Chapter 6

Increasing the reliability and durability of building materials

6.1. The industry of building materials of Ukraine in the context of globalization

Petro V. Zakharchenko[1]**, Oleksandr M. Gavrysh**[2]**, Roman D. Zakharienkov**[3]
[1, 2]Kyiv National University of Building and Architecture, Kyiv, Ukraine
[3]Ukrainian Association of Styrofoam Manufacturers, Kyiv, Ukraine
E-mail: [1]*tkd362@ukr.net*, [2]*tkd362@ukr.net*, [3]*office@aspp.com.ua*

Abstract. The condition of the building industry and the building materials industry in Ukraine is considered, production and sale of building materials are shown in dynamics. Modern building materials displace from the market obsolete inefficient products.

Keywords: brick (ceramic, silicate), autoclaved aerated concrete, dry building systems, thermal insulation products.

The building industry of Ukraine has evolved considerably during the years of independence. The large state-owned monopolies (ministries, republican and regional associations, etc.) have disintegrated or corporatized, state enterprises turned into LLCs, JSCs and others, there is practically no state order for housing construction, requirements for thermal protective characteristics of buildings and structures have significantly increased. All this, as well as the appearance of world-famous companies and technologies in Ukraine, has changed the vector of the development of the building materials industry. In this paper, we analyze the dynamics of production of the main types of building materials over the past 27 years.

Previous studies [1] found that builders during the crisis dramatically reduce the volume of construction and increase them just before the next economic downturn. The indicated dependence is particularly clearly observed in housing construction. If we recall that the vast majority of residential multi-apartment construction projects last about 3 years, it becomes clear that the implementation of the vast majority of such projects begins at the peak of demand during economic growth, and the time of their completion falls at the bottom of demand during the economic crisis, and forces organization to stop construction and threatens them with bankruptcy. So, during the economic downturns of 2002 and 2008, the rate of commissioning of housing has fallen sharply (because during a crisis it is possible to realize apartments only in completed facilities). In 2016, the volume of housing commissioning fell to 9367 ths sq. meters (Fig. 1).

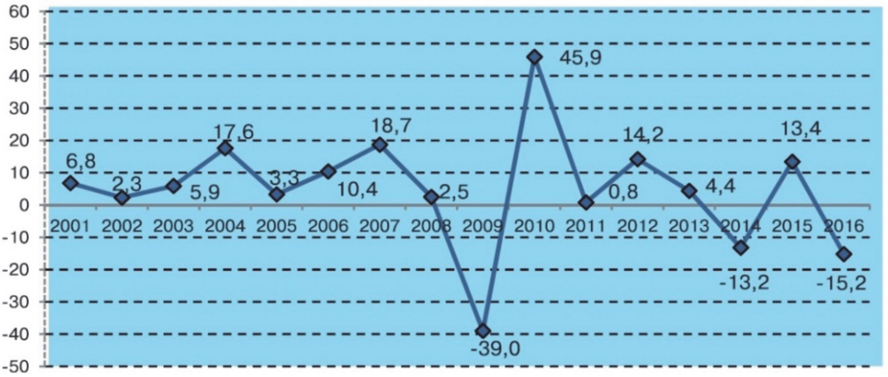


Fig. 1. Commissioning of housing in Ukraine in 2001-2016, in % to the previous year

The paper examines three markets for building materials, which determine the current level of construction.

1. Structural materials for the building of outer walls and inter-apartment/interior partitions, which include: brick (ceramic and silicate), ceramic blocks, blocks from autoclaved aerated concrete and products of house-building combines wall panels.

2. Dry building mixtures and plate materials for interior decoration of premises. This market includes building mortars, dry building systems (plasterboard), other plate materials (chipboard, fiberboard, magnesite).

3. Heat and sound insulation materials and products. This market includes the following groups of products: products based on mineral, silicate and glass wool, expanded polystyrene, foam plastics, insulating products based on expanded perlite.

Brick is one of the most common building materials used in the construction of buildings and structures, laying foundations, facing facades and when building internal partitions. The material successfully competes with cheaper for today concrete products, cinder blocks and wooden structures.

By composition and method of production, the brick is divided into ceramic and silicate.

In 1990, the volume of production of ceramic bricks was 7 billion pieces conv. bricks/year, about half of which was produced in factories with outdated seasonal technology and provided the production of M75 bricks (of rather poor quality). In the 90s, production at almost all these plants was stopped. In the new millennium, modern technologies for the production of ceramic bricks have come to Ukraine, plants have been built and reconstructed: Slobozhanska Budivelna Keramika (SBK., Romny, Sumy region), Kerameya (Sumy), Euroton (Yavoriv, Lviv region), Zagvizdiansky brick factory (Ivano-Frankivsk), “Rusinia” (Mukachevo, Zakarpattia region), a brick factory of the Kolomoyskyi plant office of building materials (Ivano-Frankivsk region), Novoaleksandrovsky brick factory (Dnepropetrovsk region), Belotserkovsky brick factory (Kyivs’ka obl.). These enterprises produce high-quality ceramic bricks: facial, clinker and ceramic blocks.

Perspective wall material - ceramic blocks are made from natural raw materials - clay. In order to obtain a porous structure in the process of production, crushed wooden sawdust or other organic components are added to the clay mass, which burn out during brick burning, forming a large number of closed micro-cavities. Ceramic blocks have high thermal insulation properties and are more economically more profitable than conventional brick. In this case, the ceramic block retains the stability and strength of a conventional brick. According to the classification of the State Statistic Service adopted in Ukraine, ceramic brick as a construction material for wall making refers to the code “Ceramic brick, non-refractory, building”. The dynamics of production of ceramic non-refractory brick is shown in Fig. 2.

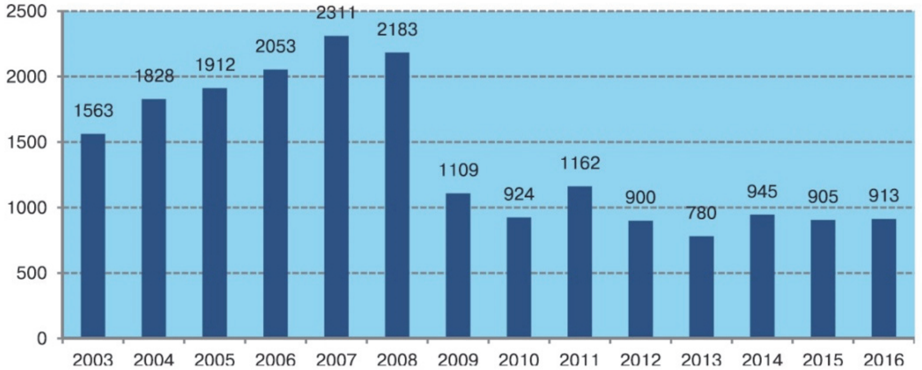


Fig. 2. Manufacture of ceramic non-refractory building brick in years 2003-2016, mln. conv. bricks

During the period 2003-2016, the production of building bricks ranged from 1.5-2.3 billion pcs. conv. bricks/year, but the last 10 years the production volumes are less than 1 billion pcs. conv. brick/year.

Thus, it can be concluded that over the years of Ukraine's independence, the volumes of ceramic bricks production have decreased 8 times, and almost half of the brick volumes are represented by high-tech products.

The silica brick is made of sand, lime and a small fraction of additives with the addition of water. Silica bricks are not subjected to roasting, but it is treated with steam in an autoclave. The process of production of silicate brick can be briefly described as follows: a moist mixture of 90 % sand, 10 % lime is poured into a press where a raw brick is formed, then it is loaded into an autoclave and exposed to saturated steam at a temperature of 170-200°C and pressure of 8-12 atmospheres. If weather-resistant, alkali-resistant pigments are added to this mixture, a colored silica brick is obtained. The water resistance of the silica brick is lower than that of the ceramic brick. Silica brick is recommended for use in laying load-bearing walls and various partitions, but it is strictly forbidden to use it when laying foundations, in laying ovens, fireplaces, pipes, socles, etc. The advantage of silica brick in front of ceramic is its increased sound insulation characteristics, which is important for erection inter-apartment or interior walls.

In 1990, the volume of production of silica bricks amounted to 2 billion pcs. conv. bricks per year. Considering the quite high technological level and significantly lower energy consumption of the technology, its production has decreased significantly less than the production of ceramic – up to 550 million pcs conv. bricks per year.

The most popular from the point of view of energy efficiency of buildings and structures are modern products made from autoclaved aerated concrete, which provide the normative heat resistance of the walls when laying the blocks in one row (single-layer wall structure, wall width 400-500 mm at a material density of 300-400 kg/m^3).

Aerated concrete is an energy-saving building material of the porous structure. Its pores contain from 50 to 90 % of air, which distinguishes concrete from other building products by the properties of the material. With a change in the porosity of the material, there is a logical change in its performance indicators - density, heat conductivity, strength.

Aerated concrete is an artificial stone, which is formed during the hardening of a porous mixture, including finely dispersed filler, blowing agent and water. Aerated concrete has the properties, on the one hand, of stone, on the other - of wood. The combination of these properties makes it an excellent building material.

Residential buildings, industrial and public buildings, as well as various agricultural premises, are being built from aerated concrete:

- aerated concrete with a porosity of 50-60 % (density of 1000-800 kg/m^3) has a sufficiently high strength and can be used as a structural material in low-rise buildings (buildings up to 5 floors), replacing silica and ceramic bricks, lightweight concrete;
- aerated concrete with a porosity of 75-80 % (density of 600-300 kg/m^3) is approaching to wood by operational parameters, a combination of high thermal insulation and strength characteristics in the material allows it to be used in single-layer outer walls of a building up to 3 floors. Walls from aerated concrete can be used separately, as well as in combination with brick, concrete (prefabricated, monolithic) and other types of products;
- aerated concrete with a porosity of more than 80 % (density 300-200 kg/m^3) belongs to the class of heat-insulating materials and can be used for erecting interior partitions. At low density, it has many advantages over other types of organic and mineral heat-insulating materials: stiffness, non-combustibility, bio-stability, environmental cleanliness, preservation of physical and technical parameters during long-term operation, durability, and availability of own raw material base for manufacturing of the products (cement, lime, sand).

The dynamics of production of this material is impressive. In 1990, Ukraine produced 400 ths. m^3 of products from autoclaved aerated concrete per year (which corresponds to 400 mln. pcs. conv. bricks/year), and already in 2017 – the volume of its production exceeded 3.6 mln. m^3/year (corresponding to 3.6 billion pcs. conv. bricks/year)

Table 1. Characteristics of technological lines and sales volumes of small blocks of producers of ANB

Manufacturer	Equipment	Location	Maximum production line power	Sales volume in 2016, ths. m^3		Change %
				m^3/day	ths. m^3/year	
AEROC (2 plants)	WEHRHAHN (Obukhiv) Universal-60 (Obukhiv) Hess (Berezan)	Obukhiv city and Berezan city Kyivs'ka oblast'	3200	1000	1033	+12 %
Oriyentyr-Budelement	Hetten (modernized line)	Brovary city Kyivs'ka oblast'	3650	1300	1349	+19 %
UDK	Masa-Henke	Dnipro city	1500	430	412	+27 %
Energy Product	Durox	Nova Kakhovka city Kherson Oblast	1300	380	383	+16 %
Ju-Ton	WKB Systems	Voznesensk city Mykolaiv Oblast	850	280	175	+17 %
TBK	Wuxi Mettle	Kherson city	400	120	0	–
PE Budtehnologiya-N	Universal-60 (2 lines)	Kupyans'k city Kharkiv Oblast	600	200	11	+4 %
KBM Corporation	Hetten	Kharkiv city	600	200	150	+4 %
PE Autocraft	Ukrainian equipment (PE INTeRBudMa)	Bershad town Vinnytsia Oblast	250	80	0	–
Zhytomyr silicate products factory	Universal-60 WEHRHAHN	Zhytomyr city	250	80	46	+10 %
Dnieper Plant of Building Materials	Extra block	Dniepro city	150	50	40	+100 %
Silikatobeton	China	Sumy city	400	150	1	–
Teplobud-Siverschyna	USSR	Chernihiv city	20	5	4	–
		Total:	13710	4275	3604	+15 %

In 1990, more than half of the housing was built from claydite-concrete panels, which, according to the State Statistic Service of Ukraine, refer to "elements of the construction of prefabricated buildings for housing and civil construction from cement, concrete or artificial stone". In recent years, the share of these products accounted for less than 15 % of the total volume of wall materials and only in 2016 reached almost 25 %.

The greatest development during the years of Ukraine independence has received the subsector of dry construction [2-5].

Dry construction is the installation of billets, building products and materials produced by industry, with the exception of the so-called "wet" processes (preparation of masonry, plaster solutions, concrete, etc.). Dry construction includes non-load-bearing structures that limit space (interior partitions), as well as interior finishing and covering of load-bearing walls, ceiling, and the installation of floors.

The development of the method of dry construction is closely related to the industrial production of gypsum boards. Since the late 50-ies in construction started to use in large volumes of building parts from plasterboards for light partitions and wall cladding. However, then the construction was much easier in comparison with the complexity and capabilities of today's dry construction. At the moment, this method is rapidly spreading and has an increasing influence on all spheres of construction: high-performance combined materials, heating and air conditioning systems integrated into dry construction, systems of ceiling, walls and floors with high sound insulation properties, board materials with wooden, glass, steel and aluminum coating, plasterboards with high heat accumulation are the several examples of development when technical and design innovation potential is almost unlimited. Plate materials in composition and design can meet almost all requirements due to structural changes and special additives.

