to Maia [1] uses "increasingly fast machines, has made the tasks of workers in this branch noisier and, consequently, generated hearing loss and other effects in an increasing number of workers". This author identified the main sources of noise for the general helper, bricklayer, and carpenter and assessed the sound pressure levels to which they were exposed during the typical tasks of these types of service through dosimetry.

The maximum levels found for each of the functions studied and the corresponding activities to which they are related can be observed in Table 1, below.

Table.1: Maximum Levels (L Max) for each function in construction and its respective activity.

Function	Activity	L_{eq}(Max)
General helper	Concrete mixer operation	84.3 dB
Bricklayer	Granite cutting and laying	104.3 dB
Carpenter	Assembly of slab forms	100.0 dB

Source: adapted from Maia [1].

Farias, Buriti, and Rosa [2] investigated the occurrence of noise-induced hearing loss in carpenters in Brazilian civil construction. The study found that 35% of the professionals presented unilateral or bilateral losses in the frequencies of 3 kHz, 4 kHz, and/or 6 kHz.

The research of Seixas et al. [3] concluded that in some countries 16 to 50% of construction workers are affected by noise-induced hearing loss, and for a certain age range this percentage reaches at least 75%. There are several studies based on noise exposure in works which show noise levels of 75 to 113 dB (A) at the operating points of the machines and noise levels between 65 and 91 dB (A) in the work environment [4–6].

2.2 Hearing protection devices

Earmuffs completely cover the worker's ears. They consist of shells, usually plastic, lined with foam pads on the sides (which come into contact with the user's head) and inside the shells. Its band consists of plastic or metal, which serves to keep the shells tightly sealed against the region of the user's ears. The band can also be separated and attached to the user's helmet.

Insertion hearing protectors, which are popularly known as earplugs, are equipment inserted into the ear canal. They may be of the preform type with a format composed of three flexible silicone, copolymer, or rubber; or mouldable flanges made of flexible foam that adapt to the size of the user's ear canal. The insert protectors may be disposable or reusable and may or may not have a cotton cord, depending on the make and model.

Beltrame [7] listed the advantages and disadvantages of earmuffs and earplugs (Table 2).

Table.2: Main advantages and disadvantages of HPD models.

Model	Benefits	Disadvantages
Earmuffs	Easy to fit and wear; Convenient for intermittent exposure; Small risk of infection; Good adaptation to users; Good durability; Comfortable in cool environments; Easy to use correctly.	High cost; Heavy; May not be comfortable in very hot and humid climates; Occupies a lot of space; Maintenance and more complex hygiene;
Earplugs	Low cost; Light; It takes up little space; Small and easy to carry; Comfortable in warm environments; Ease of substitution; Simple maintenance and cleaning.	Complexity in placement; Need for prior training; The size must be appropriate to the user's ear canal; Difficult identification for the user; Difficult to verify correct use; High risk of infection; Accumulation of dirt.

Source: adapted from Beltrame [7].

III. MATERIALS AND METHODS

As a data collection instrument, a survey structured through a questionnaire was used. The objective was to investigate the types and models of HPD most used in construction works; evaluate the perception and the habit of workers regarding the use, maintenance, and hygiene of the equipment; and to verify for how long these workers use the same HPD until their replacement, including those considered disposable by their manufacturers. The complete survey can be found in Dantas [8].

Based on the answers obtained in the survey, a suspended particle contamination test was proposed, which seeks to simulate the situation of an HPD that remains in an inappropriate place after its use, such as inside a helmet, exposed in the construction environment. This test was performed in two different ways: with and without daily cleaning of the specimens.

The specimens comprised five models of each type of insertable earplug of different national and imported manufacturers, never used before.

This study is focused on the construction industry; therefore, common products of the sector such as concrete, red ceramics, mortar, soil, sand, and sawdust were used in the tests. A mixture with equal parts of 10 g of each contaminated crushed and with granulometry standardised by means of sieve with 18 mesh opening was used. The trials described below are part of the study by Dantas [8].

