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Life cycle assessment of the polyethylene bubble foil production process

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ABSTRACT

The subject of the research is a partial model of the "Gate-to-Gate" life cycle assessment. There is the valuation production process of polyethylene bubble foil from the usage of the input material – low density polyethylene – to the production of the final product. The modelling of the environmental impacts production was executed in line with standard STN EN ISO 14040:2007, with the GaBi application software tool, weak point analysis and Ecoindicator 99. Sources entering the system comprised of 97% material sources, especially non-renewable ones, and 3% were energy sources. The outcome of the system comprised of emissions, water (75.7 %), emissions to air (15.1 %) and waste (6.97 %). Disturbance to the water environment from the point of view of eco indicators is caused by the presence of heavy metals, especially copper (32.3 %) and vanadium (24.9 %). From emissive substances into the atmosphere, the highest ratio was CO_2 (4.94 %), which contributes 83.2% to climate changes from the point of global warming eco indicator view.

Keywords: Life cycle assessment • Gate-to-Gate • Polyethylene bubble foil • GaBi

1. Introduction

The Life Cycle Assessment (LCA) method represents an important source of information in relation to the identification of goals in the field of minimisation on environmental impacts. It is a universal method which can be used in production as well as in nonproduction companies. The organisation can use the results of the LCA method even in the design phase, thus environmental impacts can be minimised, utility can be increased, and the costs related to usage and disposal can be decreased [1]. Originally, the LCA method was developed as a supporting tool in the decision making sphere. Followingly its application, it was found in product development and innovation, planning, presentation and environmental policy creation. It is considered a standard tool of environmental management in industrially and environmentally developed countries. Its main applications are focused on product comparison and product design. Whereas, in the initial phase of LCA studies, the aim was on consumer goods sold in retail and by sellers, larger products and services were also added over the last decades of the 20th century, e.g. waste management, electricity generation, automobile production with alternative sources, communication technologies. In accordance with standard STN EN ISO 14040:2007, the method is defined as collection and assessment of inputs and outputs and possible environmental impacts of the product system during its life cycle [2]. The aim of this article is to identify the most important environmental impacts caused by production process of 150 m^2 of bubble foil from LDPE granulated, partially using the LCA (Gate-to-Gate) method.

2. Material and methods

The subject of the assessment is bubble foil produced from granulated LDPE. It is a special type of shaped 100% recyclable two-layer polyethylene foil with air bubbles that is used as wrapping material in the dispatch and shipping of goods. The function unit comprises of a product in the form of 150 m^2 bubble foil.

In the extrusion process of LDPE granulate, basic input raw material is low density polyethylene LDPE in the form of granules supplied by an external company, and electricity. For the production of 150 m^2 bubble foil with a thickness of 80 μm, it is necessary to use 11.50 kg of low density polyethylene and 11.33 kWh of electricity. Output is in the form of LDPE foil with a weight of 11.1kg; and plastic waste with a weight of 0.4 kg which is a side product in the form of residues or abortive, respectively damaged product.

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The second process comprises the production of bubble foil, where the input is polyethylene foil (11.1 kg) and the output is a final product in the form of bubble foil (11.1 kg) [3].

The Life Cycle Assessment Model is a partial Gate-to-Gate model, where only one process of the whole production process is being assessed – the bubble foil production process, with defined input – polyethylene foil, and the output – final product. Limits of the system are defined from the initial usage of the input material to the production of the final bubble foil. The life cycle assessment in the phase of production was executed in line with standard STN EN ISO 14040:2007 with the use of the GaBi software tool. For model implementation, the weak point analysis and Ecoindicator 99 method was used. Input and output data were taken from the production process of the respective company and from its technical documentation

3. Results and discussion

From the point of view of the "Gate-to-Gate" life cycle assessment, we evaluated the extrusion process of LDPE granules and the process of bubble foil, where we identified the inputs and outputs (Fig. 1).