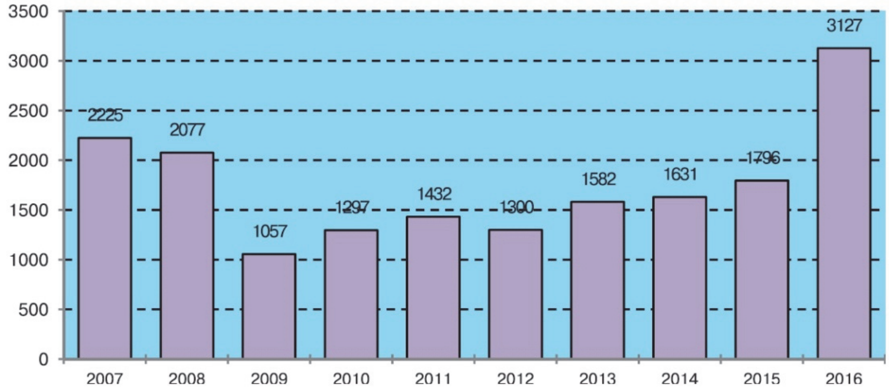


Fig. 3. Production of elements of the prefabricated structures for construction from cement, concrete or artificial stone for 2007-2016 ths. m^3

The implementation of dry construction systems, allows you to abandon the "wet" processes, increases in several times labor productivity and provides an opportunity to perform interior design of premises more better. The main material of dry construction is plasterboards.

Plasterboards are sheet products, consisting of a non-combustible gypsum core, the surface of which, besides the end edges, is faced with cardboard that glued to the core.

Plates are designed for facing walls, partition making, fire retardant structures, manufacturing of decorative and sound-absorbing products.

Depending on the properties and area of application, the plasterboards are divided into the following types:

- conventional (PB),
- moisture-resistant (PBM),
- increased resistance to open flame (PBIR),
- moisture-resistant increased resistance to open flame (PBMIR).

PB and PBIR are used in buildings and premises with dry and normal humidity regime.

PBM and PBMIR are used in buildings and premises with an increased humidity regime.

PBIR and PBMIR it is appropriate to use for cladding of structures with the purpose of increasing their limit of fire resistance in premises with increased fire danger.

Dimensions of plates, mm: length from 2000 to 4000 in increments of 500 mm; width 600 and 1200; thickness 6.5; 8.0; 9.5; 12.5; 14.0; 16.0; 18.0; 20.0; 24.0. Plates should have a rectangular shape in the plan.

PB produce with different in form longitudinal edges, glued with cardboard, which determine the way and quality of sealing joints between neighboring PBs.

Dynamics of plasterboard production in Ukraine is shown in Fig. 4.

In 1990, Ukraine produced about 6 mln. sq. m. of plasterboards. During 2003-2008, the production of plasterboards increased from 27.0 mln. sq. m. to 91.5 mln. sq. m. That is, in five years the volume of production has grown 3.4 times. The greatest growth occurred in 2007, mainly due to the commissioning of new capacities by a group of KNAUF companies. In 2009 there was a drop-in production by almost a third, but in 2010-2011 production volumes gradually increased and almost reached the 2007 levels, but in 2012 the figures decreased, and in 2013-2016 the production of the PB remained at the level of 2006.

Chipboard – this is the most common material in the production of furniture and construction. It was first started to produce in the city of Bremen (Germany) in July 1941 at the factory of the TORFITWERKE G.A. HASEKE Company. The main advantages of particle board are ease of processing, economy, reliability and high practicality, in addition, it is environmentally friendly material.

Modern production technologies make it possible to achieve a sufficiently high quality and safety of particle board products. The particle board is produced by way of hot pressing of large-dispersed chips, which obtained from technical wood of any kind and from waste of woodworking enterprises with the simultaneous introduction of thermosetting synthetic resin, as well as hydrophobizing (such increasing the water-repellent properties), antiseptic and other additives, due to which the plate acquires a special strength and durability.

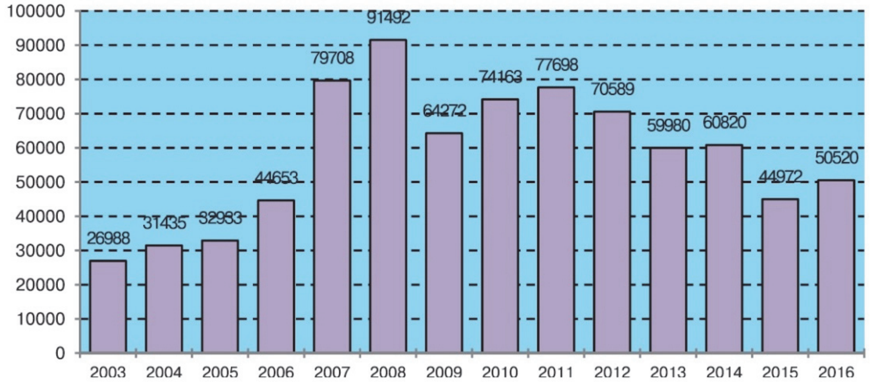


Fig. 4. Manufacture of gypsum products for construction (plasterboards) in 2003-2016 years ths. m^2

The use properties of the particle board depend mostly on their density, the shape and size of the chips, and the quantity and quality of the binder component. There are plates with a very small density (350-450 kg/m^3), small (450-650 kg/m^3), medium (650-750 kg/m^3) and high (700-800 kg/m^3) density. There are single-, three- and five-layer boards.

Fiberboards are made by hot pressing of pulp, consisting of organic, mainly cellulose, fibers, water, fillers, synthetic polymers and some special additives. The raw material for the production of boards is waste of woodworking industries and logging (cod, fines), stalks of bulrush, flax hurds and other plant materials. Depending on the pressure while pressing and the type of further processing, the wood fiber boards are divided into super-hard, hard, semi-solid and soft (insulation-finishing and insulating). For interior decoration of buildings rigid boards are used, super-hard is used for covering floors.

Fiberboard is used in housing and industrial construction for heat and sound insulation of the roof, interfloor ceilings, walls, for finishing premises, etc. Fiberboard is especially widely used in low-rise, cottage and rural construction, in standard house-building, and also in the production of furniture and packaging.

OSB (Oriented Strand Board) - boards from oriented shavings of coniferous trees, are pressed under high pressure into three layers and seep with adhesive waterproof resin. OSB-plates are produced in a format up to 3.6×7.2 meters, with a thickness from 6 mm to 30 mm. In Ukraine, the most common are OSB-boards measuring 1.25×2.5 m and thickness of 10 mm and 12 mm. They are used for wall covering, roofing, as supporting surfaces for floors, supporting structures, formwork for concrete construction and the like. They are used, next to plywood, for the manufacture of strong elements of building structures, containers, packaging, furniture and so on.

Their density is 600-660 kg/m^3. The flexural strength is 25 N/mm^2 along the fibers, 14 N/mm^2 across the fibers. The thermal conductivity is 0.13 W/(mK).

OSB on 90 % consists of natural wood, has all the characteristics of the array, but does not have knots and other defects. When working with the OSB, the tools are subjected to less wear.

According to the classification of the State Statistic Service adopted in Ukraine, board materials (plasterboards, fiberboards) as a structural material for making partitions refer to the code “Particle boards unprocessed” and “Panels, plates, blocks and similar articles of vegetable fibers or wood waste, agglomerated with mineral binders”.

The dynamics of production of wood-based panels is shown in Fig. 5.

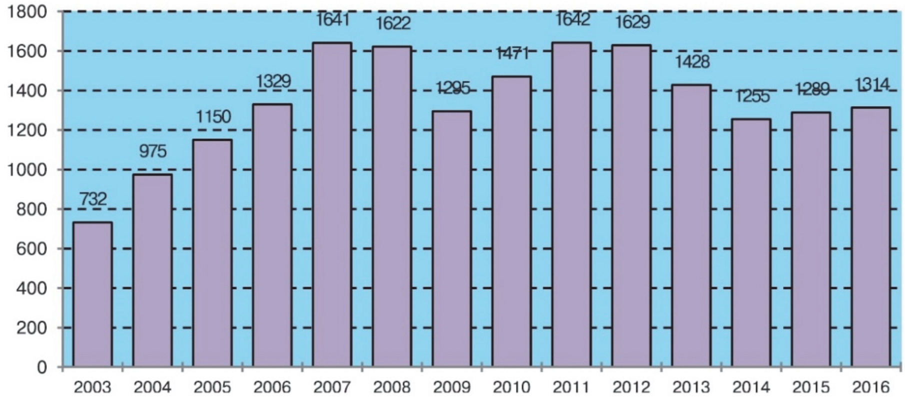


Fig. 5. Manufacture of unprocessed plasterboard in 2003-2016, ths. conv. m^3

The market of dry building mixtures directly depends on the production of binders: cement, gypsum, lime. The volume of cement production in 1990 exceeded 20 million t/year. In the 90's, the volume of production and consumption of cement fell to 5 million t/year. In the 2000s, cement production began to grow and reached its peak in year 2007 of 15 million t/year.

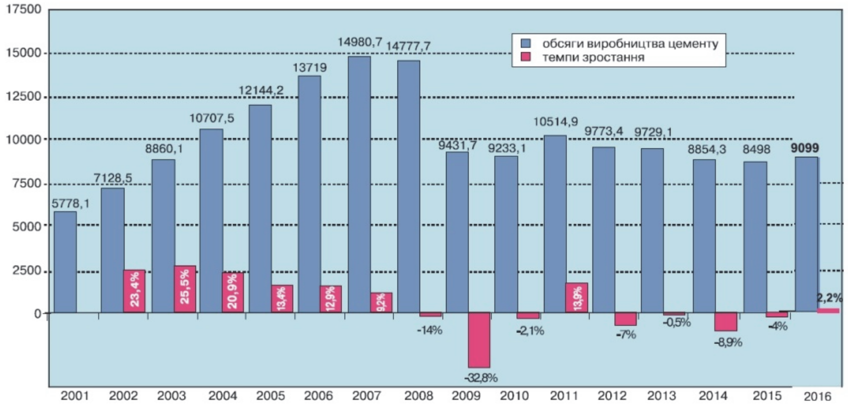


Fig. 6. Manufacture of cement by the enterprises of the association "Ukrcement", in 2001-2016 thousand tons

However, already 2008 is characterized by a decrease of 1.5 %. Due to the economic crisis during 2009-2010, there was a rapid decline in the volume of cement production (by about 37 %). In 2011, the cement industry was gradually emerging from the crisis, production volumes reached the level of 2004, but in 2012-2015 the production rates fell somewhat, and in 2016 they increased on 500 thousand t. (Fig. 6).

Information on the main producers and volumes of cement production in Ukraine is given in Table 2.

In 2014, 34 rotary kilns operated in the cement industry of Ukraine against 41 in 2013, 6 of them by dry method of production, 28 by wet ones. The production potential for clinker output was 15 million 133 thousand t/year, including 5 million 401 thousand t/year on dry production method or 35.7 % of total production capacity. Loading of the rotary kilns in 2015-2016 is amounted to 40.1 %, while the use of cement production capacities was 45.2 %.

As can be seen from the table below, almost all Ukrainian cement plants are owned by leading foreign firms. Considering the high energy production costs and the high cost of natural gas, almost all these plants have been converted to cement clinker firing by the pulverized coal mixture.

Table 2. Manufacturers of cement in Ukraine

Owner	Enterprise
Dyckerhoff (Germany)	"Volyn-Cement"
	"Yugcement"
CRH (Ireland)	"Mykolaivcement"
	"Podilsky Cement"
	"Cement Odessa"
HeidelbergCement (Germany)	"Kryvyi Rih Cement"
	"Dnieprocement"
	"Doncement"
	"Cement of Donbass"
Eurocement (Russia)	"Pushka" Kramatorsk Cement Plant
	"Balcem"
Ukrainian owners	"Bakhchisaray combine "Budindustriya"
	"Ivano-Frankivsk Cement"
	"Promcement"

In the second half of the 1990s, in Ukraine started the production of dry construction mixtures [6, 7].

Dry mixtures, in comparison with traditional solutions and concrete, have a number of advantages:

- a minimum of technological operations to bring dry mixtures into operation (mixing with water)
- reduction by 5-7 % in solution waste as a result of batch dosing;
- saving of 10-15 % of cement due to the use of plasticizing and water-retaining additives;
- stability of the composition of dry mixtures as a result of precise dosing of components and the effectiveness of their mixing;
- increasing the productivity of workers in 1.5 to 3 times due to the achievement of high technological properties of mortar mixtures and their mechanized application to finishing surfaces;
- decreasing of 10-15 % of transportation costs and an improvement in the quality of work, while reducing the labor intensity of technological processes.

Due to above advantages and unique properties, dry mixes have a wide range of applications in construction. Dry building mixtures (hereinafter-mixtures) are classified by:

- type of binder used;
- the largest size of aggregates or fillers;
- the main purpose. Depending on the type of binder used, the mixture is divided into cement, gypsum, calcareous, polymeric and complex.

Dry building mixtures modified on a cement basis of all groups should:

- when performing external works, ensure high resistance of coatings to moisture and various climatic factors, including negative and elevated temperatures;
- when performing external works, the water absorption coefficient should not exceed 0.2 kg/m^2×h 0.5 (group III3)
- easy to apply and to level.

Dry building mixes modified on a cement basis are a traditional finishing material, which is widely used for interior and exterior decoration. According to the classification of the State Statistic Service of Ukraine "Dry mortars modified on cement basis" refer to the code "Building mortars and concretes (dry), except concrete ready mix". Below are the changes that occurred in this segment during 2004-2016.

Next, consider the dynamics of production of dry building mixtures on a cement basis (Fig. 7).

As can be seen from the chart, after the fall in 2009, in 2010-2013, this segment of the market not only recovered, but also significantly exceeded pre-crisis indicators. In 2014-2015 the production of the building mixtures on a cement basis significantly decreased, and in 2016 the production volumes increased by about 45 %.

The commodity structure of the building mixtures on a cement basis in 2016 is shown in Fig. 8.

