Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Influence of Technological Process Parameters on Physical and Mechanical Properties of Clay Paving Bricks

Master's Final Degree Project

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Kaunas, 2021

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Industrial Engineering and Management (6211EX018)

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Influence of Technological Process Parameters on Physical and Mechanical Properties of Clay Paving Bricks

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Task of the Master's final degree project

Given to the student – Rolandas Avizovas

1. Title of the project

Influence of Technological Process Parameters on Physical and Mechanical Properties of Clay Paving Bricks

(In English)

Technologinio proceso parametrų įtaka fizinėms ir mechaninėms keraminių grindinio trinkelių savybėms

(In Lithuanian)

2. Aim and tasks of the project

Aim: To investigate the influence of technological process parameters on physical and mechanical properties of paving bricks.

Tasks:

1. To investigate the parameters of technological processes of clay paving bricks and determine their effect on physical and mechanical properties of clay paving bricks.
2. To examine the properties of the raw materials used for the production of clay paving bricks and their effect on the physical and mechanical properties of the final product.
3. To investigate clay paving bricks standards and requirements for physical and mechanical properties.
4. To propose solution for production line modernization and calculate return of investments.

3. Initial data of the project

Freeze and thaw resistance $\geq$ 100 cycles. Transverse breaking load $\geq$ 80 N/mm. Acid resistance < 7 % loss of mass. Investment pay back (PB) < 10 years.

4. Main requirements and conditions

LST EN 1344:2013 standards and test methods for physical and mechanical properties of clay paving bricks. Standards and regulations for equipment's, materials and quality management LST ISO 3310-1:2003; LST ISO 3310-2000; LST EN 1745:2012; LST EN 12620:2003+A1:2008; LST EN 1008:2003. LST EN ISO 14001:2015; LST EN 12620:2003.

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Summary

Clay paving bricks are manufactured from natural raw materials as clay, sand and water, most commonly used outdoors therefore, are exposed to different environmental conditions such as freeze and thaw, friction and compression. It is very important that clay paving bricks would be resistant to environmental influences and would not lose its physical and mechanical properties over the years. To ensure long service life of clay paving bricks, each produced batch of pavers must be tested by special tests in accordance with requirements of the relevant standards. However, in order to ensure high physical and mechanical properties of clay paving bricks it is necessary to study raw materials and select optimal parameters of technological process. The chemical and mineralogical composition of raw materials such as clay often differs, clay plasticity index, clay melting point, particle size depends on clay formation circumstances and place. For that reason, it is very important to investigate raw materials structure and properties in order to select the optimal parameters for the production of high-quality clay paving bricks. During this study parameters of technological process of clay paving bricks will be observed and influence of chemical compositions of different clays on physical and mechanical properties of clay paving bricks investigated. A modern solution to ensure optimal raw material plasticity were proposed in the production line of clay paving bricks. To evaluate the economic efficiency of the production line modernization solutions, an economic calculation were performed and return on investment evaluation model was developed.

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Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: Keraminių grindinio trinkelių fizinės, mechaninės savybės ir gamybos technologinio proceso parametrai.

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Santrauka

Keraminės grindinio trinkelės gaminamos iš natūralių žaliavų kaip molis, smėlis ir vanduo, dažniausiai naudojamos lauke, todėl yra veikiamos skirtingų aplinkos sąlygų, tokių kaip šaltis ir šiluma, trintis ir gniuždymas. Todėl labai svarbu, kad keraminės grindinio trinkelės būtų atsparios aplinkos poveikiui ir bėgant metams neprarastų savo fizinių ir mechaninių savybių. Siekiant užtikrinti ilgą keraminių grindinio trinkelių tarnavimo laiką, pagamintos trinkelės turi būti išbandytos specialiais bandymais pagal nustatytų standartų reikalavimus. Norint užtikrinti aukštas molio grindinio tinklelių fizines ir mechanines savybes, būtina ištirti žaliavas ir parinkti optimalius technologinio proceso parametrus. Žaliavinių molių išgaunamų iš žemės gelmių cheminė ir mineraloginė sudėtis dažnai skiriasi, molio plastiškumo indeksas, molio lydymosi temperatūra, dalelių dydis priklauso nuo molio susidarymo aplinkybių ir vietovės. Siekiant nustatyti optimalius technologinio proceso parametrus, reikalinga ištirti žaliavų struktūrą ir savybes. Šio tyrimo metu analizuojama keraminių grindinio trinkelių technologinio proceso parametrų įtaka fizinėms ir mechaninėms keraminių grindinio trinkelių savybėms. Siekiant ištirti technologinio proceso parametrų įtaką keraminių grindinio trinkelių fizinėms ir mechaninėms savybėms, atliktas eksperimentas su skirtingų tipų moliais. Optimaliam molio plastiškumui užtikrinti pasiūlytas modernus sprendimas, kurio integravimas į keraminių grindinio trinkelių gamybos liniją leidžia ženkliai padidinti ir pagerinti gamybos našumą bei galutinių gaminių kokybę. Siekiant įvertinti gamybos linijos modernizavimo sprendinių ekonominį naudingumą, atliktas ekonominis vertinimas ir parengtas investicijų atsipirkimo vertinimo modelis.