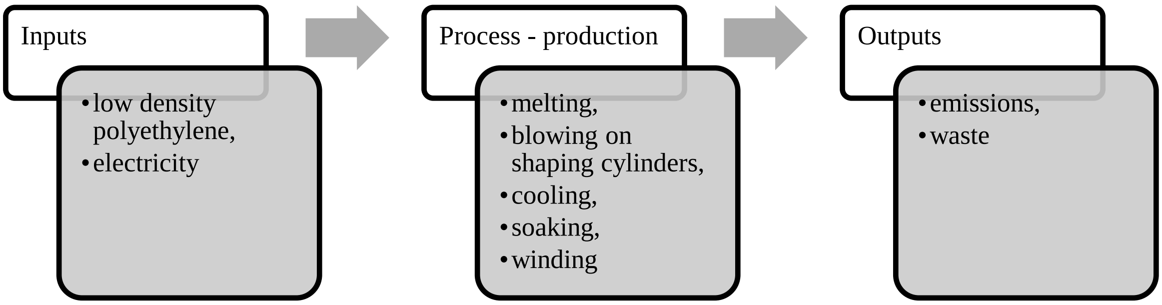

Figure 1 Unit process of bubble foil production

In the inventory phase of the life cycle, there were identified and quantified material and energy flows within the assessed process. The assessment of impacts was executed by weak point analysis – for inputs and outputs. From the balance results it is clear, that in relation to the inputs, material resources were mostly consumed (1,059 kg), from that 37.956 kg of non-renewable resources and1,021 kg of renewable resources, from that mainly water (981 kg).

From the point of view of outputs, the highest values are represented by emissions to fresh water (75.7 %). Higher value, in comparison to other monitored outputs, it had emissions to air (15.1 %), Fig. 2.

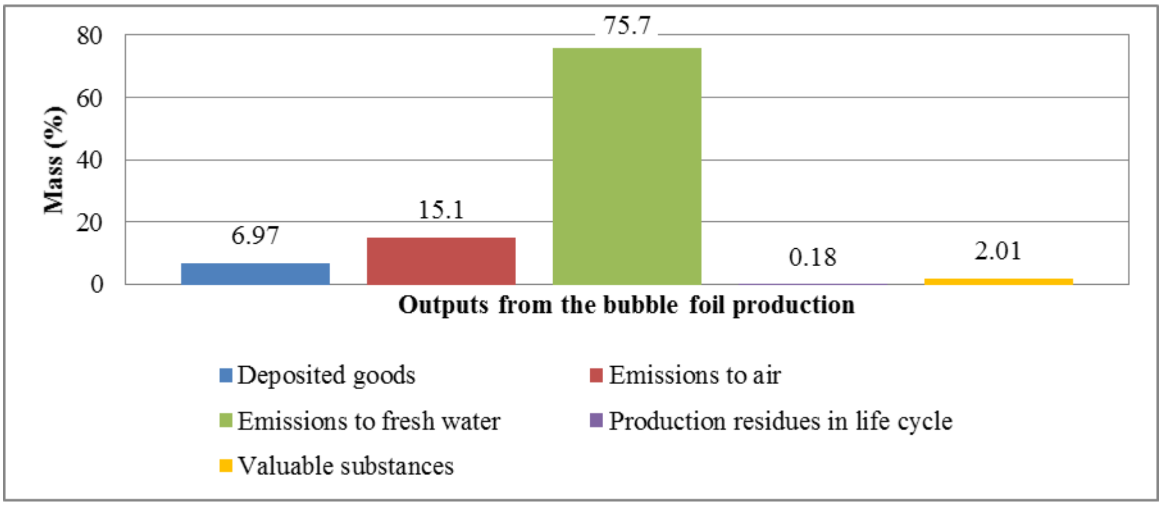

Figure 2 Outputs from the bubble foil production

Emissions to air mainly consisted of inorganic emissions (9.51 %), from that 4.94 % is CO_2. Furthermore, other emissions are represented by exhaust fumes (5.54 %). Heavy metals, radioactive emissions and organic emissions (mainly VOC) and solid particles (under 1 %) were found in a negligible amount.