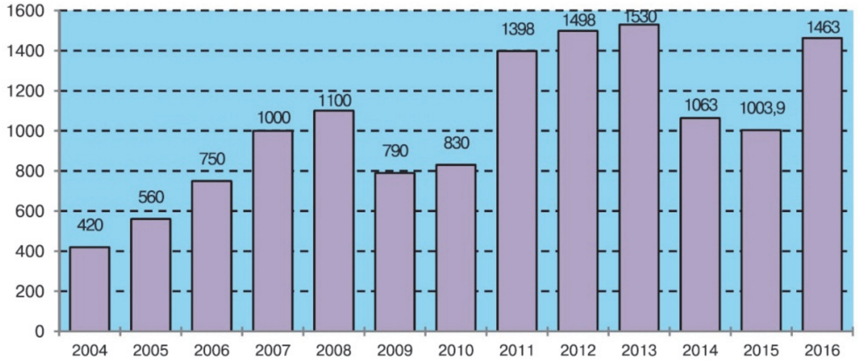


Fig. 7. Dynamics of the building mixtures on a cement basis market for 2004-2016, ths. t

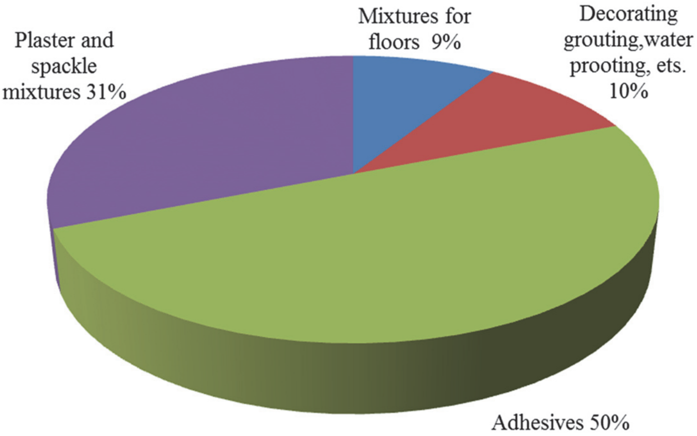


Fig. 8. Commodity structure of the building mixtures on a cement basis in 2016, %

Table 3. The main operators in the market of dry construction mixtures in 2016

Trade Mark	Volume of production, ths.t.	%
Ceresit	360	39.2
Siltek	80.4	5.7
Anserglob	53.6	6.1
Majster	91.7	6.5
Polimin	175	12.4
Kreisel	101.6	7.2
Ferozit	56.5	4.0
BudMajster	59.3	4.2
Baumit	67.7	4.8
Artisan	31.0	2.2
others	108.7	7.7

Gypsum mixes (group III2) are intended for finishing of interior surfaces of premises. They include gypsum, lime, fillers, polymer modifying components, a setting retardant and other impurity.

Gypsum mixtures must:

- not be destroyed during periodic short-term humidification;
- provide the ability to control the setting process in a wide time range (1-2 hours).

Mixtures for surface preparing are the systems containing mineral binders, fillers and various impurities, including those that reduce adherence of the mortar mixture to the tool.

Mixtures for surface preparing for finishing should:

- have adhesion with the base not less than 0.5 MPa;
- have a vapor permeability of not less than 0.1 mg/(m×h×Pa)
- be frost-resistant (for outdoor work), to withstand at least 50 freeze-thaw cycles;
- easily fit on the basis, not leave strips, lumps and not follow the tool;
- have resistance to cracking and minimal shrinkage, should not exceed 0.2 %;
- be polished and be painted, including paints on organic solvents;
- not be dripping down from the vertical surfaces;
- be water resistant.

According to the classification of the State Statistic Service of Ukraine, production, export and import of dry building mixes on a gypsum basis fall under the codes 26.53.10 “Gypsum binders”, 2520201000 “Gypsum building” and 2520209000 “Gypsum other”.

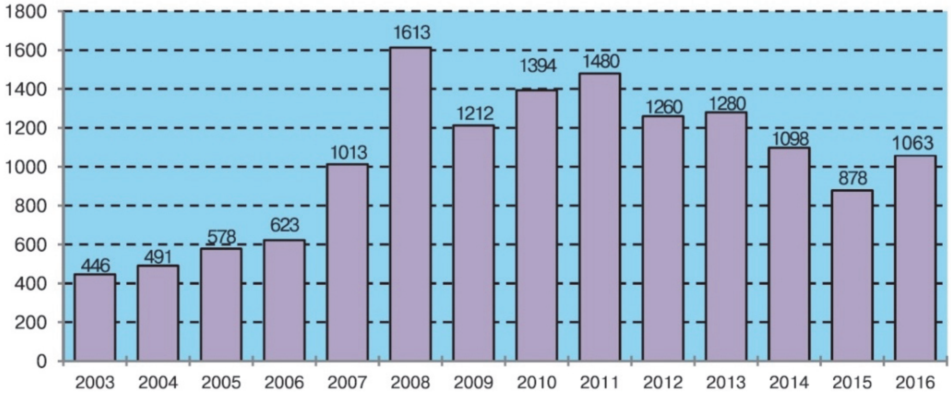


Fig. 9. Production of construction gypsum and gypsum binders for 2003-2016, ths. t

During the period of 2003-2008, the production of construction gypsum and gypsum binders increased in 3.6 times. The greatest growth occurred in 2007 and 2008, the increase was about 60 %. Mainly due to the commissioning of new capacities by a group of KNAUF companies. Due to the crisis in 2009, production volumes decreased by 25 %, and already in 2010-2011 production growth resumed and it almost reached the pre-crisis level, but in 2012 production volumes decreased. The production of gypsum binders in 2012-2013 was 1260-1280 ths. t, and in 2014-2016 it was 900-1100 ths. t.

The main suppliers are Knauf Marketing (TM Knauf), Helios (Lviv, TM Ferozit), Fomalhaut-Polimin (Kyiv, TM Polimin), Polirem-Center (Kiev, TM “Polirem”), "Factory of the building mixtures “BudMajster” (Pavlograd, TM “BudMajster”), “KREISEL-Building Materials” (TM “Kreisel”), “Terminal M” (TM “Siltek”), “Akvalit” (TM “Akvalit”).

The requirements for the thermal efficiency of buildings and structures in Ukraine are constantly growing. In 1960, the standard resistance to heat transfer *R* was 0.7 m·K/W. In 1995, it increased to 1.8-2.2 (m·K)/W, in 2006 – up to 2.8 (m·K)/W, the current norm from 2015 *R* is equal to 3.3 (m·K)/W.

One of the main reserves of energy saving is the reduction of thermal and sound insulation properties of housing and civil facilities to the modern European level, which, along with saving energy resources, will solve the problem of ensuring the normative level of comfort in the residential environment, the absence of which has become a serious social problem for residents of multi-family housing.

Modern systems for home heat insulation make it possible to reduce the cost of heating, and also have optimal sound-absorbing properties, protect against vibration. For the production of systems are used heat and sound insulation materials such as mineral wool products, extrusion and beaded expanded polystyrene and the like [8].

Each of the materials has its advantages and their engineering justified combination makes it possible to make the construction of thermal insulation at home as efficient and durable as possible.

The main types of heat and sound insulation used in Ukraine today are polystyrene and other foam plastics, their share is more than 35 %, mineral wool and glass wool products occupy 35 % and 25 % respectively, and about 1 % fall on other types of heat-insulating materials (see the following diagrams). In general, the market of thermal insulation materials in Ukraine is quite stable.

At the same time, it should be determined that the volume of the rock wool segment showed a positive trend and increased by 0.3 % compared to 2012, while the segment of the expanded polystyrene foam market increased by 0.9 %. This trend indicates that the participants of the building materials market prefer the products of stone wool as safer and non-combustible and cheaper products made of expanded polystyrene.

The world and domestic construction industry today offers a wide choice of heat and sound insulation materials, each of which has its own technical characteristics and scope.

In the general balance of the use of heat and sound insulation in Ukraine, which has developed today, about 65 to 70 % of materials are used in enclosing structures, about 15-17 % are used for installation insulation, 8-10 % for heat insulation of pipelines, 4-5 % for sound insulation, and for the refrigeration industry – about 0.6 %.

Nomenclature and classification of heat-insulating and acoustic products.

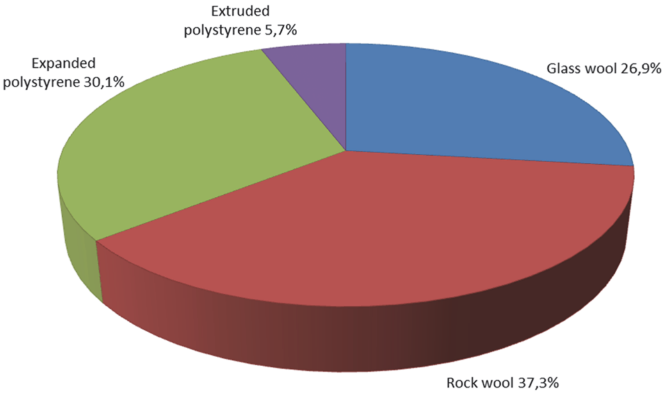


Fig. 10. Market structure of heat and sound insulation materials of Ukraine in 2016, thousand cubic meters

Heat-insulating and soundproof materials according to GOST B16381: 2011, are classified according to form, appearance, structure, type of raw material, density, stiffness (relative deformation of compression), thermal conductivity, flammability.

In terms of form and appearance, the materials are divided into:

- piece products (plates, blocks, brick, cylinders, semi-cylinders, segments);
- rolled and corded (mats, cords, tows);
- loose materials (mineral wool and glass, expanded perlite and vermiculite).

cotton wool and products based on it

One of the main types of heat and sound insulation materials in our country and abroad today is silicate wool and products based on it. This production accounts for more than 50 % of the total volume of thermal insulation materials.

The use of fibrous products in construction during the warming of brick walls reduces by 50 % the demand for bricks, reduces the consumption of cement and lime by 2.5-3 times, labor costs at construction sites and the estimated cost of construction with the same heat resistance of enclosing structures.

Silicate wool (the general name of glass and mineral wool) and products made of it are the most common form of heat and sound insulation materials. Silicate wool consists of fibers of microscopic thickness, which in most cases are placed chaotically, and the particles of solidified melt that have not formed into fibers (so called “korolki”). The quality of melt processing in fiber is determined by the presence of “korolki” contained in the resulting silicate wool, and thus, by the purity and insulation characteristics of silicate wool.

The main property of silicate wool is incombustibility in combination with high heat and sound insulating ability, resistance to temperature deformation, non-hygroscopicity, chemical and biological resistance, environmental friendliness and ease of installation work.

Products made of these materials retain thermal insulation and mechanical properties at the initial level for decades.

In addition, the use of products from these materials provides a good sound insulation of enclosing structures. Mineral and glass wool significantly reduce the risk of standing sound waves inside the enclosing structures, providing an increase in the insulation index from air noise.

The advantages of mineral wool and fiberglass insulation are the ability to apply them depending on their technical characteristics not only in the form of solid and semi-solid slabs in the facade structures, but also in the form of soft slabs and mats in frame structures, for example, in panels of the type “sandwich”.

Production of silicate wool and products from it shows a positive dynamics: from 370 ths. m^3 in 1990 to 5.2 mln. m^3, while the presence of basalt deposits in Ukraine allowed producing of stone wool at a higher pace in comparison with glass wool.

Table 4. Market of heat insulation materials of Ukraine

Thermal insulation material	2015		2016		Growth 2015/2016, %
	Volume, ths. m^3	Share, %	Volume, ths. m^3	Share, %	
Rock wool	2943.4	37.2	3024.9	37.3	2.8
Glass wool	2122.0	26.8	2176.1	26.9	2.5
Expanded polystyrene EPS	2480.2	31.2	2442.4	30.1	-1.5
Extruded polystyrene XPS	376.6	4.8	461.0	5.7	22.4
TOTAL	7922.2	100.0	8104.4	100.0	2.3

The segment of mineral wool insulation in 2016 grew by more than 2.5 % compared to 2015. If we consider the thermal insulation markets on the basis of glass fiber and basalt separately, then the consumption of fiberglass insulation increased by 2.5 %, based on basalt by 2.8 %. According to the forecasts of some experts, in the future, these growth rates should be maintained.

More than 95 % of the needs of the Ukrainian market of thermal insulation on the basis of fiberglass is satisfied by the products of four manufacturers of mineral wool insulation “TechnoNicol”, “Knauf Insulation”, URSA, ISOVER.