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Introduction

In nowadays production of building materials, as the entire construction industry, are on the path of rapid development and innovation. As the construction industry moves forward and needs of customers grows and increases, traditional building materials not always satisfies builders, final users and consumers. Today users of construction and building materials very often pay attention and evaluate environmental friendliness and utilization factors. The market needs forcing manufacturers to seek for new production technologies and improve existing ones. As consumers are increasingly demanding eco-friendly, natural and simple, quick-to-install and durable building materials, manufacturers must accept those challenges and produce products that meets high standard requirements as well as the demands of customers. However, high parameters of physical and mechanical properties still remain the main factors which indicate the quality and durability of building materials.

Paving bricks are widely used and well-known building materials attributed to the elements of small architecture, which are mostly used to pave sidewalks, private and public yards, pitches, fuel stations, roads. Currently there are many types, shapes and colours of paving bricks available in the market, however, all of them are usually manufactured for outdoor use and have to withstand various environmental conditions. Therefore, the production process and the quality of raw materials become very important factors which ensure the required physical and mechanical properties of the final products.

The necessity to examine raw materials stems from the objective of producing high quality end products that meets the requirements of customer needs and official standards. The mineralogical and chemical composition of raw materials such as clay may vary according to its place of formation, also the plasticity of the clay, melting point, and relative amount of moisture are very important factors which ultimately affect the manufacturing process and the properties of clay paving bricks.

High-quality paving bricks will have to withstand long service life, freezing and thawing, external forces, effect of acids and friction, stay resistant to water absorption, that is why manufacturers of paving bricks are strictly regulated by the requirements of standards for the physical and mechanical properties of products. In order to produce high-quality paving bricks which, meet the requirements of the standards, it is necessary to harmonize production processes in assessing the properties of raw materials, it is often necessary to perform many tests until the most optimal production parameters are determined and selected.

The aim of this project is to investigate the influence of technological process parameters on physical and mechanical properties of clay paving bricks.

The tasks of this project are:

- to investigate the parameters of technological processes of clay paving bricks and determine their effect on physical and mechanical properties of clay paving bricks;
- to examine the properties of the raw materials used for the production of clay paving bricks and their effect on the physical and mechanical properties of the final products;
- to investigate clay paving brick standards and requirements for physical and mechanical properties;
- to propose solution for production line modernization and calculate return of investments.

1. Relevance of the research

Clay is a natural and recyclable raw material extracted by specialized equipment from the depths of the earth. Clay is formed during the process of rock erosion in the earth's crust, it has a different mineralogical and chemical composition. Clay as a raw material is widely used in many industries, but perhaps the most often the products from clay can be found in a building construction sector. Clay engineering bricks, ceramic roof tiles, wall blocks, clay paving bricks are well-known products in the construction industry, besides they are mainly characterized as eco-friendly and durable [1].

1.1. Materials and additives

Clay is the main raw material in the production of clay building materials, other raw materials such as quartz, dolomite, feldspar, slags, ash, iron minerals are used in relatively small quantities. If clay is relatively greasy, sand which contains quartz, as additive, is valued more because its lean the composition of clay and provides positive effect on products during the drying and firing processes. By adding additional additives to clay substance, such as sand, perlite, alkalis, soluble salts or other flammable additives as wood chips, straws, tea, oat or husk waste, it is possible to provide additional desired physical and mechanical properties to the final product [2, 3].

In many cases the quality of clay paving bricks mostly depends from the mineralogical and chemical composition of clay, clay origin surroundings, additional additives which are used in the production of clay paving bricks and the selection of production methodology. After the production of specimens and evaluation of the adhesion of materials at the specified temperature, the evaluation of quality of the final experimental products, the optimal production parameters can be proposed and selected [2].

Clay usually consists of alumina (Al_2O_3), silica (SiO_2) and magnesium (MgO) or magnesium + water ($MgO + H_2O$), other elements of various amounts such as calcium (Ca), iron (Fe_2O_3), sodium (Na), potassium (K) and others, are also presents in clay mass. According to the chemical composition of clay and the content of Al_2O_3, clays are divided into several groups as presented in Table 1 [2].

Table 1. Groups of clay according to the amount of chemical oxide [2]

Chemical oxide	Content in clay	Content in clay	Content in clay	Content in clay	Content in clay
Al_2O_3	> 45 %	45 % – 38 %	38 % – 28 %	28 % – 14 %	< 14 %

From the perspective of the mineralogical composition of clay, clays are divided in-to different types, e.g., kaolinite, halloysite, pyrophyllite, muscovite, smectite. From all the types of clay kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) is the least contaminated with colouring oxides and is pure, white in colour [2].

At the beginning of the production process, it is required to identify the mereological and chemical composition of raw materials and later to examine them. The quality of raw materials such as water, soil, sand, clay is determined by the analysis of chemical and mineralogical composition [2, 3].