3.1 Suspended Particle Contamination Test without Hygienisation Process

The purpose of this test is to simulate the exposure of hearing protection equipment to suspended impurities in the environment surrounding the work site over a period of several days. First, the weight of each HPD was determined using a digital scale with an accuracy of 0.0001 g. In a container of approximately 2000 cm^3, 10 g of the contaminant mixture was placed. After closing the container, it was shaken for 30 seconds in order to lift the lighter particles. After suspension of the particles, the HPD were inserted into the vessel so that they came into contact with the formed dust without touching the particles accumulated in the bottom, as shown in Figure 2, below. After remaining for one hour inside the container, the HPD were removed and the weights re-measured. This process was repeated for five days, with a 24-hour interval between each contamination and weighing.

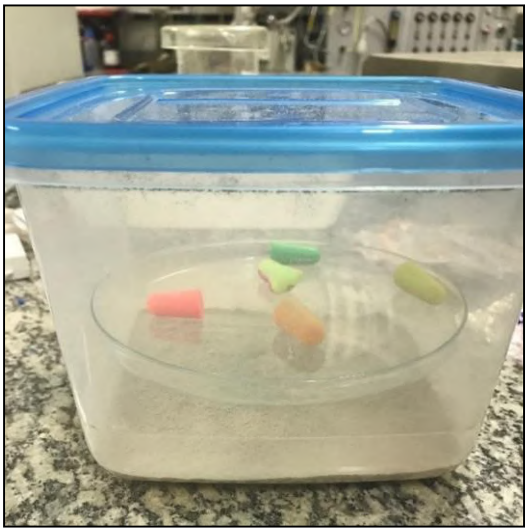

Fig. 2: Test for the dust contamination of ear protectors

The mass gain, represented by the difference between the final and initial weights of the protectors, is due to the accumulation of suspended particles deposited on the surface of the ear protectors inside the test vessel.

3.2 Suspended Particle Contamination Test with Hygienisation Process

The sanitised particle contamination assay was performed in the same manner as in the first step. On each test day, the test specimens were weighed and subsequently placed into the vessel with the suspended contaminant mixture for 40 minutes. After passage through the test vessel, the specimens were weighed again.

The difference in this test is that, after contamination and weighing, the guards went through a standardised cleaning process. The hygienisation process sought to simulate washing with soap and water, which is recommended by most manufacturers. For this, a mixture of 50 mL of distilled water and 5 mL of neutral detergent was used in each wash. Each HPD was inserted into a 100 mL glass beaker containing the blend and agitated by vortexing using a magnetic bar for 30 seconds.

After the sanitisation, the equipment was again weighed in order to verify how much water was absorbed by the material. Finally, the specimens were placed for 24 hours in a greenhouse with controlled temperature and humidity (35ºC and 55%) so that the water absorbed in the hygiene process could be eliminated. After the time in the greenhouse, the equipment was again weighed to measure the amount of contaminants that remained adhered to the HPD after the hygiene process.

The cycle described above was repeated for five days, representing the average time of use of the equipment by the workers.

IV. RESULTS AND DISCUSSION

4.1 Survey carried out with civil construction workers

A total of 113 responses were obtained from workers from three different civil construction companies in the cities of Rio de Janeiro and Niterói, state of Rio de Janeiro, Brazil. The sample contained responses from people with different functions, different levels of experience, and different levels of schooling. They were mid-level/technical, fundamental, and with no complete training.

The Survey was divided into three clusters, and the results will be presented in Figure 3, divided as follows:

- Profile of respondents;
- Scenario found in civil construction works related to hearing protection; and
- Habits and perceptions of workers related to the use of hearing protection devices.