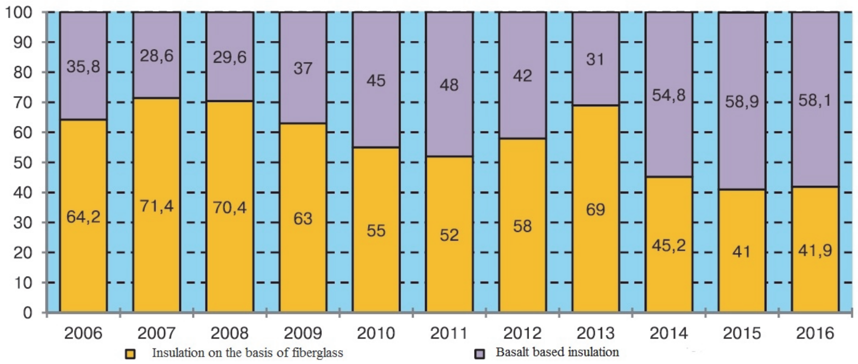


Fig. 11. Distribution of the market of fibrous thermal insulating materials of Ukraine in 2006-2016, %

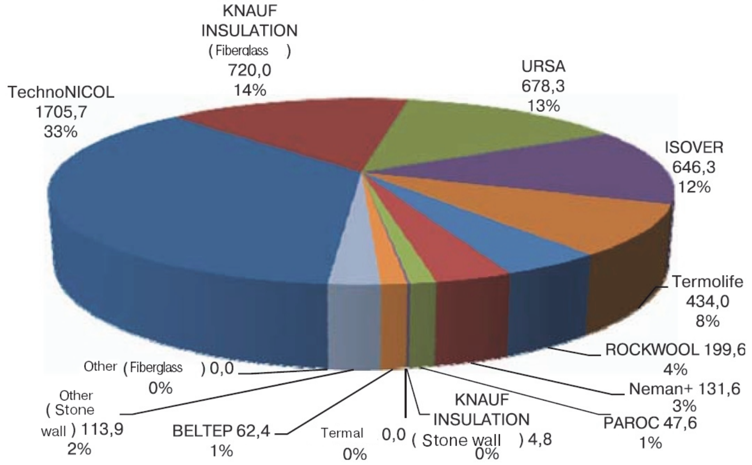


Fig. 12. The market structure of the mineral wool (stone wool + glass wool) of Ukraine 2016 ths. m^3, %

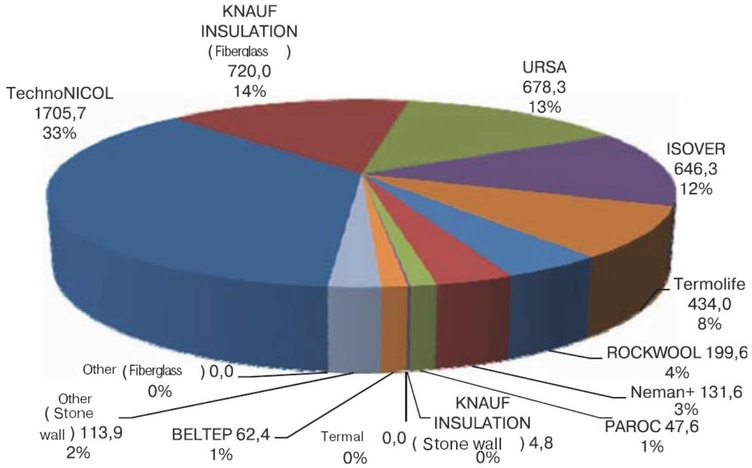


Fig. 13. The market structure of the expanded polystyrene thermal insulation EPS of Ukraine 2016, ths. m^3, %

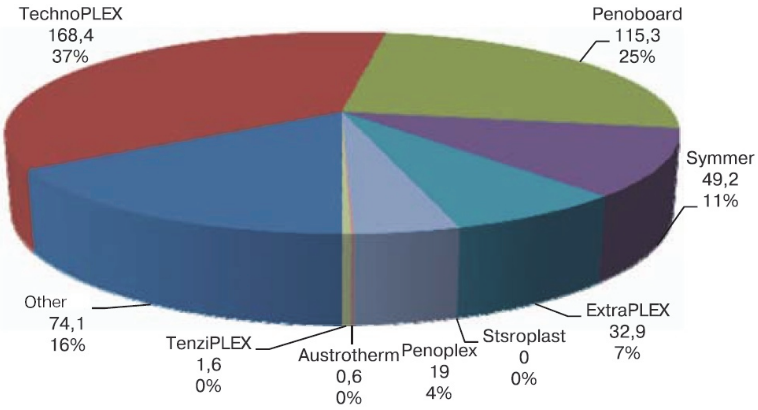


Fig. 14. The market structure of the expanded polystyrene thermal insulation XPS of Ukraine 2016, ths. m^3, %

The market structure of the expanded polystyrene thermal insulation EPS of Ukraine 2016 is presented in Fig. 13. The market structure of the expanded polystyrene thermal insulation XPS of Ukraine 2016 is presented in Fig. 14.

By the results of 2016, it is evident that the tightening of the requirements for energy efficiency of buildings and the introduction of a regime of increased energy savings and the economic crisis have led to changes in the market of TIM, but those changes will further activate the Ukrainian market as early as 2017. Forecasting trends for 2018, it should be noted that the segment of light positions of mineral wool will further develop.

In 2016, a new thermal insulation material produced by BASF Neopor appeared on the thermal insulation market.

Neopor® is the newest technical solution offered by BASF for effective thermal insulation in the construction of new and reconstruction of existing buildings. BASF represents Neopor® as an innovative development based on polystyrene with the trade name Styropor®, has been successfully applied for thermal insulation and packaging for many years. Neopor® is a polymer (EPS) granulate of expanded polystyrene. Expanded polystyrene based on Neopor® is of silvery-gray color, because it contains graphite, which significantly increases the thermal insulation properties of the material. Expanded polystyrene based on Neopor® significantly exceeds other insulation materials, because compared to the latter it has much higher thermal insulation properties. This decisive advantage reduces the cost of heating the house and increases the value of housing, taking into account the growing environmental requirements. As a result: Neopor® is a contribution to resource saving and the opportunity to create a favorable microclimate in a residential area.

Excellent efficiency of thermal insulation made of Neopor® material is a significant advantage in practical construction for architects, engineers, builders and developers. Absorption or reflection of infrared radiation with Neopor® material significantly reduces the thermal conductivity of the building. The material to a lesser extent than conventional thermal insulation boards, allows the heat to pass through.

Absorption and reflection of infrared radiation can significantly reduce the heat outflow caused by radiation. Using of Neopor® is most advantageous where, with a low absolute density of thermal insulation, you need to achieve maximum efficiency of thermal insulation. Neopor® thermal insulation with a density of 15 kg/m^3 are provided, for example, with a thermal conductivity of $\leq$ 0.032 W/(m·K). For a typical EPS of comparable density, the thermal conductivity parameter is $\geq$ 0.037 W/(m·K).

The production of thermal insulating products based on expanded perlite is successfully developing in Ukraine.

Expanded perlite is the basis of effective heat and sound insulation materials. One of the significant advantages of perlite is that it reduces fire hazard and increases the fire resistance of structures. Perlite is part of flame retardant paints, pastes, fire retardant plaster, it is used as fillers for light concrete. Perlite materials are capable of improving the physical properties of existing structures. The regulation of the humidity of constructions and of the microclimate of premises is one of the peculiarities of materials based on perlite. This material is biologically stable, such that it cannot be decomposed and rotten under the action of microorganisms, is not a favorable environment for insects and rodents. Chemically inert - neutral to alkali and weak acids. Perlite is environmentally friendly and sterile material, non-toxic, does not contain heavy metals.

Expanded perlite is a porous material obtained by thermal treatment of crushed volcanic water-containing rocks. After firing, expanded perlite is divided into sand (< 5 mm) and crushed stone (5-20 mm), depending on the grain size.

Expanded perlite sand DSTU BV. 2.7-157: 2011 (GOST 10832-2009). Building materials. The expanded perlite sand and crushed stone. Technical specifications. Divide into ordinary PSO – with grains of any fractions in the size from 0.16 mm to 0.5 mm, large PSL – with grains of the fraction (1.25-5) mm, the average PSA – (0.16-2.5) mm, small PSS – (0.16-1.25) mm, powdered PSP – less than 0.16 mm.

Table 5. Technical data Neopor®

Property	Unit	Designation code acc. to EN 13163	Metrics for insulation products made of Neopor® EPS®			Standard
			EPS 70	EPS 100	EPS 150	
Thermal conductivity, λ_D	W/(m·K)	–	≥ 0.031	≥ 0.030	≥ 0.030	EN 13163
Thermal conductivity, rated value	W/(m·K)	–	≥ 0.032	≥ 0.031	≥ 0.031	Deutsche a.b.Z
Compressive strength at 10 % deformation	kPa	CS (10)	≥ 70	≥ 100	≥ 150	EN 826
Tensile strength perpendicular to plane of board	kPa	TR	≥ 100	≥ 150	≥ 200	EN 1607
Flexural strength	kPa	BS	≥ 115	≥150	≥ 200	EN 12089
Shear strength	kPa	t	≥ 35	≥ 60	≥ 85	EN 12090
Dimensional stability after 48 h at 70°C	%	DS (70, -)	≤ 1	≤ 1	≤ 1	EN 1604
Deformation after 48 h at 20 kPa and 80°C	%	DLT (1) 5	–	≤ 5	≤ 5	EN 1605
Deformation after 168 h at 40 kPa and 70°C	%	DLT (2) 5	–	–	≤ 5	EN 1605
Water vapor diffusion resistance factor μ	–	–	20-40	30-70	30-70	EN 12086
Thermal linear change coefficient	K^{-1}	–	$60\text{-}80 \cdot 10^{-6}$	$60\text{-}80 \cdot 10^{-6}$	$60\text{-}80 \cdot 10^{-6}$	DIN 53752
Reaction to fire	Euroclass	–	E	E	E	EN 13501-1
Chemical resistance	Insensitive to water, most acids, and lyes. Sensitive to organic solvents.					
Biological behavior	No influence on microorganisms. Does not decay or rot. Chemically neutral, not soluble in water. No known health hazards.					

Perlite-cement dry mixtures. Used in Europe and Ukraine in the form of heat-insulating plaster mixtures, lightweight billets for the floor and solutions for masonry. They can be used both for the construction of new and for the reconstruction of old buildings that do not meet the current requirements for thermal protection.

Perlite-concrete wall blocks. Full-walled blocks with the density of 500-700 kg/m^3 are manufactured using the vibration-pressing method and are used in Ukraine for the construction of low-rise, multi-storey and high-rise buildings. Due to the granular structure and the presence of a glassy phase of perlite filler, perlite concrete has better thermal-technical characteristics than autoclaved cellular concrete of similar density.

Thermal-insulated plates in the shell. Promising development of NDIBMV – non-flammable thermal-insulated plates made of expanded perlite on an inorganic binder in a shell with the effect of reflective insulation.

Characteristics:

- density – 200-250 kg/m^3;
- thermal conductivity (piped products) – 0.05-0.06 W/(mK);
- thermal conductivity (using vacuum or modified gas medium) – 0.02-0.03 W/(mK);

- compressive strength is 0.2-0.3 MPa.

Perlite products on liquid glass are produced of two types – perlitephosphogel and perlite calcine lightweight.

Perlitephosphogel products consist of perlite expanded sand (60-70 %) and liquid glass (40-30 %). Products are used for fire protection and thermal insulation of building structures, equipment, pipelines at temperatures up to 600°C.

When installing a waterproofing coating, plates, on which paper is fixed with the help of bitumen, are used to insulate structures, equipment and tanks.

The products are manufactured in the form of plates, shells (semicylinders) and segments with a length of 450-1000 mm, width (for plates) – 250-500 mm and internal diameter (for shells and segments) – 57-426 mm, thickness 40-100 mm.

Perlite-ceramic products are made of a mixture of expanded perlite sand and plastic refractory clay.

The products are intended for thermal insulation of industrial equipment, furnaces and pipelines at a temperature of no more than 875°C.

Perlite-ceramic products are divided according to the density into brands: 200, 220, 250, 300, 350, 400. Products are produced in the form of plates, bricks, shells and segments.

Lightweight refractory perlite-chamotte products consist of expanded perlite sand (3-13 %), refractory clay (16 %) and chamotte (71-81 %).

Based on the above, we can conclude that the building materials industry of Ukraine is a powerful player in the market of building materials and products and a leading country in the post-Soviet space in attracting of modern foreign technologies.

It can be predicted that by 2025 traditional building materials, ceramic and silicate bricks will be replaced with clinker bricks and products made from autoclaved aerated concrete. The segment of dry building mixtures will significantly increase its presence in the total production of binders. With an increase in construction volumes, dry construction systems (plasterboards), whose production capacity can reach 200 mln. m^2/year, will be increasingly in demand.

References

[1] **Zakharchenko P. V., Gavrysh A. M., Sokha V. G., Reva V. I., et al.** A Guide to the Market of Materials for Internal Arrangement and Decoration of Premises (According to 2015). Under the General Editorship of Prof. Zakharchenko P. V., KNUBA, IE Pavlenko, 2016, p. 252.

[2] **Zakharchenko P. V., Lenga G., Gavrysh A. M., Piven N. M.** Technology and Goods Management of Dry Construction Systems. KNUBA, Edition 2, IE Pavlenko, 2011, p. 512.

[3] **Zakharchenko P. V., Gavrysh A. M., Kashchenko T. O., Piven N. M.** Workshop on Technology and Goods Management of Dry Construction Systems: Tutorial. KNUBA, Edition 2, LLC Publishing Workshop, 2016, p. 384.

[4] **Zakharchenko P. V., Gavrysh A. M., Karpenko O. P., Petukhova O. M.** Technology and Goods Management of Dry Construction Systems: Fire Protection of Building Structures. Tutorial. KNUBA, IE Pavlenko, 2012, p. 392.

[5] **Zakharchenko P. V.** Recommendations on the design and installation of partitions with plasterboards KNAUF, which are required fire safety and fire protection of building structures. Annex 2 to the tutorial “Technology and goods management of dry construction systems: fire protection of building structures”. KNUBA, IE Pavlenko, 2012, p. 50.

[6] **Karapuzov E. K., Sokha V. G., Ostapenko T. Ye** Materials and Technologies in Modern Construction: Textbook. Higher Education, 2006, p. 495.

[7] **Zakharchenko P. V., Sokha V. G., Piven N. M.** Waterproofing Systems. Consumer Properties. Test Methods and Devices of Arrangement. Tutorial. KNUBA, LLC Publishing Workshop “SPD Pavlenko”, 2017, p. 180.

[8] **Zakharchenko P. V., Gavrysh O. M., Dolgy E. M., Galagan Y. O.** Thermal and Sound Insulation Materials and Products in Energy-Saving Technologies. Textbook. Masters, 2008, p. 340.

Petro V. Zakharchenko, Kyiv Nationality University of Building and Architecture. Honored master Education of Ukraine, Full Member of the Academy of Building of Ukraine. Professor, Doctor of Philosophy, Ph.D. Technical Science, head of Department of Goods Management and Commercial Activity in Building. Total number of his publications is 220.

Oleksandr M. Gavrysh, Kyiv Nationality University of Building and Architecture. Honored Builder of Ukraine. Professor, Doctor of Philosophy, Ph.D. of Philological Science. Full Member of the Academy of Building of Ukraine. Total number of scientific publications is 115.

Roman D. Zakharienkov, State University of Telecommunications, Communications Engineer. President of Ukrainian Association of Styrofoam Manufacturers, Corresponding Member of the Academy of Building of Ukraine. The Association's purpose is solving common problems for certification of raw materials and products, dissemination of information about products and possible technologies for its use, support for the development and introduction of appropriate production and technologies, study and sharing the best practices of manufacturers and users of products, assistance in attracting domestic and foreign investment in the industry.