Ruban (2012) came to a different finding, as she executed research in the life cycle of polyethylene plastic bags [4]. The highest values, in relation to the production process, reached emissions to air. On the other hand, there were nearly any emissions to fresh water or deposited goods. All the by-products were recycled and used again in the production process. The difference in results was caused by the composition of the input material and used technology in production. Harding, Dennis, von Blottnitz, Harrison (2007) compared the partial life cycle of plastic products, also among them products from low density polyethylene LDPE. They came to the result, that the production process needs a significant amount of water [5]. This fact implies a higher production of waste water. Production of emissions to air, in comparison to waste water, is negligible during the production process of LDPE plastic products.

Assessment of the environmental impacts of the bubble foil production process were done by the application method: Ecoindicator 99. Belaňová, et al. (2014) classifies these most often selected categories: carcinogens, organic substances causing respiratory diseases, inorganic substances causing respiratory diseases, climate changes, radiation, ozone layer depletion, eco toxicity, acidification, eutrophication, soil usage, consumption of minerals and fossil fuels [6]. In our research, the following indicators were used: global warming and climate change, ozone layer depletion, acidification, eutrophication, human toxicity, terrestric ecotoxicity, freshwater aquatic ecotoxicity, with the results summarised in Tab. 1 (only indicators with a value over 1 % are mentioned).

Table 1 Percentage assessment of the impacts of the bubble foil production according to selected Ecoindicator 99

Global Warning and Climate Change		Ozone Layer Depletion		Acidification		Eutrophication	
CO_2	83.2	trichlorofluoromethane	47.9	SO_2	66.3	NO_2	77.1
Methane	14.1	dichlorotetrafluoroethane	41.7	NO_2	28.4	Nitrogen oxides	12.0
Hydrocarbons	2.34	dichlorodifluoromethane	8.45	Nitrogen oxides	4.41	Chemical oxygen demand	10.7
		Hallon	1.51				

To be continued Tab. 1

Human Toxicity		Terrestric Ecotoxicity		Freshwater Aquatic Ecotoxicity	
Heavy metals to Air	31.0	Heavy metals to Air	81.1	Copper	32.3
Hydrogen fluoride	28.5	Chromium	5.43	Vanadium	24.9
NO_2	12.8	Arsenic	3.54	Hydrocarbons to fresh water	18.3
Volatile organic emissions to Air (VOC)	14.1	Emissions to fresh water	6.32	Heavy metals to Air	4.26
Emissions to fresh water	7.62			Volatile organic emissions to Air (VOC)	5.07

Categories of environmental impacts can be divided into the following three main groups, according to [7,8]

- depletion of sources (energy and materials, landscape, water);
- impact on human health (impacts on the working environment, toxicology impacts, non-toxicology impacts);
- ecologic and global impacts (acidification, reduction of stratospheric ozone, ecotoxicology impacts, eutrophication, global warming, habitat changes and biodiversity impacts, formation of photo-oxidants).

The results of our research show, that the consumption of sources represents one of the most significant environmental impacts of the bubble foil production.

Taking into consideration the above three main groups of environmental impacts, 97% comprises of the consumption of sources (especially the material ones). Gironi, Piemonte (2011) came to the conclusion, that increased consumption of non-renewable sources is connected to the production of plastic bottles from polyethylene [9]. In terms of the Ecoindicator 99 categories, plastic bottle production has a strong impact on the decreasing quality of ecosystems (acidification, eutrophication, ecotoxicity, landscape changes).

In our research, the group of indicators: ecologic and global wastes showed ecotoxicity in terrestrial and water ecosystems, the presence of heavy metals (81.1 % for terrestrial ecosystems, 57.2% for water ecosystems).

Greene (2011) compared the life cycle of shopping bags made from polyethylene, LDPE and paper. Production of 1,500 pc plastic bottles from LDPE produces 0.04 t CO_2, which contributes to global warming and climate changes [10]. Table 1 shows how CO_2 contributes 83.2 % to climate changes from the point of view of global warming indicators.