Clay is a universal material the properties of which can be improved with the help of various additives. In order to improve its properties, various laboratory tests are required. After the determination of mineralogical and chemical composition of clay, particle size, plasticity index, drying temperature, melting point and the investigation of physical and mechanical properties of the final product, the selection of additives for improvement of the composition of clay and the selection of optimal production parameters are available [2, 3].

1.2. Standardization and quality

Standardization of building materials is a tool used to ensure that materials meet the same requirements and quality standards. For a certain groups or companies which manufactures the same products, uniform requirements for the properties of final product are established, thus ensuring that the products of the lower quality will not enter the market. The relevance of the standardization of clay paving bricks is obvious as the standards establish and define uniform characteristics for overall dimensions, shape, size, strength and quality. However, it would be wise to note that uniform standards for building materials are only set in certain continents or regions, because weather conditions are different therefore, the environmental impact is different. At the same time, consumers of building materials may expect to purchase desired quality materials without large deviations from norms, as requirements of standards guarantee main product characteristics [4].

The manufacturers of clay building materials in the EU have to comply with the same requirements for the physical and mechanical properties of their production which are set in the various standards. The minimum limits of the physical and mechanical properties of clay paving bricks are fixed and cannot be lower than specified in EN 1344:2013/AC:2015, which is mandatory for all clay paving brick manufacturers in EU, that is why it is very important to analyse and investigate the requirements of those standards before beginning of production process. Mentioned standard specifies the requirements of clay paving bricks which are used in the flexible and rigid form of constructions. The standard has been developed and is mandatory for rectangular clay products in the construction industry, which are intended for paving pavements, commonly used outdoors, including roofing coverings and roofing coverings units, but may also can be used indoors. The meaning of flexible construction form is defined as construction in pedestrian traffic areas and vehicle traffic areas, the rigid construction form is defined only as constructions in pedestrian traffic areas. The standard EN 1344:2013/AC:2015 also specifies all necessary test methods to perform on clay paving bricks, defines sequences of tests, specifies the calculation methodology's and provides related formulas, explains terms and conditions [5].

Despite the facts that requirements of building material standards are very important factor for manufacturers, standards should not be overemphasised, as they only set a minimum value of the properties and it is often worthwhile to produce higher value-added products, as such products rapidly gain market demand and their enduring value is undisputed. Development and production of higher value-added products allows to save expenditures on installation and service in the future. Buildings made of high-quality building materials have higher thermal and strength properties, are resistant to environmental and time effects, often their aesthetic properties are higher as well. The relevance of standards in production is not only to ensure the quality of the building materials, it is also to ensure the materials are save for use and makes no negative impact to environment, as well to human health. However, any product, including clay paving bricks, particularly effects the environment at any stage of its living life. To keep those negative impacts to minimum or below established norm requirements of standards are taking place [6].

Standardization also makes possible to perform certain calculations that are related to the consumption of paving bricks, engineering bricks or other building materials before the construction began. As the dimensions of clay paving bricks or engineering bricks are strictly defined it becomes simple to calculate the needs for those materials, to calculate window and door openings, to estimate the quantities of packages, and calculate total net weight or even transportation costs [4].

2. Scientific and engineering novelty

Clay paving bricks are building materials which has been used in western Europe road construction industry for more than 300 years. In nowadays clay paving bricks still retain their popularity and are used wherever high quality and exceptional variety of colours are required. Despite the modernization of production methodology and production equipment's, the main stages of production process have not changed substantially for many years. The mechanized clay paving brick production process can be divided into the nine main production steps shown in Fig. 1 [7].