6.2. A new method for determining an acoustical characteristic of building materials

Tamaz Natriashvili[1], Merab Chelidze[2], David Nizharadze[3], Jemal Javakhishvili[4]
LEPL R. Dvali Institute of Machine Mechanics, Tbilisi, 0112, Georgia
[2]Corresponding author
E-mail: [2]*merabchelidze@yahoo.com*

Abstract. The modern digital technique and software give the ability that the sound absorption coefficient was measured by the method of the sound amplitudes decay in a closed chamber, namely in the impedance tube, by means of the ratio of the subsequent attenuating reflected waves. Taking into account the influence of the length and diameter of the impedance tube on the process of decay of sound waves, a new study of sound propagation in an impedance tube is presented, on the basis of which the sound absorption coefficient is determined much easier.

Keywords: sound, wave, reflection, reverberation, decay, absorption, measurement, vibration.

1. Introduction

Sound, a form of energy, is caused by molecules vibrating in a gas, liquid or solid and it propagates in the air as waves by changing of atmospheric pressure i.e. by disturbance of the air pressure. Sound after exposure to solid materials is converted into vibration and thus spreads into them. The frequency or pitch of the noise, measured in hertz, is the number of sound waves emitted per second.

Noise can be described as unwanted sound, the intensity of sound depends on pressure levels which are measured in decibels (dB). Previous studies have shown that the results for an absorption coefficient test are dependent on the testing method, that is, the absorption coefficients of the same material with the same properties will vary depending on the testing method. Sound insulation refers to the ability of the building material to resist the transmission of airborne and impact sound. Some existed typical noise levels are given in Table 1. It should be noted that all the noise levels presented in Table 1 are different for different countries, for example, the highly developed countries have more stringent requirements.

Table 1. noise levels in pascals and decibels

Noise	Explanations	Pascal	dB
Lower threshold of audibility	Sound is not heard	$2\cdot10^{-5}$	0
A quiet rustle of leaves	Is heard at a distance of 1 m	$6.32\cdot10^{-5}$	10
At night	The sound pressure level provided for by the standards for living rooms	$6.3\cdot10^{-4}$	30
In the afternoon		0.002	40
In the workplace intermittent noise	The sound level should not exceed	6.3	110
Impulse noise at the workplace	Permissible for a short period in the form of impulse noise	35.1	125
Jet plane at the start	Feeling of pain in the ears at a distance of 1 m	63	130
The environment in which high sound pressure	Even for a short period of time it is inadmissible to remain	112.5	135
Excessive sound pressure	Causes a rupture of the septum of the ear can even lead to death	2000	160
Epicenter of the explosion	Causes death of a person	200000	200

2. The new heat and sound-insulation building materials

To solve the problem necessary the creation of low-cost building materials based on local resources. Creation of such materials in the local area makes it possible to improve, as the sound insulation so heat insulating characteristics, which is connected with the decision of very important social and economic problems. It should be noted soundproofing material has very good heat insulation characteristics as well.

Sound insulation and heat proofing characteristic of building wall partitions are improved greatly when foam concrete is used in it as a layer of the sandwich. For obtaining foam concrete is used soon spoiling organic components that are very uneasy (clumsy) for little and serial enterprises in terms of storage and transportation costs. The foam material created by us on the basis of local raw materials is cheap and durable because it is based on inorganic materials and they are rosin and glue. The noted technological process is new and, possibly, promising in our market.

To develop a new production technology for relatively cheap sound-proof building materials and to determine the acoustic and heat non-conductive characteristics for the materials obtained, it is necessary to simplify the method of determining the absorption coefficient of materials, so that in practice it is widely used in production and at homes by citizens.

3. Theory of propagation and reflection sound waves.

Measureless and frequency dependent the sound absorption coefficient α presents the main acoustical characteristic of materials and in agreement of the determination is the ratio of the absorbed E_{abs} and the incident E_{inc} energies [1-3].

$$\alpha = \frac{E_{abs}}{E_{inc}}. \tag{1}$$

Though in some cases α is determined as a relation all not reflected energies with incident energy:

$$a = 1 - \frac{E_{ref}}{E_{inc}} = \frac{E_{abs} + E_{tran}}{E_{inc}}, \tag{2}$$

where in a consent of the conservation energy $E_{inc} = E_{ref} + E_{abs} + E_{tran}$.

Besides of the vacuum, the sound is propagated in any materials. The sound is appeared by any disturbance of the air pressure p; density ρ; environment particles speed v and temperature t. The functional connection between air pressure and density is expressed by adiabatic equation $p = f(\rho)$. The differentiation of which gives the sound composition equation [4-6]:

$$\frac{\partial p}{\partial x} = \frac{1}{c^2}\frac{\partial p}{\partial t}, \tag{3}$$

where c – the speed of sound propagation

The solution of the equation of (1) may be presented by two periodic and harmonic propagating waves [6]:

$$p = A\cos(\omega t - kx) + B\cos(\omega t + kx). \tag{4}$$

For periodic oscillations (4) takes view:

$$p = f_1\left[\frac{c}{\omega}(\omega t - kx)\right] + f_2\left[\frac{c}{\omega}(\omega t + kx)\right], \tag{5}$$

where $k = \frac{\omega}{c} = \frac{2\pi f}{c} = \frac{2\pi}{\lambda}$ waves oscillations, $\lambda = \frac{c}{f}$ – is length of waves.

For harmonic waves, Eq. (5) takes the following form:

$$p = A\cos\frac{\omega}{c}(ct - x) + B(ct + x) = A\cos(\omega t - kx) + B\cos(\omega t + kx). \tag{6}$$

The Eq. (6) frequently is presented in a complex form for simplifying summing calculation operations of different frequency waves:

$$p = \left(\overline{A}e^{-jkx} + \overline{B}e^{-jkx}\right)e^{-jkx} = \overline{A}e^{-jkx-jkx} + \overline{B}e^{-jkx-jkx}. \tag{7}$$

In accordance with equations of (6) and (7) the incident and reflected flat waves are summed that is, depending on the phase of the waves, the corresponding amplitudes increase or decrease. In accordance with equations of (4) $p = X(x)T(t)$ if there will be taken two private solutions and they will be supplied in Eq. (3) then will be obtained equations which left and right parts will equal [6]. There may be such solution where they will equal to $-k^2$:

$$\frac{1}{C^2}\frac{\partial^2 T}{\partial t^2} = \frac{\partial^2 p}{\partial t^2} + \frac{1}{X}\frac{\partial^2 X}{\partial x^2} = -k^2. \tag{8}$$

From Eq. (8) are obtained two equations with following solutions, which are analogous of oscillation of material [6]:

$$\frac{\partial^2 X}{\partial x^2} = -k^2 X,\ \ X = A\cos(kx + \varphi_x),\ \ \frac{\partial^2 T}{\partial t^2} = -k^2c^2T = \omega^2 T,\ \ T = B\cos(\omega t + \varphi_t), \tag{9}$$

where $\omega^2 = k^2c^2$.

The solution of wave equations is equal:

$$p = XT = C\cos(kx + \varphi_x)\cos(\omega t + \varphi_x). \tag{10}$$

The obtained equation describes free oscillation of standing waves. So private solution of the equation $p = X(x)T(t)$ gives us possibility from endless solutions were searched the standing waves equation. The solution of plane waves can be represented as in form standing waves so moving waves. Moving plain waves are characteristic for unstable processes and standing waves for periodic and stable processes [6, 7].

Usually, α is in a functional dependence with the sound incidence angle of θ_{inc}. When sound waves are fallen on the materials by the right angle the absorption ability of the materials are denoted by αN. So, the simplest method evaluation of materials absorption ability αN and surface impedances ∂N are to use the impendance tube in which are generating plane waves [3-5].

When a simple wave falls at a right angle at the point $x = 0$ on the body of separation of two media (Figure 1), then a part of the wave is reflected, and the other part is transmitted into the second environment. The propagation of sound in both media is described by the wave equation and they can be integrated independently of each other [3, 6].

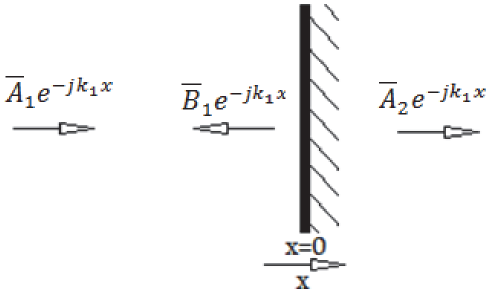


Fig. 1. Sound reflection, transition and two media separating barrier

The solution of the incident and reflected wave equations is equal to:

$$\overline{p}_1 = \overline{A}_1 e^{-jk_1 x} + \overline{B}_1 e^{-jk_1 x}. \tag{11}$$

But the solution of the transmitted equation is equal to:

$$\overline{p}_2 = \overline{A}_2 e^{-jk_1 x}. \tag{12}$$

Since the second environment is presented as endless that $\overline{B}_2 = 0$ so the sum of incident and reflected sounds pressures P1 located at left side of dividing barrier must be equal to penetrated sound pressure P2 located at the right side of the barrier [6]:

$$(\overline{P}_1)_{x=0} = (\overline{P}_2)_{x=0}, \ \overline{A}_1 + \overline{B}_1 = \overline{A}_2. \tag{13}$$

Theoretical analysis of the above-described sound equations shows that the sound wave in materials behaves similarly to the vibration wave, which makes it possible for the absorption coefficient to be determined by the decay process of the reverberating amplitudes, as in the case of the theory of oscillations. Moreover, the sound in the materials is spread in the form of vibration and vibration is the source of the creation and propagation of sound waves in the atmosphere.

The full period of propagation plane waves from one side covers of the tube to another and back, i.e. one full cycle T_{lon}, is a ratio of the double length of the tube to the speed of sound propagation in air. If the length of the tube is more than 4 diameters, stable flat and standing waves form in the tube in the longitudinal direction [3, 4, 7]. When the noise source is turned off, in the tube, the amplitudes of the standing and plane waves are fallen at the same speed. In accordance with formula (1), the value of decay of sound amplitudes in each cycle is equal to the transmitted and absorbed sound energy by the materials on the side covers of the tube.

White and octave waves emitted by a sound source create very complexly and unstable reverberating waves in the impedance tube when simple (coherent) sound waves of frequency f create simple waves oscillating with a frequency f in the tube. Sound waves, circulating in a closed impedance tube, are repeatedly reflected from the side covers of the tube. The resulting reverberating plane waves act on each other, are summed up and create stable standing waves in the tube (Fig. 2). The absorbent material, that is fixed to the side end of the tube (Fig. 2), causes a change in the amplitude of the standing waves [3, 8, 9]. Experimental investigation showed that little appreciable differences are obtained in the results from using the short and long tubes.

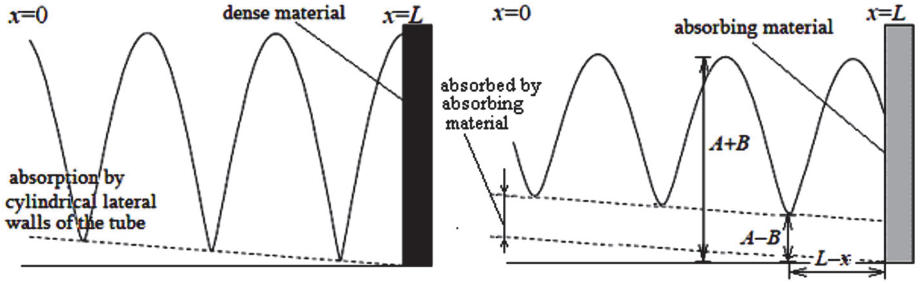
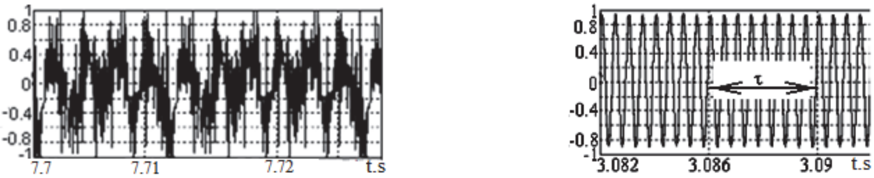


Fig. 2. Standing waves in the impedance tube

4. Experimental investigation and obtained results

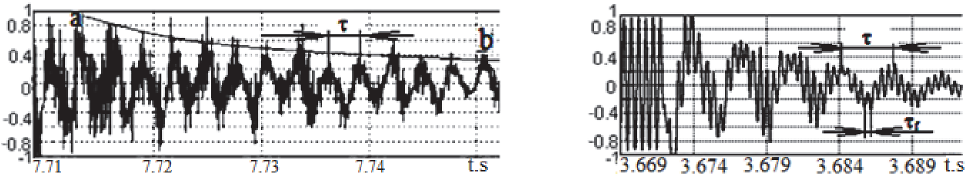
Performed theoretical and experimental studies, by the help of modern digital technologies, have shown that the propagation of the waves of white noise in a closed tube creates and establishes a complex unstable reverberating oscillation (Fig. 3(a)). It should be noted that in the case of white noise and an impedance tube with a length $L = 0.63$ m, along the tube side, covers clearly are visible longitudinal reverberating sound waves oscillations with the frequency of $f_{lon} = 300$ Hz, whose frequency is equal to the ratio of the sound speed s to the double length of the tube 2L, i.e. $f_{lon} = s/2\text{L}$ [3, 13]. If the sound source is coherent, for example with a frequency of 2000 Hz, coherent waves with a frequency of 2000 Hz are also installed in the tube, but in this case, practically, noticeable longitudinal oscillations with frequency $f_{lon} = 300$ Hz are not detected (Fig. 3(b)).



a) $f_1 = 300$ Hz; $\tau = 0.0033$ sec b) $f = 2000$ Hz; $\tau_f = 0.0005$ sec; $\tau = 0.0036$ sec

Fig. 3. Reverberating white a) and coherent b) sound waves in the impedance tube

In the tube, since the moment the sound source is turned off, a transient process of decay of the reverberating amplitudes occurs until the sound waves completely disappear (Fig. 4(a)). Approximately the frequency of the decay of longitudinal waves with white noise is equal to $f_{lon} = 300$ Hz, and for a coherent noise source Fig. 4(b), $f_{lon} = 285$ Hz ($\tau = 0.0036$ sec), and both are related to the length of the impedance tube.



a) $f_{lon} = 300$ Hz, $\tau = 0.0033$ sec b) $f_{lon} = 285$ Hz, $\tau_f = 0.0005$ sec, $f = 2000$ Hz

Fig. 4. Decay processes of white a) and coherent b) reverberating sound waves

According to Fig. 4(b), the period τ and the frequency f of the decay reverberant sound amplitudes can be calculated as follows. The period of coherent sound waves τ_f is equal to time mark interval divided by the number of amplitudes of this interval τ_f = (3.689-3.684)/11 = 0.0005 sec. Thus, in accordance with the period τ_f, the frequency of the noise source is $f = 1/\tau_f$ =1/0.0005 = 2000 Hz. Consequently, the period and frequency of longitudinal oscillations will be $\tau = n\tau_f = 7\cdot 0.0005 = 0.0035$ sec. $f_{lon} = 1/\tau = 285$ Hz. Where n is the number of amplitudes in the period τ. The curve ab in Fig. 4(a) shows the average rate of the decay process of group amplitudes of longitudinally reverberating waves.