4. Conclusion

Application of the LCA method does not guarantee decreasing the amount of emissions or enegry consumption, but it enables the identification of the "weaknesses" in the production process, and suggests possible technology improvements from a sustainable development perspective. The method represents a basic analytic tool for the identification of negative impacts in unit and system processes as well as complex industrial production processess. Producers in different industries, often execute the LCA analysis in order to compare their own production with their competitors, or to assess the possibilities on how to improve the environmental profile of their products.

Using the GaBi programme and the application of the weak point analysis, we have identified the weak points in the bubble foil production process taking into consideration the inputs and outputs. The results of our research shows, that the production of a certain amount of bubble foil consumes a much morehigher amount of natural non-renewable sources. During the production process, plastic waste is also created, mainly in the form of spoils, respectively redundant foil parts which are not repeatedly used by the company we analysed. Recycling of plastic waste on LDPE polymere base comprises technology processing on recycling lines. Granulate suitable for further usage in production is created. Its processing would represent more efficient usage of material input sources.

Acknowledgements

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Aluminium foam and its acoustic properties

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ABSTRACT

In spite of existing European and national legislative aimed at noise abatement, public interest and concern about noise are high. The EU Directive 70/157/EEC for setting and controlling environmental noise is aimed at the creating less noisy and more pleasant environment for European residents within „ Sustainable Development in Europe." The authors are presenting a methodology for measuring of selected acoustic descriptors, sound absorption coefficient and sound transmission loss) for acoustic materials, which are currently in process of development. Authors present the results of their scientific - research works, joined with the research of acoustic properties of new material - aluminium foam. The emphasis is layed on the research of sandwich construction, created on the base of aluminium foam material. The aluminium foam becomes known as new suitable acoustic material used for many areas of industrial practice. In the contribution is presented the methodology of acoustic descriptors measuring of new developed acoustic materials. The methodology was verified on the aluminium foam material, which application possibilities are the subjects of the intensive research of research teams in the world.

Keywords: Aluminium foam • Sound • Absorption coefficient • Sound transmission loss • Noise

1. Introduction

Noise reduction in the life or working environment is important for increasing the quality of the environment. Design of the noise reduction measures consists with different phases. One of the important phase is selection of suitable materials that are able apply for specific condition. Determination of acoustic properties of materials is necessary step before the application of these materials [1].

In spite of existing European and national legislation, aimed at noise abatement, public interest and concern about noise are high. Directive of EU 70/157/EEC for setting and controlling environmental noise is aimed at creating less noisy and more pleasant environment for European residents within "Sustainable Development in Europe" [2].

Harmful effects of environmental noise are various and they can be produced in various ways. They can be categorised into three main categories: effects influencing health, impacts on quality of life and financial implications on affected persons.

Noise protection measures for reducing the effect of noise caused by transportation (road, railway and air transport) can be passive and active. Active measures try to prevent the origination of noise, while passive measures are adopted only then, when noise arises. Passive noise protection measures can be divided into two groups, namely: measures preventing acoustic noise propagation (noise barriers and/or walls, noise protection embankments and the like) [3-5].

The aim article is present the results of their scientific - research works, joined with the research of acoustic properties of new material - aluminium foam. The emphasis is layed on the research of sandwich construction, created on the base of aluminium foam material.

2. Material and methods

2.1. Impedance tube

Impedance tube is tool used for measurement and determination of acoustic properties of the materials (Fig. 1).

Figure 1 The impedance tube [6]

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The two-microphone method is shown schematically in Fig. 2 below.

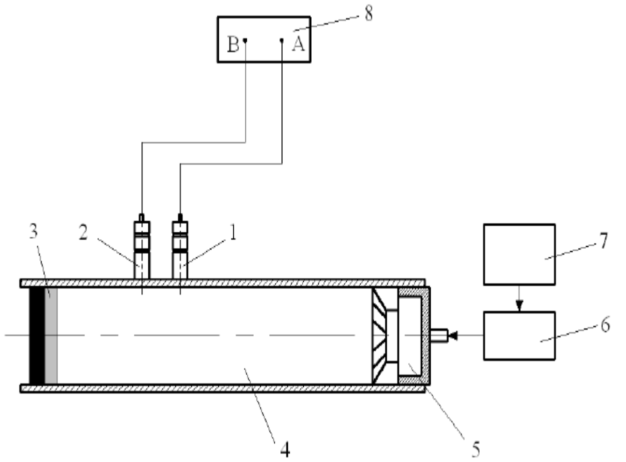


Figure 2 Displaying of the test equipment [7]