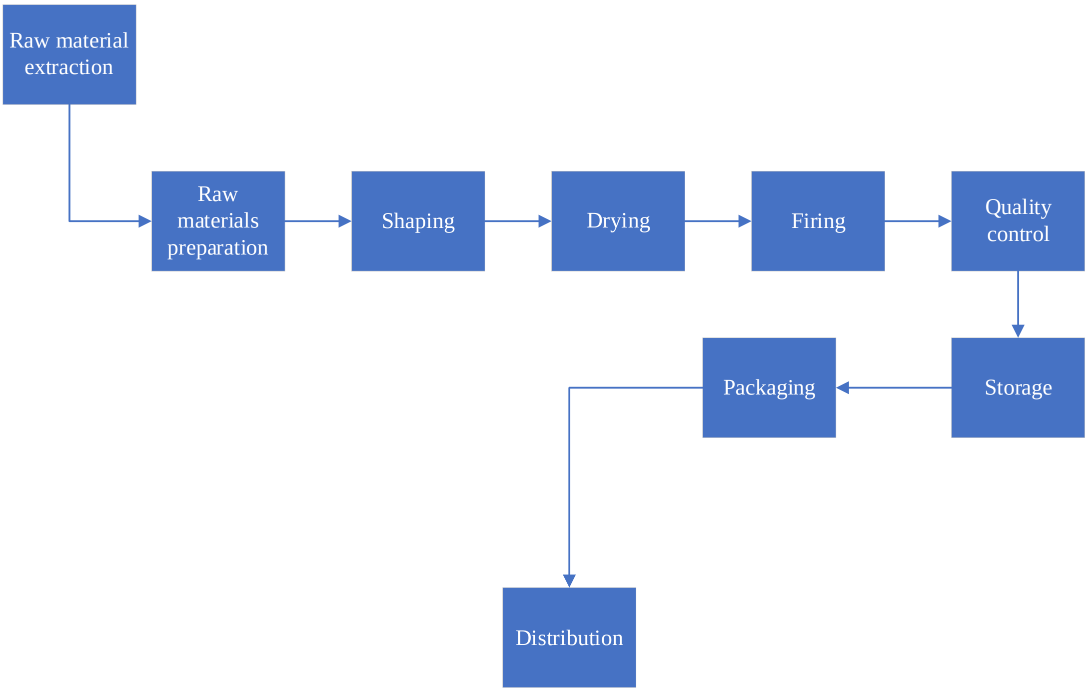

Fig. 1. Clay paving brick production process [7]

However, harmonization of all production steps, calculations and selection of production parameters, coordination of the whole production process requires complex researches and modern solutions. Ultimately, there are many factors which are influencing on final physical and mechanical properties of clay paving bricks and one of those factors is the heterogeneity of raw materials [8].

2.1. Optimization of production parameters

In order to produce high-quality clay paving bricks, it is necessary to understand the complexity of interacting material systems. Modern methods of statistical analysis for calculation and evaluation the relationships between interaction of raw materials and production conditions are vital. The analysis of variance confirmed, that final building materials made from clay with the higher content of calcium oxide (CaO) and higher content of silicone oxide (SiO_2) were characterized as higher in compressive strength. However, higher compressive strength of clay building materials were achieved only under the certain production conditions, it was confirmed that strength properties of clay building materials were positively affected by the square firing temperature conditions. After discovery of interactions and corelations between raw materials and other production parameters the development of second-order polynomial models was applied. Mathematical models which were based on the results of performed tests allowed to make very accurate predictions of compressive strength and water absorption of building materials. However, the main advantages of those methods the allowance to save a lot of time and means to be spent on tests and experiments [8].

Research by applying statistical-mathematical models, for the selection of optimal production parameters were conducted by Milica Arsenvic, Slavka Stankovic, Zagorka Radojevic and Lato Pezo [8]. Various samples of heavy clays were collected, chemical analysis determined and different specimens as tiles, blocks, cubes were produced and fired under the certain but the same conditions displayed in Table 2.

Table 2. Independent variables [8]

Specimen	Firing temperature °C								
Clay tiles	800	820	850	870	900	930	950	1050	1100
Clay blocks									
Clay cubes									

After evaluation of applied parameters and properties of the specimens, the relationships between the production parameters and raw materials were determined and second order polynomial models were developed. Chemical oxides of clay as Al_2O_3, MgO, CaO, Fe_2O_3, Na_2O, SiO_2 and the parameters of firing temperatures provided in Table 2, were assessed as independent variables or inputs and measures of compressive strength and water absorption as dependent variables or outputs. The combination of statistical-mathematical models and regression analysis were performed with the modern computer soft programs which allowed to determine and select the optimal production parameters provided in Table 3 [8].

Table 3. Determination of optimal production parameters

Inputs										Outputs				
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	Temp	*CSB*	*CSC*	*WAT*	*WAB*	*WAC*
55.33	15.20	4.26	8.76	2.18	0.88	1.39	0.10	0.53	950	13.92	29.83	20.68	20.44	20.12
50.93	10.15	4.42	11.58	4.10	1.35	1.44	0.10	0.90	950	15.31	32.22	21.08	21.04	20.2
50.67	11.47	4.73	10.63	3.58	1.26	2.24	0.08	1.08	950	16.91	33.33	20.14	20.18	19.47
54.49	13.91	5.09	8.05	3.7	1.14	1.7	0.08	0.46	950	13.32	32.45	19.66	19.61	19.39
52.08	13.04	4.16	11.13	1.65	1.16	1.64	0.20	0.39	950	16.58	32.39	21.44	21.63	20.96
52.09	11.41	4.81	8.93	3.57	2.59	3.11	0.15	0.68	1000	13.88	29.69	19.37	19.92	19.37
54.49	13.91	5.09	8.05	3.7	1.14	1.7	0.08	0.46	1000	15	29.56	19.79	19.85	19.26
58.34	15.35	3.89	6.93	2.21	1.29	1.83	0.09	0.38	1050	13.16	28.66	20.13	20.85	20.39
57.07	19.54	7.13	2.78	1.87	1.65	2.59	0.12	0.38	900	27.72	53.02	15.13	15.46	14.95
67.99	17.07	5.41	0.43	1.53	0.70	1.57	0.01	0.78	900	50.60	79.21	10.40	11.15	10.69

Values provided in Table 3 illustrates calculated relationships between materials and production conditions, based on which the optimization of production process parameters may be implemented very accurately without additional tests or experiments. Depending on chemical composition of clay and amounts of chemical oxides, firing temperatures, which are inputs, Table 3 provides very accurately calculated compressive strength values of blocks (CSB) and cubes (CSC), also provides water absorption values of tiles (WAT), blocks (WAB) and cubes (WAC), which are outputs. Statistical-mathematical approaches as second order polynomial models and fuzzy synthetic optimization method positively correlated together and could be adopted in production of building materials from clay for optimization of production parameters and avoidance of additional costs [8].