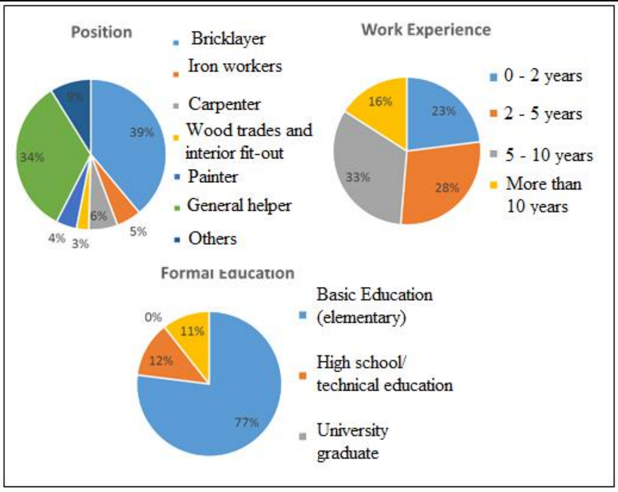

Fig.3: Respondent profile

It should be noted that, at the end of this first cluster, it is possible to verify that the majority of workers in the sample are bricklayers. Most respondents have more than five years of experience in the field and the most common training among respondents was full elementary education. Thus, it is noted that the sample actually reached the desired audience in the survey, which were the professionals who work directly in the operational part of civil construction works.

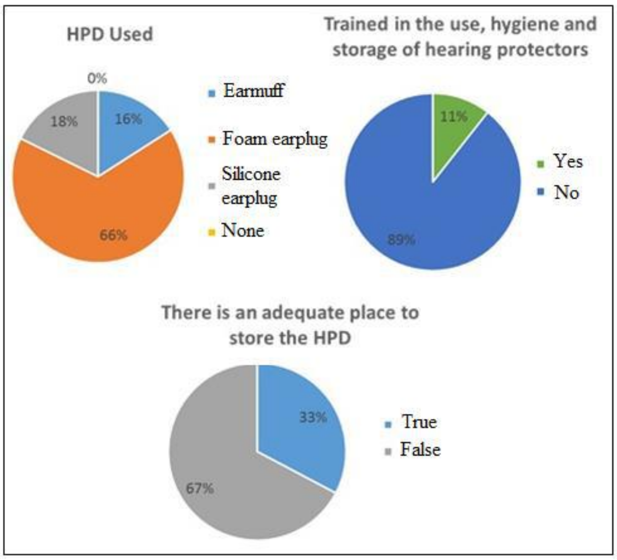

Fig.4: Scenario found in civil construction works related to hearing protection

As can be seen from the graphs depicted in Figure 4, above, the most commonly-supplied HPD are foam and silicone earplugs. None of the respondents stated that they did not receive hearing protection equipment from their company.

Training is a major segmental failure point—89% of respondents reported having not been trained in the use, hygiene, and storage of hearing protectors.

Finally, the third question in this cluster referred to the existence of an adequate place to store the HPD when not in use. This statement was answered as false by 67% of the respondents, so a large number of workers do not have a clean place to store the equipment after use. This means that the HPD end up being stored in pockets, cabinets, drawers, tied to the helmet, and other places that are subject to contamination by the work environment. When they use the dirty protector again, the contaminants can come into direct contact with the auditory canal of these workers.

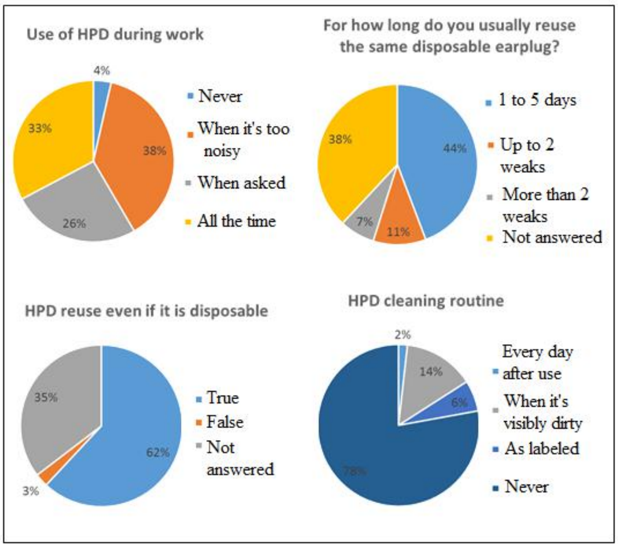

Fig. 5: Habits and perceptions of workers related to the use of HPD.

The third and last cluster (Figure 5) aimed to capture the behaviour of the civil construction worker. It can be seen that the vast majority of respondents only use the HPD when they perceive some loud noise. This fact demonstrates that the safety culture is not yet fully integrated into the day-to-day work of construction workers.