1- microphone A, 2 - microphone B, 3 – test sample, 4 impedance tube, 5 – sound of source, 6 – amplifier, 7 - signal generator, 8 – system

A sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube. A multi-channel spectrum analyser is used to obtain the transfer function (frequency response function) between the microphones. In this measurement, the microphone closer to the source is the reference channel. From the transfer function H12, the pressure reflection coefficient R of the material is determined from the following equation [8-9]:

$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} \cdot e^{j2k(L+s)} \quad (1)$$

where L is the distance from the sample face to the first microphone and s is the distance between the microphones, k = 2·f/c, f is the frequency, and c is the speed of sound. From the reflection coefficient, the absorption coefficient α and normalized impedance Z/ρ0c of the sample may be determined from the following equations [8-9]:

$$\alpha = 1 - |R|^2 \quad (2)$$

$$Z / \rho_0 c = \frac{1+R}{1-R} \quad (3)$$

The microphones must be mounted flush with the inside wall of the tube and isolated from the tube (to minimize sensitivity to vibration).

The sound source should provide sound energy over a frequency and intensity range sufficient for testing. It is important for the sound source to have a high power rating (e.g., 50 to 100 watts) so that high intensity sound may be generated inside the tube for certain types of testing. For example, the absorption of many materials is dependent on the intensity of sound. It is therefore helpful to test such materials at several levels above and below field conditions [2].

2.2. Aluminium foam as acoustic material

A period of 21-th century is connected with the development of new materials or by creating of new structures of materials. There are existing three types of various structures, which are used for the materials as plastics, ceramics and metals.

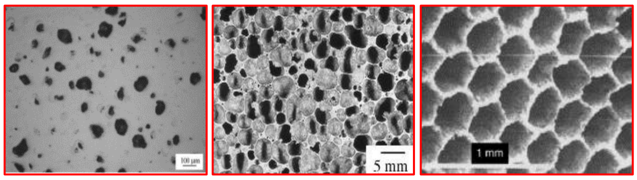


Figure 1 Comparison of cellular substances from different materials [10]

a.)porous metal, b.) stochastics celular material – foam aluminium, c.) regular celular material – aluminium honeycomb

It is essential to differentiate cellular material from "porous metal", which can be defined as the amount of closed spherical pores, which do not create any kind of repeatable pattern [11].

These cellular materials can be made from different polymers, glass, or metal. The metallic foams belong to the cellular material, where the foam structure forms by a nucleation (vaccination) and by a growth of gas pores in the liquid metal for the foam formation. In the Fig. 3 are shown individual non-uniform distributed pores. The walls of the pores contain imperfections due to the expansion of the foam and refrigeration.

The powder metallurgy is the backbone of production of aluminium foam by Alulight method. For thus obtained aluminium foam is preferably a continuous aluminium surface layer and the porous internal structure [10].

The production was patented early in 1963 for this method, but it was not used very much, especially because from it was not produced any parts. The scientists were lacking more knowledge concerning of the construction principles that are essential and necessary for the application of aluminium foam. Just some time ago, it was developed technological procedures, which in addition to reducing production costs, allow the production of very light structural parts reinforced with steel or ceramic braces, and so begins those reinforced aluminium foam finds application also in the design practice. The products of these procedures have been developed by the Institute of materials and machine mechanics SAV in Bratislava. The main company was Austrian Alulight International Company of Ranshofenu [12].

The production process begins by mixing of aluminium powder with a foaming agent (TiH2, ZrH2). The second step is the cold isostatic pressing and subsequent hot extrusion, but when it is in the solid state. The result is a semi-finished product in the form of rods and different profiles.

After melting of the semi –product, the hydrogen is loosen and creates pores in the aluminium melt. By cooling of the foam is obtained rigid aluminium foam [10,12].