2.2. Research and development of raw materials

Despite the fact that mineralogical and chemical composition of clays is influenced by the place and conditions of its formation [2], in order to increase physical and mechanical properties of clay building materials modern research studies are carried out.

By application of semi dry moulding production method, the micro structure and porosity of clay bricks were significantly improved, as a result, bricks manufactured by this method were more freeze and thaw resistant. Based on the results of analysis, it has been established, that the most effective way to increase number of freeze and thaw cycles is addition of calcium containing additives into the clay mass. The different structuring additives with the content of calcium oxides very synergically correlated together and provided necessary characteristics to the porous structure of clay bricks. After analysis of the micropores a high content of reserve pores in bricks structure were determined. During the investigation were observed, that the injection of calcium containing additives into the clay mass with preliminary plastic preparation and following granulation allowed to form the optimal porous structure of ceramic bricks [9]. The results of the study are provided in Table 4 below.

Table 4. Cycles of freeze and thaw [9]

Specimens	Cycles of freeze and thaw
Specimens with calcium containing additives	152
Specimens from pure clay wihouth additives	4

Others [10], to reduce the amounts of various wastes and increase the properties of building materials, incorporated wastes into the clay mass for the production of high-quality wall bricks [3, 10, 15]. Were confirmed, that addition of granite and eggshell waste additives to the clay mass provides positive effect on physical and mechanical properties of clay bricks. Addition of 20 % granite waste additives and 10 % of eggshell waste additives of clay mass to raw clay, allowed to achieve brick compressive strength properties of 3.2 MPa, water absorption 12.2 %, bulk density 1.16 g/cm3 which was more above the standard requirements. The experiment was executed according to the following methodology displayed in Fig. 2 [10].

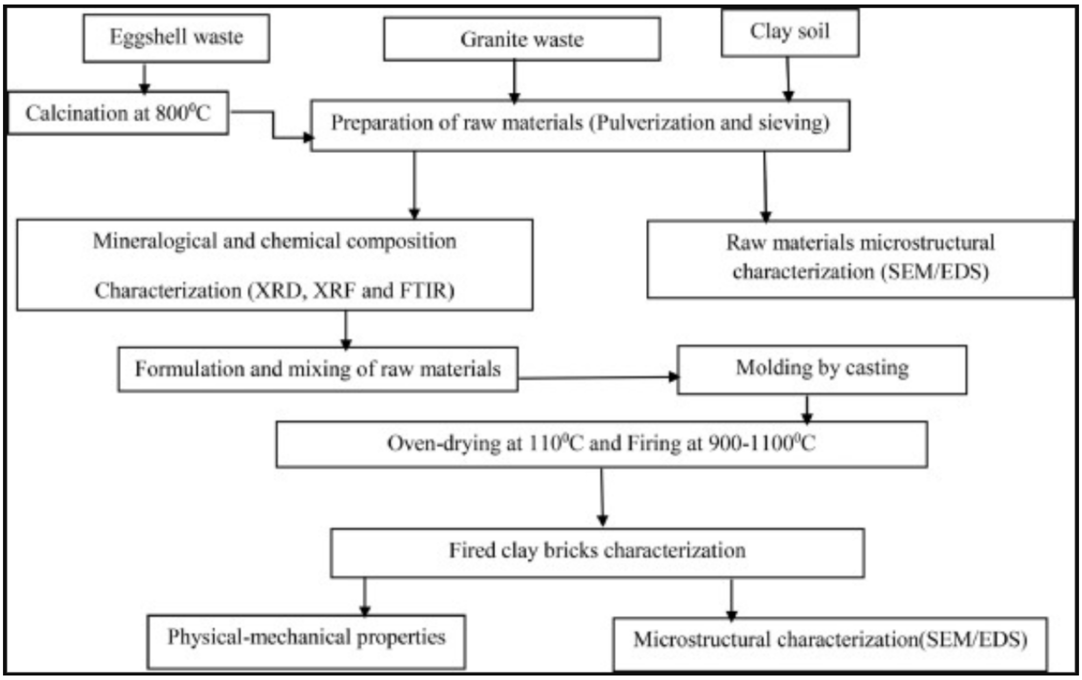

Fig. 2. Brick production process with waste additives [10]

3. Analysis of similar research development

Every day manufacturers of building materials face complex uncertainties in the production process which requires accumulated experience and new researches to resolve. Manufacturers often produce quality products which contribute to well-being of all, however it is also the cases that the side effects created by the production process in very negative manner effects ecosystem of our planet [11, 13].

3.1. Alternative production methods

As the human population constantly grows necessity of building materials expands. However, production process of building materials from clay often high in energy consumption. Therefore, continuous production leads to high emission of greenhouse gases and contribution to rapid development of climate change. It has been estimated that in India more than 20 % of all greenhouse gases comes from factories of construction industry [11].