Regarding the time they use the disposable protector until it is replaced, 44% reported that they use the same equipment for one to five days, 11% for up to two weeks, and 7% for more than two weeks of work. Respondents who did not use the disposable HPD had their responses described as "not answered" in the graphic. Considering only the valid answers, that is, the workers who use the disposable HPD, the percentages go up to 71% who use the equipment for one to five days, 17% who use it for up to two weeks, and 11% for more than two weeks of work.

The vast majority of respondents, 78%, admitted that they never clean the HPD and only 2% reported washing the equipment daily after use. The percentage of respondents who never do the HPD sanitisation or do so only when they visually notice that the equipment is dirty, is very high, 92% of the sample analysed. This fact may also be

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directly related to the lack of training and guidance. Examining only this group, it is noticed that the percentage that never received training is 98%.

4.2 Results of laboratory tests

4.2.1 Suspended particle contamination test without cleaning process

For the results, the arithmetic mean of the values obtained for the three different test specimens of each manufacturer was considered. The complete tables of results for this assay can be found in Dantas [8].

It is possible to observe that all the protectors presented an average weight gain between 0.98 and 1.47% of the initial weight, with each test day. The total weight gain was 6.19% between the first and the last test day, representing a mean aggregation of 0.031 g of contaminants on the mouldable protectors during the period.

Analysing the graphs shown in Figure 6, it is also possible to notice that models 2 and 5 were the ones that had the greatest addition to their initial masses: 6.44% and 6.25% gain, respectively, during the five days of tests. These percentages, however, are not far from those observed for the other models, which remained close to 6%.

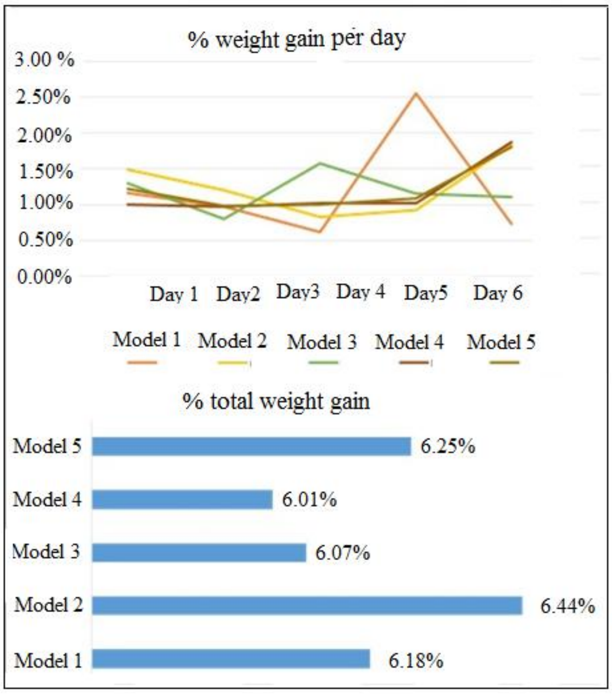

Fig. 6: Results of the mass gain tests of contaminants

4.2.2 Suspended particle contamination test with cleaning process

For the results, the arithmetic mean of the values obtained for the three different test specimens of each manufacturer was considered. The complete tables of results for this assay can be found in Dantas [8].

On average, the water uptake by the test specimens was similar, close to 15% of their weights after passage through the contaminant box. This absorbed water mass was eliminated by drying the specimens in an oven for 24 hours. The final calculations of the amount, by weight and mass percentage, of contaminants added to the test specimens at the end of the test days are shown in the following table 3.

Table.3: Final results of the suspended particle tests with cleaning process for foam earplugs.

FINAL RESULTS: DAY 5 X DAY 1			
Model	**Final Weight (g)**	**Total Aggregation (%)**	**Total Aggregation (g)**
1	0.4044	5.72%	0.0230
2	0.6266	7.12%	0.0420
3	0.4901	4.06%	0.0194
4	0.5932	5.02%	0.0288
5	0.5572	5.87%	0.0315
Mean	**0.5343**	**5.56%**	**0.0290**

It is possible to verify, from the results presented in the tables, that despite cleaning, all of the protectors showed mass gain. This increase at the end of the five test days varied between 4.06 and 7.12% more than the initial weight of the specimens. The mean total gain was 5.56% between the first and last test day, representing a mean aggregation of 0.029 g of contaminants in the mouldable pads during the period.