For maximum use of aluminium foam to produce components, the low tensile strength prevents him for utilizing. The micro-cracks and non-uniform surface layer leads to a fracture of components already at very low-stress. To avoid this event, a ceramic or metal grid is used or perforated sheets. This reinforcement is used in the production of aluminium foam by powder metallurgy, where is inserted inside the foam able forms together with semi-product. Such reinforcement ensures the transmission of tensile stress by reinforcement and a porous structure is stressed only by pressure. The Fig. 4 shows the reinforced foam aluminium and its bending with and without reinforcement [13].

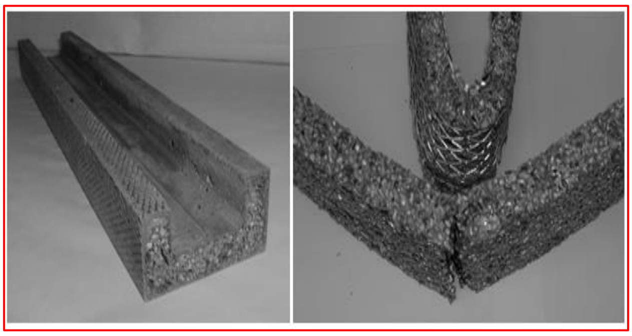
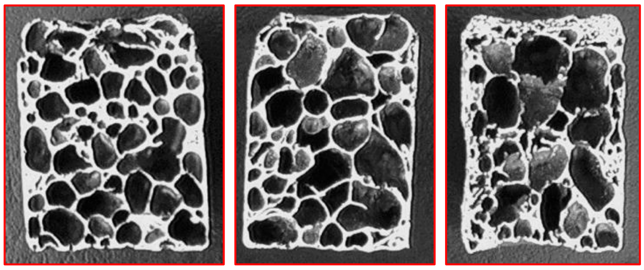


Figure 4 Bending of reinforced and non-reinforced foam aluminium [13]

The partial reinforcement ensures to obtain required mechanical properties of aluminium foam at the minimum weight of part. Therefore, its utilisation in the design is preferred, mainly in automation or traffic technics. Its mechanical properties can also be used in the manufacture of components required to absorb noise and impact energy and vibration damping. This material is also used for the production of heat shields. Except for structural applications it is often used as a decorative material, for example as wallcoverings of airplanes, railways, buses and in the areas where many people meet together (cinemas, theatres, etc) [13].

The foaming temperature is a parameter influencing the pore size and porosity of the component. The Fig. 5 shows the effect of temperature on the cell structure, which means that the best porosity is obtained at its optimum temperature. The foam able precursor can not expand at very low temperatures. However, the result is not good nor on the other hand, because too high temperature will cause foam collapse [14].



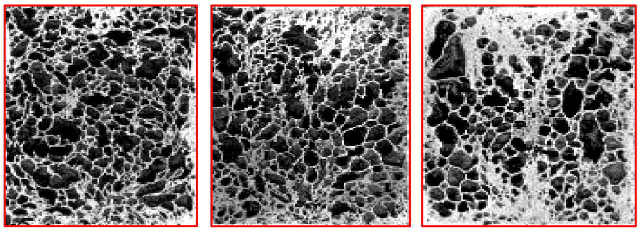
a.) b.) c.)

Figure 5 Influence of temperature on pore structure [14]

a.) low temperature – shortage of expanding, b.) optimal temperature – the biggest expanding, c.) high temparature – foam colaapse

The result of the porous structure is diversity with a stronger and corrugated pore walls. The foaming temperature must be about 10-20 °C higher than the melting point of the alloy, thus ensuring optimal pore porosity. Their size is more united and the pores are uniformly distributed in the foam [10].

Another of the parameters influencing the pores of the foam is the time. The structure of pores as function of time is shown in the Fig. 6. The slower foaming oxidizes the precursor surface, thereby increasing the resistance to expansion of the foam. The resulting porosity is therefore rather low. Long periods foaming occurs in draining (drying), causing thickening of the foam structure. Enough time improves the homogeneity of the pore structure [15].