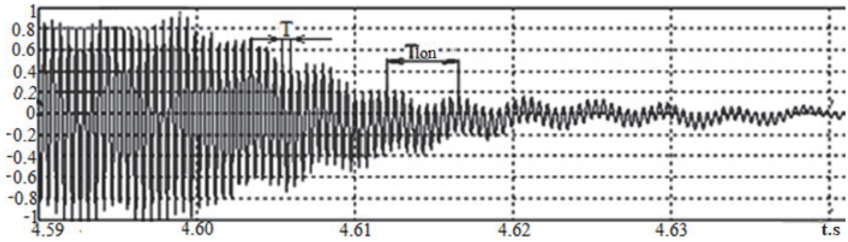


Fig. 5. Sound decay exited frequency $f = 2000$ Hz, decay frequency $f_{lon} = 200$ Hz, $L = 0.8$ m

It should be noted that in any process of decaying waves, in conjunction with the frequency f emitted by the sound source, frequencies of longitudinal waves are observed, which are created in a long tube by frequent reflections from the side covers of the tube (Figs. 5-7).

To improve the accuracy of measurement, the sound reflection coefficient of the tube wall should be close to 1, i.e. material for the tube should be bronze, with a minimum wall thickness of 5 mm, although the tube material may be steel [5, 10, 11].

Thus, in an impedance tube, two types of waves are simultaneously generated: 1) waves with a frequency f emitted by the sound source, and 2) longitudinally reflecting waves produced in the tube. The process of decay standing waves in an impedance tube are combinations of sums of frequencies f and f_{lon}, which decay at different frequencies and times.

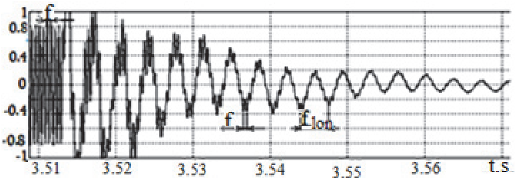


Fig. 6. Sound decay, exited frequency f = 2000 Hz, decay frequency f_{lon} = 250 Hz, L = 60 cm

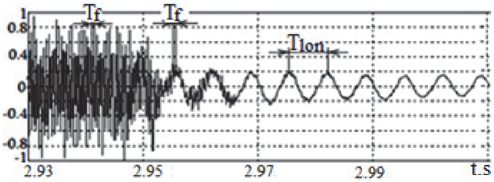


Fig. 7. Sound decay, exited frequency f = 2000 Hz, decay frequency f_{lon} = 150 Hz, L = 1 m

The fact that the ability of a material to absorb sound energy is related to the frequency of sound is clearly visible in Figs. 6 and 7, where high-frequency f waves emitted from a sound source are absorbed faster than longitudinally reverberating low-frequency sound waves f_{lon} excited in an impedance tube, although at a given frequency, in the presence of another absorbent material (e.g., a cork tree), they can decay simultaneously (Fig. 5).

Each longitudinally oscillating amplitude (wave), reflected by the side covers during the decay, contains a set of white noise amplitudes emitted by the noise source (Fig. 4(a)), and in the case of coherent noise, it contains only a few amplitudes [12,13]. The number of coherent amplitudes contained in longitudinally oscillating waves is directly related to the tube length and is equal to $n = L \cdot 2 \cdot f / s$. Fig. 6 shows that one longitudinal wave of 2000 Hz contains 7 radiated waves when the tube length is 0.6 m, but with a tube length of 1 m, one amplitude contains 13 emitted coherent amplitudes from the noise source Fig. 7.

In accordance with formula (1), the absorption coefficient α, in the case of amplitudes decay of complex form, also can be determined by the ratios of reflected amplitudes Figs. 5-7.

Figs. 8 and 9 show the processes of decay in the presence of coherent sounds of 100 and 2000 Hz, occurring in an impedance tube of length $L = 0.585$ m. In Fig. 8, we see the process of decay of a sound with a frequency $f = 100$ Hz, whose decay frequency is $f_w = 47$ Hz which contains 5.7 waves, the decay frequency of which is $f_{lon} = 285$ Hz. Since the length of the sound wave of 100 Hertz is 334·0.01 = 3.34 m and 5.8 times the length of the tube $L = 0.585$, then for one full period of the 100 Hz wave, the tube reflects 5.8 times in lengthwise direction, so L_w = (1/285)·6 ≈ 47 Hz.

As for Fig. 9, the length of one sound wave of 2000 Hz is 0.167 m and 3.5 times less than the length of the tube $L = 0.585$ m. A very interesting process takes place in an impedance tube when the source of coherent noise is cut off. In the process of sound attenuation, because of the absence of waves emitted by the sound source, the previous reflected waves assume the role of a sound source, so in this case standing waves are created by additional reflected waves, otherwise standing waves will not be created in the tube (Eqs. (6), (7)). Thus, in the decay process, in closed spaces, twice reflected two waves moving in opposite directions create standing waves which frequency is increased two times Fig. 9. Therefore, out of 3.5 longitudinally oscillating amplitudes, 7 standing oscillating amplitudes are obtained.

To achieve standing waves, it is necessary that the length of the tube is more than 3-4 diameters, and above 1700 Hz the diameter of the tube should not exceed 30 mm. Since the decay of sound waves at 2000 Hz recorded in Figure 9 was performed by a tube 100 mm in diameter, so the shape of the decay differs from the decay mode shown in Fig. 10 where the decay process was made by means of a tube with a diameter of 25 mm. So high-frequency sound waves emitted by a noise source during the decay process at each longitudinal reverberating amplitude (wave) do not practically change in magnitude.

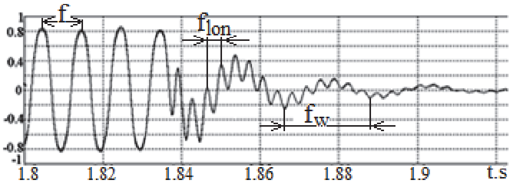


Fig. 8. Sound decay, exited frequency f = 100 Hz, decay frequency f_{lon} = 285 Hz, f_w = 47, L = 58.5 cm

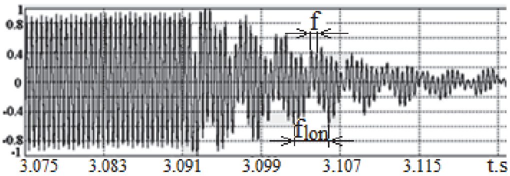


Fig. 9. Sound decay, exited frequency f = 2000 Hz, decay frequency f_{lon} = 285 Hz, L = 58.5 cm

Fig. 11 shows the process of decay of waves in an impedance tube, when high-frequency sound waves emitted by a noise source have $f = 200$ Hz. and the frequency of standing waves created in the impedance tube has $f_{lon} = 285$ Hz. In this case, the amplitudes of the longitudinal oscillations, as compared with Fig. 8, increase significantly since the indicated frequency is closer to each other, i.e. a resonant phenomenon is created in the tube and when the source of noise is turned off, the decay of the amplitudes of the longitudinal oscillations occurs almost at the frequency that has a coherent noise source.

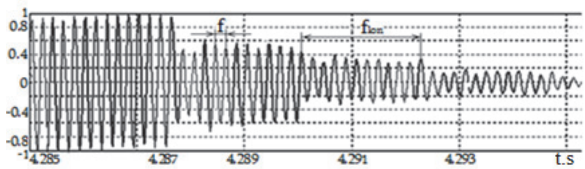


Fig. 10. Sound decay, exited frequency f = 5000 Hz, decay frequency f_{lon} = 415 Hz, L = 40 cm

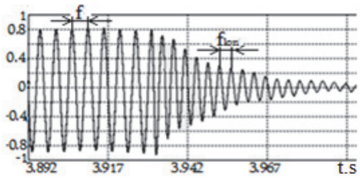
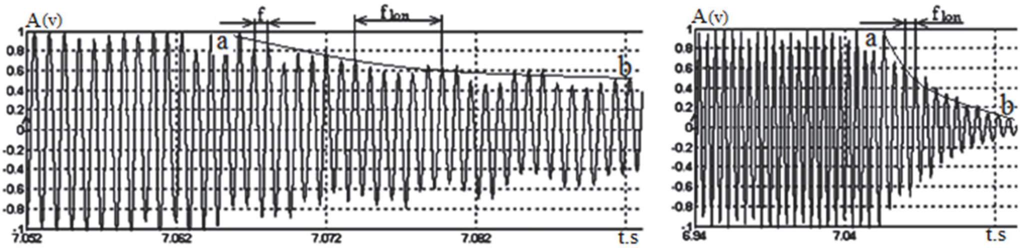


Fig. 11. Exited frequency f = 200 Hz, decay frequency f_{lon} = 285 Hz, L = 58.5 cm

The program VT RTA-168 makes it possible to look for such a deployment scale when the longitudinal decay waves (Fig. 12(a)) will be represented in a clean longitudinal reverberating form without shown of waves emitted from the sound source (Fig. 12(b)). The curve ab on both oscillograms shows the time duration and the attenuation rate of the longitudinal oscillation amplitudes in Fig. 8(a) in the expanded form and in Fig. 8(b) in compressed form.



a)

b)

Fig. 12. Sound decay processes, a) exited f = 1000 Hz, decay f_{lon} = 150 Hz, b) Waveform is compressed

The rate of decay of plane waves in an impedance tube is determined by the imperfect reflection of sound from both sides, the propagation of sound in the air, and the resistance of the side walls to the sound waves propagating along the length of the tube, as confirmed by experimental studies. If one side tube cover is replaced by a sample material that has a different absorbent capacity, the sound decay rate in the tube will be changed accordingly Fig. 13.

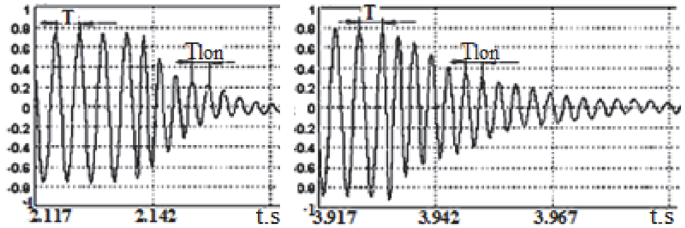


Fig. 13. Sound decay of concrete and marble, exited f = 200 Hz, decay f_{lon} = 250 Hz, L = 65 cm

On the basis of experiments, a theoretical point of view was proved that by the selection of the tube length, the wave frequency created in the tube maybe coincided with the frequency of the coherent wave radiated from the sound source i.e., when the length of the tube coincides with a certain wavelength of sound. When the sound frequencies f and f_{lon} are the same, the wave attenuation is determined mainly by the absorbing capacity of the material situated from the longitudinal side of the tube.

But it should be noted that in all the cases considered, we are dealing with the absorption coefficient associated with the frequency of longitudinal oscillations arising in the tube itself, rather than the frequency emitted by the noise source. But on the basis of the conducted experiments it can be concluded that for a certain ratio of the length of the tube and the length of the exciting coherent wave, the frequencies f and f_{lon} can coincide with each other Fig. 14.

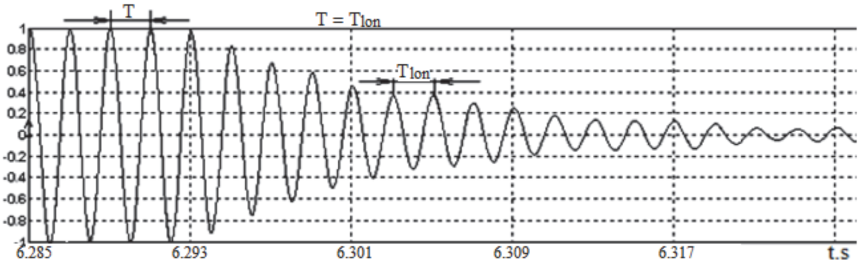


Fig. 13. Sound decay, exited frequency f = 500 Hz, decay frequency f_{lon} = 500 Hz

So, the equality of frequencies f_{lon} and f is reached by regulating of changing the tube length. To achieve this, the length of the tube should be 1/4 of the length of the sound waves. In addition, to ensure flat waves, the length of the tube should be more than 3/4 tube diameters.

Fig. 15 shows the recorded waveforms in which the damped frequency processes of 200, 500, 1000, 2000, 5000 and 10,000 Hz emitted by the sound sources and the frequency of the decay waves generated in the impedance tube are equal, and this was achieved by adjusting the length of the tube for each frequency. Using the oscillograms obtained in this way, the absorption coefficients of the materials studied for any spectrum were determined. The exception was 10,000 Hz, where, during the decay, the frequency was 10,000 Hz at a frequency of 3,000 Hz. According to the calculation, the length of the tube should be 17 mm in order for the decay of the amplitudes to occur at a frequency of 10,000 Hz Since the length of the microphone was 20 mm, we had to use a tube 25 mm long. Thus, in the process of damping together 10,000 Hz, the attenuation frequency of 3000 Hz is also allocated. The waveforms of decay shown in Fig. 15 are obtained for the case when the sample of the test was the cork tree installed at the side end of the tube.