It is noted that the aggregation of material to the protectors was very similar to the result obtained without daily cleaning of the same, which was 0.031 g on average (Figure 7).

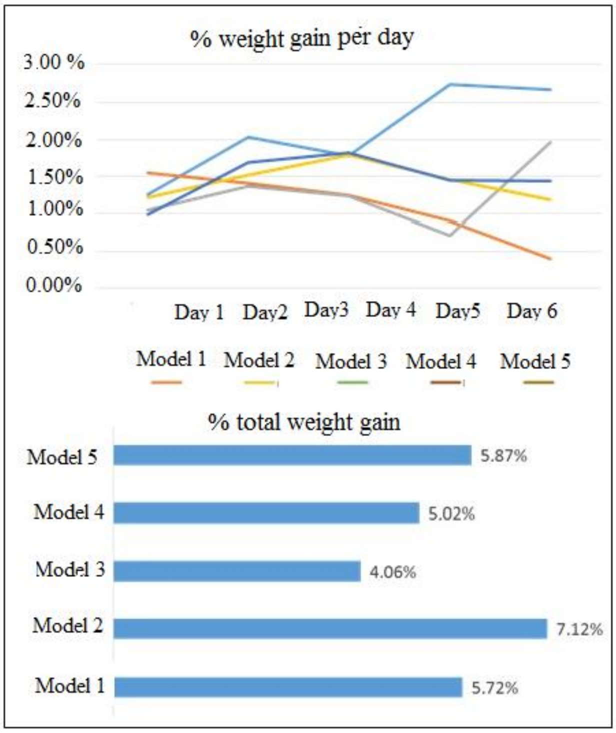

Fig. 7: Results of the cleaning of contaminated samples

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4.2.3 Comparison between HPD contamination results with and without cleaning process

Based on the assumption that the hygiene process of the hearing protection equipment has the purpose of removing the accumulated contaminants, it was expected that, after drying, the weights of the specimens would be similar to those before the passage through the chamber of solid particles; that is, the protector would have its mass increased by the accumulation of the solid particles on its surface, but after cleaning and evaporation of the accumulated water, it would return to some value close to its original weight as these particles would have come off during washing. Following the logic of this reasoning, at the end of the five test days, the equipment would present a mass gain much lower than those that did not go through the hygiene.

However, this was not the behaviour presented by the specimens that were submitted to the cleaning process. They reached increases of mass similar to those that were not washed after exposure to dust, as can be seen in the comparative graph of Figure 8, below.

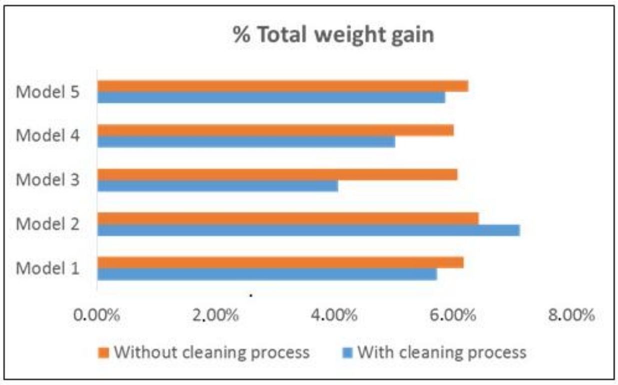

Fig. 8: Comparison of results with and without sample cleaning

Finally, based on the tests carried out, it is possible to admit that the dust present in civil construction when adhering to the ear protectors, when not removed, can cause problems in the auditory canal and consequently hearing diseases as shown in the diagram in Figure 9.