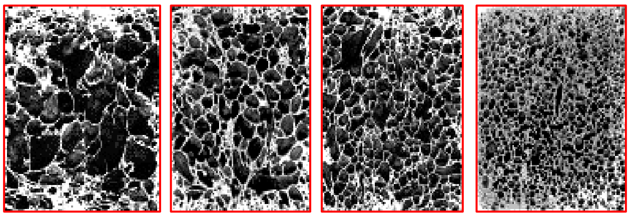


a.) b.) c.)

Figure 6 Influence of time on the pore structure [15]

a) 420 s., b.) 790 s., c.) 1120 s.

The effect of surroundings and its properties are also important in the process of foaming and porosity. It is also important to the action of external forces/ pressure - Fig. 7. The high pressure prevents the growth of pores, and thus can contribute to a uniform structure of these pores. The lower pressure causes greater pores with strong walls. Too low pressure creates pores with asymmetrical walls. The influence of external pressure is dependent on the type of alloy and the surface tension [16].



0.05 MPa 0.1 MPa 0.2 MPa 0.3 MPa

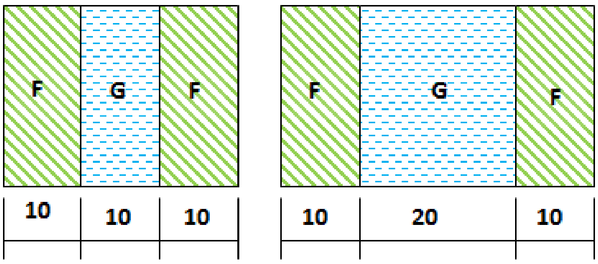
Figure 7 Influence of the external pressure on the pores structure

2.3. Experimental measurement acoustic of aluminium foam

For measurement was prepared two samples of aluminium foam with diameter 60 mm as shown Fig. 8. By the measurement was determined sound absorption coefficient and transmission loss. Sound absorption is defined, as the incident sound that strikes a material that is not reflected back. Sound Transmission Loss (STL) represents the amount of sound, in decibels (dB), that is isolated by a material or partition in a particular octave or 1/3 octave frequency band.

Figure 8 Aluminium foam samples

Measurement was realized with two samples. Between the two layers of aluminium foam was air gap. First sample with air gap 10 mm and second sample with air gap 20 mm. Thickness of aluminium foam was 10 mm. Samples are shown in Fig. 9.



SAMPLE 1 SAMPLE 2

Figure 9 Investigated aluminium foam samples

Legend: F – aluminium foam, G – air gap

3. Results and discussion

After the preparing samples was realized measurement of acoustic properties – sound absorption and transmission loss from 100 Hz to 2,500 Hz.

The Table 1 and the Table 2 show the average results of measurement of sound absorption and transmission loss of both samples. Measurement was realized repeatedly 20 times.

Table 1 Sound absorption coefficient of aluminium foam samples

Frequency [Hz]	Sound absorption coefficient	
	Sample 1	Sample 2
100	0.12	0.09
125	0.05	0.07
160	0.04	0.07
200	0.06	0.09
250	0.10	0.13
315	0.12	0.21
400	0.20	0.38
500	0.31	0.66
630	0.64	0.99
800	0.99	0.82
1,000	0.71	0.51
1,250	0.55	0.35
1,600	0.47	0.38
2,000	0.48	0.38
2,500	0.31	0.25

Table 2 Transmission loss of aluminium foam samples

Frequency [Hz]	Transmission loss [dB]	
	Sample 1	Sample 2
100	5.81	5.81
125	6.27	6.25
160	6.85	6.78
200	7.49	7.31
250	8.11	7.85
315	8.76	8.41
400	9.42	8.82
500	9.78	8.88
630	10.00	8.65
800	9.57	8.38
1,000	9.68	11.51
1,250	12.74	17.94
1,600	20.87	25.61
2,000	25.09	28.63
2,500	32.84	35.92

Sound absorption coefficient for sample with air gap 10 mm reach the best value for frequency 800 Hz and sample with 20 mm air gap for frequency 630 Hz. Influence of bigger air gap is clear for lower frequencies to 630 Hz, sound absorption coefficient reach better values for sample with 20 mm air gap. For frequencies over 800 Hz better values of sound absorption coefficient was achieved with sample with 10 mm gap.