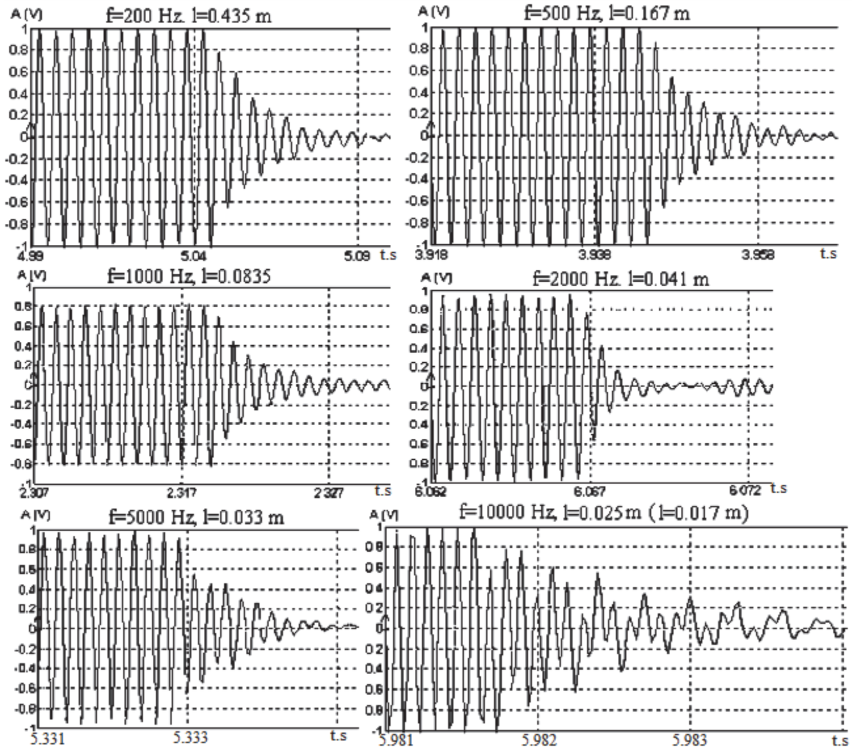


Fig. 15. Achievement of equality of excitement and fading frequencies by means of regulation of the tube length (sample material is cork)

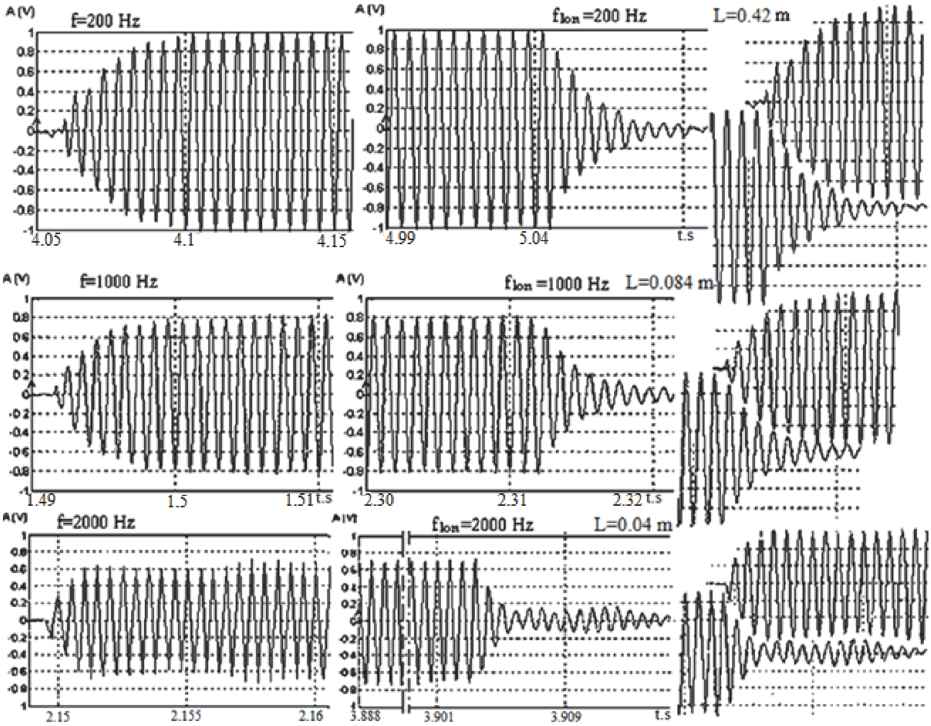


Fig. 16. Mirror images of forming and decay amplitudes at the presence of low sound energy

Theoretically, at low power, in a closed space, in particular in an impedance tube, the amplitudes of sound waves should increase gradually and also gradually decrease, i.e. have an antipolar form, which is fully proved by experimental studies. Fig. 16 shows the processes of increasing and decreasing amplitudes of standing waves in a closed space at the time of the switching on and turn off the low-level noise source. With a low-power sound source during the study, it was also found that in closed chambers (in the tube), the growth and decay of the sound amplitudes occurs at the same rate and they have the form of mirror images (Fig. 16).

The mirror images of processes of forming and attenuation of sound standing waves once more confirm that the presented method is correct, perspective and new, furthermore sound absorption coefficient can be determined also by the process of increase of reverberating sound amplitudes. Especially it should be noted that the process of decay of the reverberating sound amplitudes obtained by the method described above is very stable. In addition, the accuracy of the measurement of decay rates is practically independent of the measurement conditions, types of measuring instruments and their accuracy.

Experimental studies show that the amplitudes of reverberating sounds decay nonlinearly [4], which corresponds to the def curve shown on the oscillogram of Fig. 17. The rate of decay on the intervals de and e_f is different and consequently different absorption coefficient will be obtained. If we intend that de and e_f are linear intervals in conformity with linear intervals ac and c_b than the formula for calculation sound absorption coefficient will be simplified. According to oscillograms of the decay of reverberating sound waves, the sound absorption coefficient can be calculated from the following simple Eq. (14), in a manner analogous of calculation the damping coefficient in the theory of oscillations [10, 14, 15].

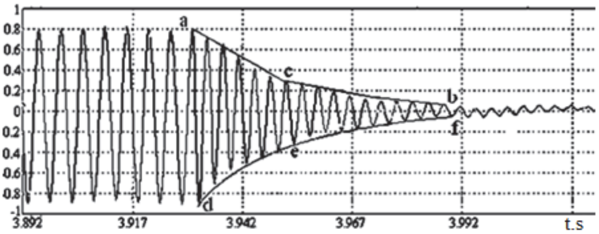


Fig. 17. Determination of sound absorption coefficient by decay of reverberation amplitudes

$$\alpha_k = \frac{A_a - A_b}{mA_a}, \tag{14}$$

where A_a and A_b – maximal and minimal amplitudes on the calculation interval accordingly, m – the number of amplitudes of decay, or increase on the calculation interval. Evidently, that average value of absorbing coefficient, entirely for def curve, will be the average mathematical sum of separated ac and c_b linear intervals. At least from a practical point of view, it is desirable that a certain absorption coefficient indicates a high sound pressure at a level of 120-70 dB. In Fig. 14, such an interval is represented by the nonlinear curve de and linear ac. In the theory of vibration, the absorption coefficient for ac range is calculated using $[a, b]$ interval by adding 2 in the Eq. (15):

$$\alpha_k = \frac{2}{m}\frac{A_a - A_b}{A_a}. \tag{15}$$

In such cases, it is desirable that the lengths of high inclination curves $a_c(d_e)$ and low inclination curves $c_b(e_f)$ were approximately equal.

Theoretically, when the length of the radiated wave is bigger than the length of the tube the length of the tube must be increased otherwise the frequency of generating of the plain waves become higher i.e. in the tube will be created high-frequency standing waves.

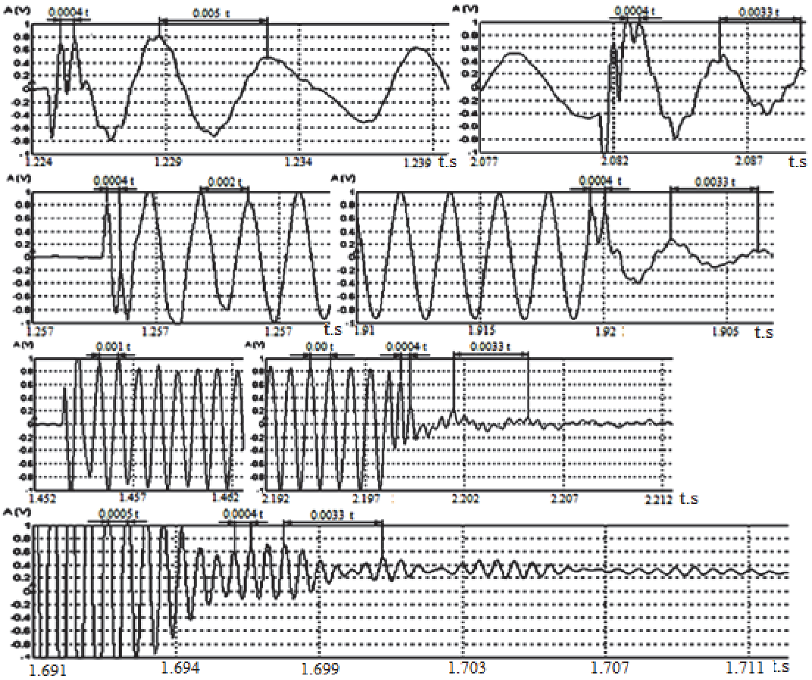


Fig. 18. The tube length and reverberation sound frequency

Figure 18 shows the processes of creation and attenuation of frequency waves of 2500 Hz, when 200, 500, 1000 and 2000 frequency waves excited from a noise source are acted in a tube with a length of 35 mm. At the beginning of short periods of growth and decay of amplitudes, i.e., pulses of 0.0004 sec. appear during periods of unstable processes. For all waves, the fundamental attenuation frequency is 300 Hz, and it is accompanied by a frequency of 2500 Hz.

Based on numerous experimental studies, a new method for measuring the sound absorption coefficient showed a greater sensitivity to the measurement of the acoustic properties of materials. Fig. 19 shows some oscillograms of the decay of the sound amplitudes, the absorption coefficients of which were calculated from Eq. (14). In addition, the method for determining the sound absorption coefficient, based on the decay of the sound amplitudes, proved to be very stable and accurate in spite of the measurement requirements, measuring devices accuracy and types were violated.

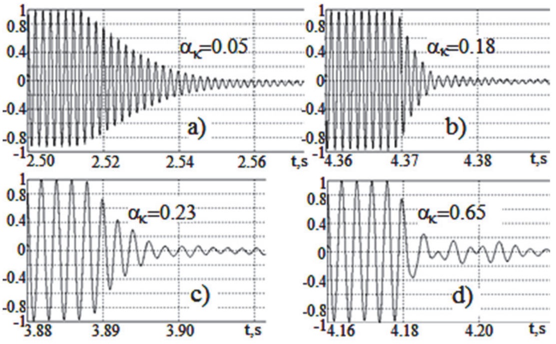


Fig. 19. Oscillograms of attenuation amplitudes at 500 Hz with samples of a) water, b) tiles, c) plywood and d) cotton

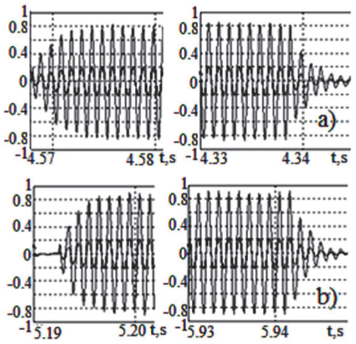


Fig. 20. Oscillograms a) a tightly closed lid, b) an incomplete lid on the side of the noise source

For example, Fig. 20 shows the entering and decay waveforms that were obtained for a wet porcelain plate when, in one case, the tube cover was tightly closed α_k = 0.125 and in another case, the cover on the side of the noise source was practically open α_k = 0.128. Since the absorption coefficient is determined by the ratio of the subtraction of the maximum and minimum amplitudes $(A_a - A_b)$ to the maximum amplitude Aa of the given interval, therefore errors that appearing due to inaccuracies of the measuring devices, instability of measurement conditions and the environment are not great, unlike the existing methods in which they greatly affect the obtained results. If equal values appear in the numerator and denominator simultaneously, in our case the measurement errors, they will not cause the change of the fraction. Here the main thing is that during the decay of the sound amplitude (approximately 0.01 sec.), no changes occurred on the background sound.

On the basis of theoretical and experimental studies shown that the sound absorption coefficient for various materials possible to determine in the open space without an impedance tube by means of conventional measuring instruments in acceptable accuracy for wide consumers. As studies have shown for carrying out measuring operations, a test material of approximately 1 m^2 area and a reflecting wall is required and the possibility to vary the distance from 0.03 to 1 m. The microphone should be installed in the center next to the test material and the loudspeaker at the wall also in the center. Other reflective materials should be removed at least 3-5 m that during the attenuation of the reverberating amplitudes, sound reflected from other materials was not penetrated into the work area.

Fig. 21 shows the process of decay of reverberant sound amplitudes when the distance between the sample and the reflecting wall is $L = 0.93$ m. On the basis of investigation may be said the process of decay sound waves in the open space is identical to the process that takes place in the closed tube, but in order to achieve the same sound pressure level in open space, it is necessary to increase the loudspeaker capacity by more than 70-80 units in comparison to the tube where it was 1-2 units. When the distance from other reflective materials was more than 3 m, the effect of the reflective waves of the spectra of 500 and 5000 Hz was minimal, but the condition was broken for the 2000 Hz oscillogram.