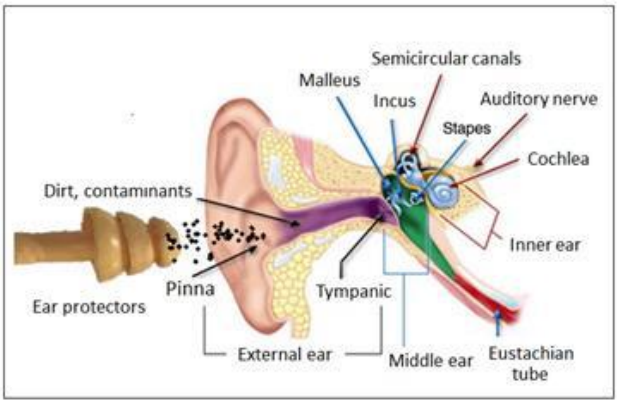

Fig. 9: Diagram of contamination of ear of worker

V. CONCLUSION

It should be noted that the worker's education level influences his or her concern with work safety norms and, consequently, the use of HPD during working hours. It was also an influence factor in the responses of the experience time in the function. Among the workers who do not use hearing protection, we highlight the group of professionals with little experience, 0 to 2 years, and those with more than 10 years, where the change of habit is more difficult. For example, many of these workers use phrases such as "I have always done so."

In the laboratory tests, the equipment gained mass when exposed to the contaminants found in civil construction. This fact evidenced the need for training regarding the hygiene of the hearing protector. This item is of concern, as the survey revealed that 89% of respondents do not have training in the correct use, hygiene, and custody of the HPD.

Regarding the performance of the moulded auditory protectors in the tests, it was verified that, even though they went through the washing process, the equipment also had an increase in mass. This fact demonstrates that sanitation decreases but does not eliminate the contamination of the equipment. This can be explained by the porous material of which the foam protectors are formed. The water carries the solid particles into the foam cavities, where they settle more and more deeply until the cleaning process is not able to eliminate them.

Based on the results of the surveys and trials, it can be concluded that the mouldable insertion hearing protection equipment is efficient in relation to the noise attenuation and protection of the hearing of the workers. However, the way they are used and sanitised can influence the contamination of these protectors, and both a lack of information from the manufacturers and little or no training of the workers on these factors were noted.

REFERENCES

[1] P. A. Maia, P.A. (1999). O ruído nas obras da construção civil e o risco de surdez ocupacional (The noise in construction works and the risk of occupational deafness), Masters dissertation, Faculdade de Engenharia Civil, Universidade Estadual de Campinas, Campinas, Brazil, (in Portuguese).

[2] Farias, V. H. V., Buriti, A. K. L. and Rosa, M. R. D. (2012) Ocorrência de perda auditiva induzida pelo ruído em carpinteiros (Occurrence of noise-induced hearing loss in carpenters), Rev. Cefac, Campinas, Brazil, v. 3, n. 14, 413–422. (in Portuguese).

[3] Seixas, N., Neitzei, R., Camp, J. and Yost, M. (1998). An assessment of occupational noise exposure in construction trades, University of Washington,

Department of Environmental Health, Washington. July 9.

[4] Maia, P.A. (2001). Estimativa de exposições não contínuas a ruído: desenvolvimento de um método e validação na construção civil (Estimation of non-continuous exposures to noise: development of a method and validation in civil construction), Thesis, Faculdade de Engenharia Civil, Universidade Estadual de Campinas, Campinas, Brazil, (in Portuguese).

[5] Lie, A., Skogstad, M., Johannessen, H. A., Tynes, T., Mehlum, I. S., Nordby, K.C. and Tambs, K. (2016). Occupational noise exposure and hearing: a systematic review. International archives of occupational and environmental health, v. 89, 351–372.

[6] Hager, L. (2012) Support the 85/3 Occupational Noise Exposure Project. Sound and Vibration, v. 46, 1–4.

[7] Beltrame, L. A. (2010). Desenvolvimento de Software para seleção de Equipamento de Proteção Auditiva (Software Development for Selection of Hearing Protection Equipment), Masters dissertation, Escola Politécnica, Universidade de São Paulo, São Paulo, Brazil, (in Portuguese).

[8] Dantas, L. F. (2017). A proteção auditiva dos trabalhadores da construção civil e os impactos da contaminação nos protetores de inserção (Hearing protection of construction workers and the impacts of contamination on insert protectors), Masters Dissertation, Universidade Federal Fluminense, Brazil, 2017 (in Portuguese).