The production of clay bricks is not exception, the calculated figures indicate very difficult situation caused by this industry. During the firing process of clay bricks very large amount of greenhouse gases are daily released into the environment [11]. Table 5 below provides the information of greenhouse gases in grams are released into the environment per one brick (1 pcs.) firing process.

Table 5. Greenhouse gas emissions per 1 manufactured clay brick [11]

Greenhouse gas emission per 1 fired brick		
Type of gas released	**Bottom value in grams**	**Top value in grams**
Carbon dioxide	70.0	282.0
Black carbon	0.001	0.29
Carbon monoxide	0.29	5.78
Particulate matter	0.15	1.56

Assessing the fact that annual production of clay bricks is occupy large place in the industry of building materials, the greenhouse gases which appears during the manufacturing process while firing clay bricks really intimidates. The average numbers of manufactured bricks in the selected regions per year are given in Fig. 3 [11, 12].

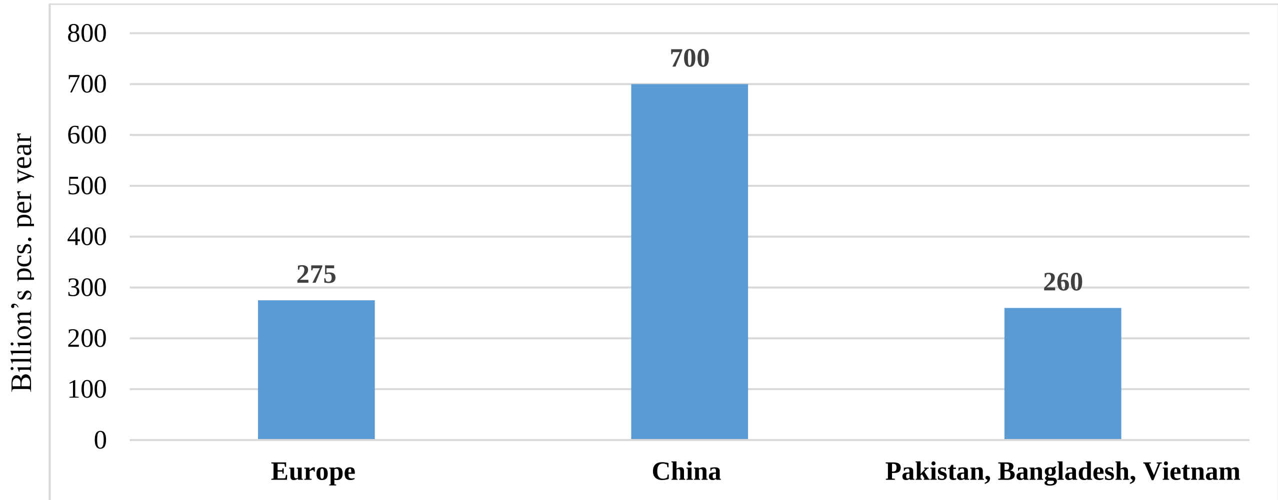

Fig. 3. Average numbers of produced bricks per year [11, 12]

However, for the improvement of clay building materials production process, new and modern production methods were suggested [13, 14, 15].

In order to produce building materials without firing process, innovative solutions for saturating building materials with geopolymers were suggested. It has been confirmed that high moisture absorption has a significant negative effect on the strength properties of building materials. There's been determined that specimens manufactured from raw material of soil, which mainly consisted of silicon (SiO_2) and alumina (Al_2O_3), and mixed with various geopolymers, which mainly consisted of sodium hydroxide (NaOH) and sodium silicate activators, were characterized as low in moisture absorption and with increased compressive strength properties. Specimens from raw material of soil with addition of 5 % of sodium hydroxide (NaOH) and 20 % of sodium silicate activators of raw material mass, demonstrated compressive strength of 10.4 N/mm^2, even after the immersion into the water for 24 hours [13].

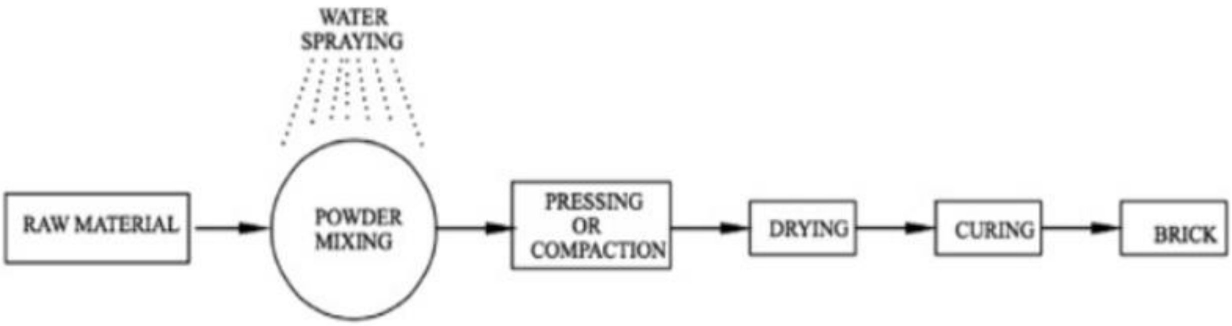

Fig. 4. Alternative brick production methodology [11]