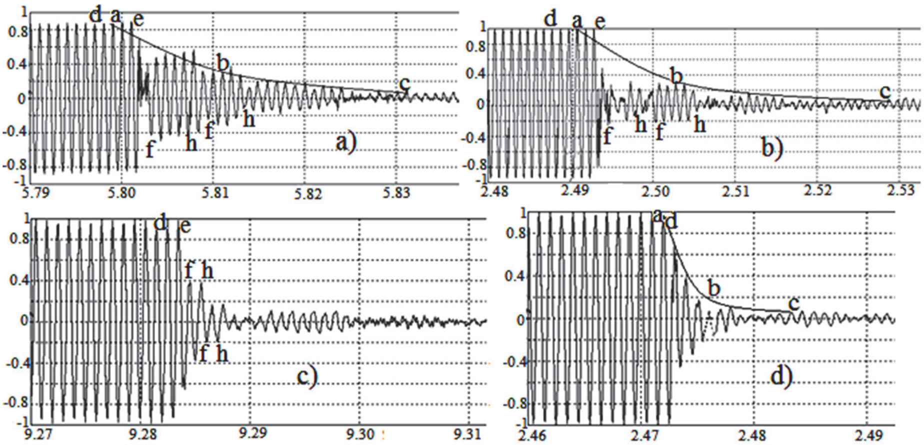


Fig. 21. Determination sound absorption coefficient in the open space

The oscillograms a) and b) of figure 21 are obtained at the condition of the distance $L = 0.9$ m. At this distance, about 5 waves with a frequency of 1000 Hz are placed. Indeed 334/2·1000 = 0.167 m and 0.9/0.167 = 5.4 that clearly is seen on the decay regimes oscillograms. Each stage (step) of the decay contains almost five amplitudes. The oscillogram of the decay mode of the sound shown in Fig. 21(b), differs from the oscillogram Fig. 21(a) only in that the distances between plywood and the wall was changed insignificantly, which caused every second half-wave of the sound wave to enter the antiphase state, i.e., on the basis of Eqs. (6), (7), the amplitudes of the corresponding periods are suppressed.

Although the average decay rate of the amplitudes is the same in both cases. The oscillogram showed in Fig. 18(c) was obtained when the distance was $a = 0.20$ m. In this case, we have two amplitudes at each level (stages). But oscillogram d) was obtained when the distance was 9 mm i.e. 1/4 the part of the length of 1000 Hz of sound wave frequency. In this case, the decay process proceeds at the same frequency, which has a source of coherent noise i.e. the decay process of reverberating waves is analogous that happens in the impedance tube shown in Figs. 13, 15. It should be specially noted that all four oscillograms obtained by the decay processes performed on the plywood have approximately equal attenuation rate and absorption coefficient $\alpha = 0.27$-0.29, calculated by the Eq. (14). Each oscillogram has three and a half steps of the amplitudes of decay.

As seen when calculating the absorption coefficient using the presented method, the time factor does not play any real role since the damping times a) and b) of the oscillogram are 2.5 times larger than the decay time of the regime c) and 5 times of the regime d) but obtained sound absorption coefficient for four cases are practically is equal.

When the sound incident on the material, it is reflected, absorbed and transmitted, as shown in Fig. 22.

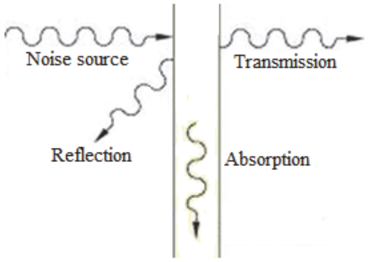


Fig. 22. Sound incident on a material

Ideally, the sound absorption coefficient defined as the fraction of the randomly incident sound power absorbed by the surface, but in the practice (experimentally) it is operationally defined as a collection of absorbed and transmitted parts of the sound. In this sense an open window is considered a “perfect” absorber, but is really a perfect transmitter. The coefficients determined are based on this conception; that is, that what is not reflected is “absorbed”. The open window is taken as the standard absorber with a coefficient of 1.00, or 100 per cent absorption [4].

As practice shows, in a number of cases, it is necessary to know the absorbing capacity of materials, regardless of the determination of transmitted energy, which is still difficult to determine. It can be said that today used method for this purpose is based on the simultaneous use of four microphones in an impedance tube which requires quite complicated calculations, high-precision measuring types of equipment and so on. This method is based on the theory of transfer function method for sound propagating in a tube where the acoustic transfer function is calculated as a substitute of the spectral densities. This method requires a four-channel FFT analyzer and four spaced microphones and working with the convolution integrals and their Fourier transforms.

The obtained results of the decay process of complex and coherent reverberation sound waves performed in closed spaces showed that the determination of the sound absorption coefficient can be greatly simplified. This method allows that instead of a tube with four microphones, a tube with two microphones were used, where the sample separates the cameras. Theoretically, if the sound is not transmitted completely through the test material, the absorbed energy will be equal to the energy not reflected, that is, subtraction of the incident and reflected energies, and coefficient of absorption by material will equal $\alpha_t = 1 - \alpha$.

But in the case when a part of the sound waves is transmitted through the test material, then the energy absorbed by the material is equal to the subtraction of the energy of the incident and transmitted energy, ie, the damping factor will be equal to the ratio of the subtraction of the sound energy of the incident and transmitted amplitudes of the first and second cameras by a fixed corresponding amplitude of the first camera. Since the values of the incident and the transmitted sound amplitudes are measured in different chambers, it is obvious that in such cases it is necessary to increase the requirements for the accuracy of the measuring instruments and the correct installation of the test material in the measurement work.

Fig. 23 shows the processes of decay and transmission of sound waves in the presence of test materials mouse pad and cotton.

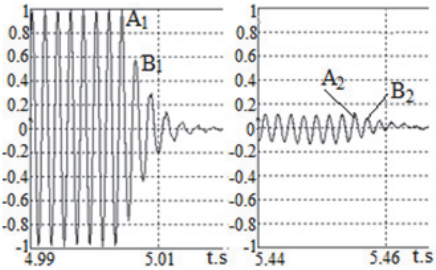


Fig. 23. Decay and transmited processes at the presence of mouse pad testing material

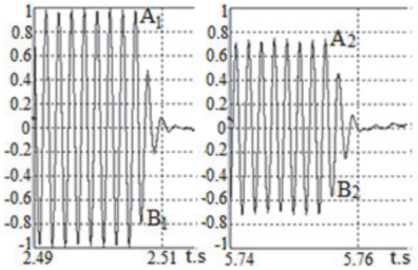


Fig. 24. Decay and transmited processes at the presence of cotton testing material

The presented oscillogram makes it possible to measure the damping coefficient of the material according to the Eq. (16):

$$\alpha_t = \frac{A_1 - A_2}{A_1}. \qquad (16)$$

In Figs. 23 and 24, A1 and B1 denote the sound amplitudes of the decay in the room of the sound source and A2, B2 – the sound amplitudes in the sound receiving room.

Although a clean cotton fabric has a higher sound absorption capacity than a mouse pad, a clean cotton fabric lets more sound energy into the receiving chamber than a mouse pad i.e. mouse pad directly absorbs more sound energy than cotton fabric.

It should be noted that when coherent sound passes through the materials, in some cases additional spectral components appear Fig. 25, which in principle makes it possible to investigate the structural state and damage of some materials.

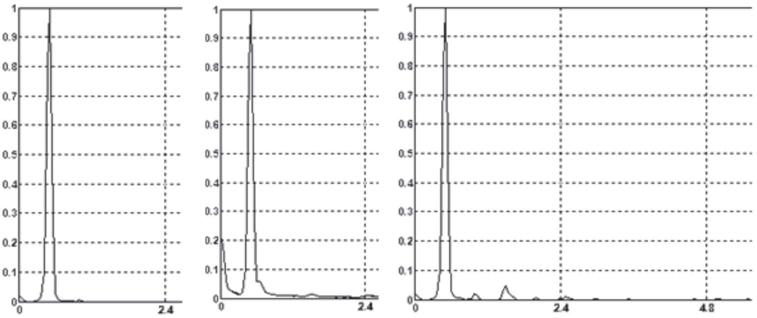


Fig. 25. Amplitude-frequency features of 500 Hz transmitting coherent sound source waves

The conducted studies showed that, according to the proposed method, the results of the test of the study and determination of the absorption coefficient do not depend on the test condition, i.e. the absorption coefficients of the same material with the same properties do not depend on the test condition, accuracy, and type of measuring instruments. The method of determination of the absorption coefficient by means of decay of the reverberating waves is sufficiently stable, demonstrates a high sensitivity to the materials acoustic characteristics and a low sensitivity to errors admitted during the measurement. Therefore, may be concluded that after some further improvement, the presented method has a good prospect of wide use.

More than 200 the scientific literature, which was considered and analyzed by us, that cover period of 1927-2014 years, among them 6 fundamental monographs, did not contain calculations of absorption coefficient by the presented method and are not shown waveforms in which clearly are shown decay and rate tempo of reverberation amplitudes in the materials. By noted waveforms, graphically, may be determined absorption coefficient in the materials that are a new method and must be perspective for further elaboration and refinement.

5. Conclusions

The method of determining the absorption coefficient in materials by the decay of standing waves with the help of an impedance tube allows, with the help of cheap and low-current devices, the measured value of the coefficient was practically acceptable and accurate, which gives a wide possibility of its use in practice.

The method of determining the absorption coefficient using the process of reverberating decay waves is fairly stable and shows a low sensitivity for all made errors in the measurement process.

The wide dissemination of modern digital technologies, PCs and software allows measuring the ability of sound absorption of materials and absorption coefficient with the necessary accuracy without special laboratories in conditions of wide consumptions.

The conducted studies showed that, according to the proposed method, the results of the test for the absorption coefficient do not depend on the condition of performing test, that is, the absorption coefficients of the same material with the same properties do not depend on the test condition, accuracy, and type of measuring instruments.

If we do not take into account the sound attenuation in the air, the time factor plays no real role in calculating the absorption coefficient by the presented method.

Since the absorption coefficient is determined by the ratio of the subtraction of the maximum and minimum amplitudes to the maximum amplitude of this interval, errors resulting from inaccuracies in measuring devices, instability of the measurement conditions and the environment are small, since the errors occurring in the numerator and denominator simultaneously, in our case measurement errors, they do not cause a change in the fraction, only here is necessary that the measuring devices were linear in the measuring ranges.

References

[1] Acoustics in Buildings. FESI Document A4. October, 2007.

[2] **Igolkin A. A., Rodionov L. V., Chess E. V., Kox A. I.** The Sound-Absorption. The Methods of the Measurements. Samarskiy State Aerospace University, Name of the Academician S.P. Koroleva, 2010.

[3] **McGrory Mathew, Castro Cirac Daniel, Gaussen Olivier, Cabrera Densil** Sound absorption coefficient measurement: re-examining the relationship between impedance tube and reverberant room methods. Proceedings of Acoustics, Fremantle, Australia, 2012.

[4] **Watson Floyd R.** The Absorption of Sound by Materials. University of Illinois Bulletin. Vol. 25, 1927.

[5] **Seybert Andrew F.** Notes on Absorption and Impedance Measurements Two Microfone. University of Kentucky Lexington, KY 40506-0108, 2007.

[6] **Eugen Skudrzyk** The Foundation of Acoustic. Basic Mathematics and Basic Accounts. Springer-Verlag, Wien, New York, Vol. 1, 1971, p. 520.

[7] **Kinsler Lawrense E., Frey Austrin R., Coppens Alen B., Sanders Jeimes V.** Fundamentals of Acoustics. 4th Editions. New York, Toronto, 1982, p. 550.

[8] **Crendall I. B.** Acoustics. 2009, p. 168.

[9] **Seybert Andrew F.** Notes on Absorption and Impedance Measurements. University of Kentucky Lexington, http://www.spectronics.net/Notes%20on%20Absorption%20Measurements.pdf

[10] **Genkina M. D.** The Vibrations in Technique. Reference Book in 6 volumes. Under Editing. Machine building, 1981.

[11] **Muehleisen R. T.** Measurement of the Acoustic Properties of Acoustic Absorbers. Illinois Institute of Technology, 2007, p. 30.

[12] **Chelidze M. A., Nizharadze D., Javackishvili Tedoshvili J. M.** Investigation of sound absorption. Modern achievements of Science and Education 7th International Conference, Jerusalem (Israel), 2016, p. 66-71.

[13] **Chelidze M. A.** Investigation of Sound absorption coefficient by decay of standing waives in the impedance tube. GESJ: Physics, Vol. 1, Issue 17, 2017.

[14] **Chelidze M. A., Javaxishvili J., Nizharadze D., Tedoshvili M.** Investigation of sound absorption coefficient by energetic method. Proceedings of 7th International Conference on Science and Education, Rome (Italy), 2017, p. 3-9.

[15] **Chelidze M. A.** Investigation of sound absorption characteristics in materials by help of subtraction method on the base of PC. Science and Education 8th International Conference, 2015, p. 24-27.

Tamaz Natriashvili received Ph.D. degree in machine technology from Georgian Technical University, Tbilisi, Georgia in 2003. Now he works as director of the Institute of Machine Mechanics, Tbilisi, Georgia. His current research interests include technical novelties in the field of automobile engines.

Merab Chelidze received Ph.D. degree by the decision of the Council of the Georgian Polytechnical Institute of March 29, Tbilisi, Georgia, 1982. Now he works at Institute of Machine Mechanics. His current research interests include mathematical modeling, dynamics investigation, machines calculation on the toughness and endurance, the study of problems of determining of acoustical characteristic of building.

David Nizharadze received Ph.D. degree in biology science from the Institute of Plant Biochemistry and Biotechnology of the Georgian Science Academy, Tbilisi, Georgia, in 1989. Now he works at the Rafael Dvali Institute of Machine Mechanics, Tbilisi, Georgia. His current research interests are modern thermal insulating materials.

Jemal Javakhishvili received Ph.D. degree in technical science and engineering from the Polytechnic University of Baku, Baku, Azerbaijan, in 1983. Now he works at the Rafael Dvali Institute of Machine Mechanics, Tbilisi, Georgia. His current research interests include investigations in the heat engines and modern thermal insulating materials.