Result of measurement of sound absorption coefficient in frequency range 100 – 2500 Hz shown in the Fig. 10.

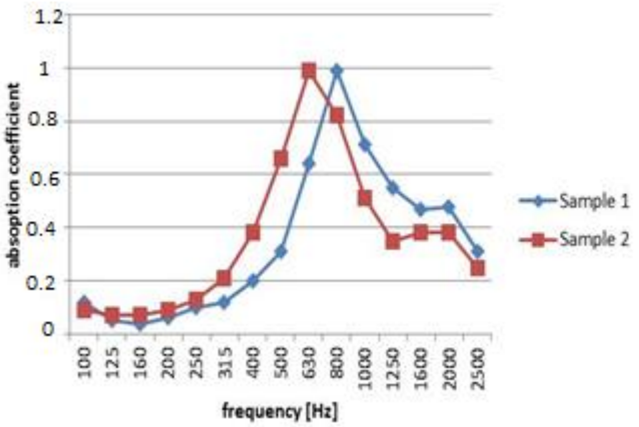


Figure 10 Comparison of sound absorption coefficient of aluminium foam samples

Measurement of transmission loss of both aluminium foam samples start with value 5.81 dB for 100 Hz frequency.

By increasing the frequency value of transmission loss is also increasing. For frequencies 100 – 800 Hz results for both samples are similar. For frequencies over 1,000 Hz better values of transmission loss are achieved with sample with bigger air gap. Result of measurement of transmission loss in frequency range 100 – 2,500 Hz shown in the Fig. 11.

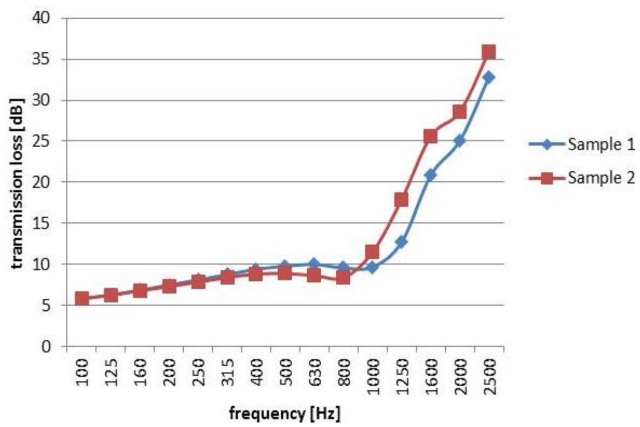


Figure 11 Comparison of transmission loss of aluminium foam samples

4. Conclusion

The aluminium foam is a cellular structure consisting of a solid metal, as well as a large volume fraction of gas-filled pores. Aluminium foam is material that is new progressive material with variety of applications. Aluminium foam is applicable mainly in automotive, and building industry but also in other fields of industry.

Foam structures are both durable and lightweight, with a large surface area to volume ratio. The unique mechanical properties of aluminium foam include a high strength to weight ratio and a completely isotropic load response. By the comparison of acoustic properties of aluminium foam samples with other comparable materials with same thickness acoustic material is clear that values of sound absorption coefficient for low frequencies to 400 Hz is much lower by the comparison with other materials. In the frequency band 630 – 1,250 Hz sound absorption coefficient of aluminium foam samples achieves very similar values or better values by the comparison to other acoustic materials. Transmission loss of aluminium foam samples achieves values very similar to values of other acoustic materials. Main advantage of use of aluminium foam is application to environment with difficult conditions (humidity, temperature, solid aerosol and vibrations). Aluminium foam is suitable to these environment and also keeps proper acoustics properties

Aluminium foam is a new material with variety of application that is suitable for self-supporting lightweight panels for road and building construction, non-flammable construction materials and coatings in hotels, shopping malls and other public areas with heat and sound insulation effect, significantly non harmful to environment.

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