Other claimed [14], that for the production of non-fired building materials from clay, the addition of lime and Portland cement to kaolinite clay mass may provide positive effect on the properties of final building products. Ground granulated slag were used during the experiment as a stabilizer from 10 % to 20 % of kaolinite clay mass respectively. Different mixtures with the addition of lime and Portland cement from 4 % to 16 % of clay mass were added and specimens moulded and dried for 3, 28, 90 days. During the observation of the results was noticed, that specimens with the optimal amount of stabilizer contented lower amount of moisture. The specimens with the optimal content of lime and Portland cement demonstrated 20 % higher properties of compressive strength. However, specimens with the optimal amount of stabilizer, lime and cement, after 90 days of drying demonstrated even higher compressive strength properties by 27 % and 33 %, were noticed that the amount of moisture in specimens, between 28 days and 90 days of drying, remained almost the same [14].

There are also production methodologies suggested and discussed, that reduction of greenhouse gases could be achieved by replacing firing process of clay building materials to the curing process of them on the sun. Conducted study provides information of alternative production process of clay blocks which are manufactured directly on the building site and further dried on the sun. As a result of this production process, the emission of greenhouse gases could be significantly reduced not only due to the cancellation of firing process, but also because of reduction of transportation, while clay blocks are manufactured directly on the building site and no transportation with HGV are necessary [15].

Mentioned study provides detailed calculations and the amounts of greenhouse gases which are generated and released during the different production processes of clay blocks. In the conclusions of the study were confirmed, that the emission of greenhouse gases may by significantly reduced only by changing production process of clay blocks and other building materials from clay, where firing process is applied [15].

3.2. Influence of waste and secondary raw materials on properties of clay building materials

In order to reduce the amounts of agricultural wastes generated annually, new modern and innovative solutions have been proposed in the production of clay building materials [16, 17, 18].

It has been established that, 5 % addition of oat and barley husk to low melting point clay, which chemical composition displayed in Fig. 5, provides positive effect on physical and mechanical properties of clay specimens, which was heated at 1000 °C temperature in electric oven. Compressive strength of specimens was determined around 9.5 MPa, water absorption around 14 %, total brick porosity around 35 % [17].

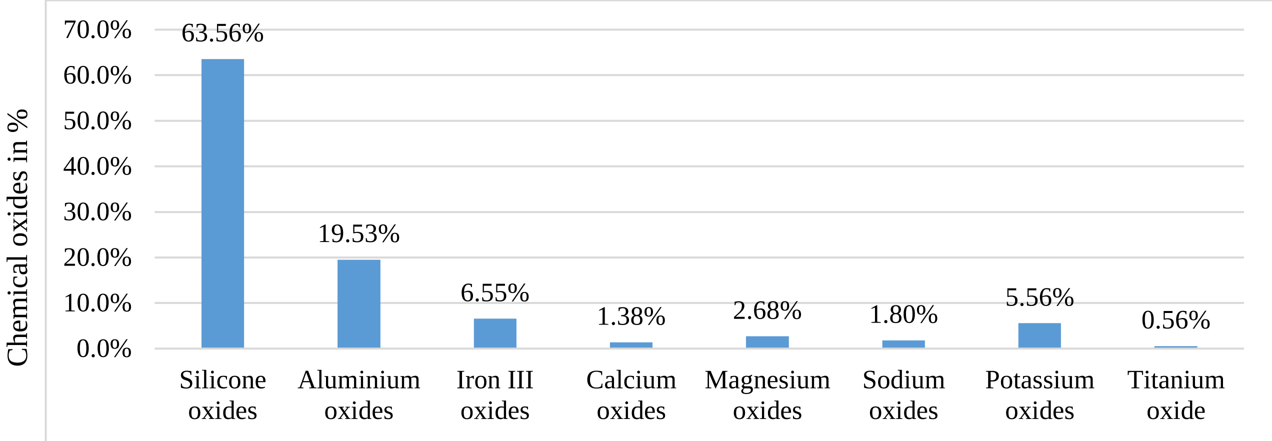

Fig. 5. Chemical composition of low melting point clay [17]

Dry matter content of oat husk used in the experiment was determined around 86 %, barley husks around 88 %, but the organic matter content was 94 % and 97 %, respectively. Specimens were manufactured according to the production methodology provided in Fig. 6 [17].

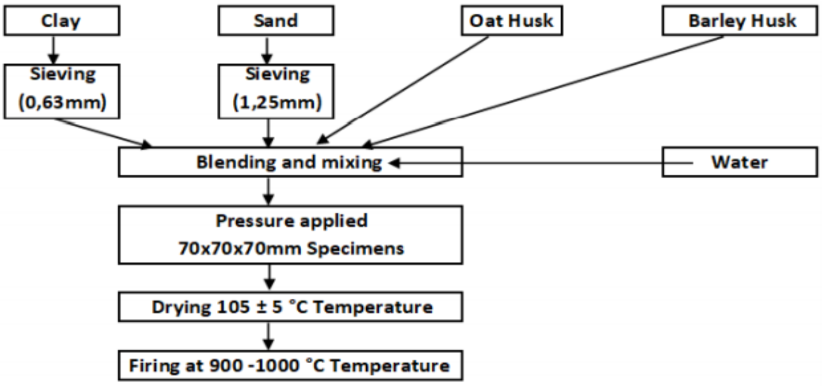

Fig. 6. Clay brick production methodology with addition of oat and barley husk waste [17]

Others investigated [17], that addition of tea waste from 5 % to 12.5 % of clay mass to clay, could also very positively contribute on thermal properties of clay bricks. During the experiment, specimens from clay with addition of tea wastes were prepared and fired at 950 °C and 1050 °C temperatures. The results of the experiment confirmed, that addition of tea wastes to the clay mass of 5 %, 10 % and 12.5 % of clay mass, respectively, influenced the changes in the microstructure of the brick and effected formation of larger micro-pores, this contributed to the better thermal properties and the reduction of total brick mass. It was estimated, that by addition of tea wastes in-to the clay mass, it is possible to improve thermal properties of bricks up to 42 %, which is mean energy savings, and also reduction of total weight of bricks because of the larger pores [18].

4. Engineering methods applied for solving similar problems

Properties of clay building materials, including clay paving bricks, mostly are influenced by the used raw material characteristics, such as chemical and mineralogical composition, plasticity, content of moisture, raw material particle size, viscosity, melting point, shrinkage. However, others very important production factors as material drying temperature and conditions, firing temperature and conditions, atmosphere in the furnace, heating rate and heat intensity, design of furnace, and even firing time are parameters of production process, which must be matched for the achievement of optimal results and products [19, 20, 21].

4.1. Structure determination of silicate raw materials

In the scientific literature, clay minerals are referred to layered silicate materials, which due to their crystalline structure, are most suitable as raw materials for the production of many products and goods. Also, the information of chemical, physical and thermodynamic phenomena, that have long occurred in the earth's crust, can be obtained from the mineralogical and chemical structure of clay [22, 23].

According to the chemical composition of minerals and the arrangements of atoms, clay minerals could be classified as vermiculite, chlorite, kaolin, halloysite, pyrophyllite, muscovite, smectite, mica minerals. Each mineral has specific arrangement of its structure which ultimately provides effect on final physical and mechanical properties of building or other materials-products from clay [22, 23].

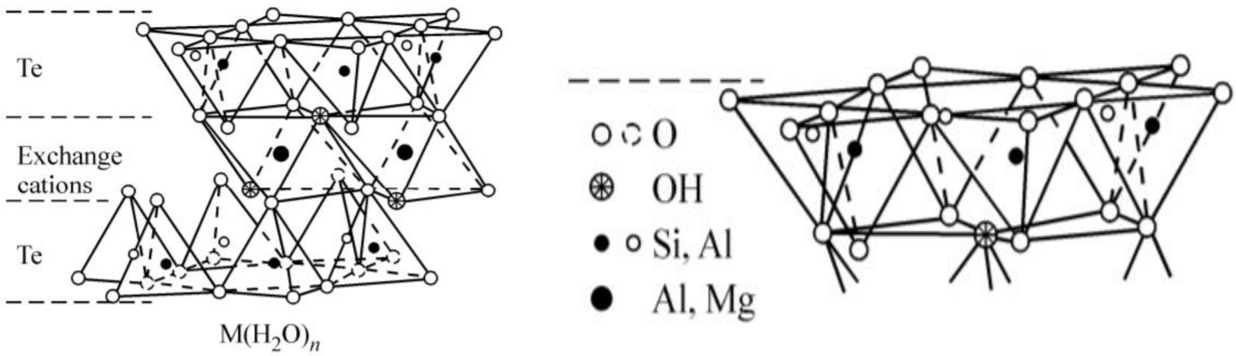

Fig. 7. Smectite structure and cation exchange [22]

However, most of naturally occurred clays are not composed of only single mineral, often clay mass consists of several mineral compounds, that due to their similarity of atoms, creates strong interconnections between layers, thus leads to creation of a new structures. The chemical composition of clay minerals which mainly consists various amounts of the chemical elements displayed in Table 6 [22, 23].

Table 6. The main chemical elements of clay [23]

Chemical oxide							
Silicone oxide	**Aluminium oxide**	**Iron oxide**	**Calcium oxide**	**Magnesium oxide**	**Titanium oxide**	**Sodium oxide**	**Potassium oxide**
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O

In order to investigate structure of clay and other silicate additives and secondary raw materials, various methods of analysis are available. Nowadays most common methods for determination of silicate material structure are x-ray diffraction methods (electron and neutron diffraction methods), spectroscopic methods (x-ray fluorescence spectroscopy, infrared spectroscopy), microscopic examination methods, thermographic material research methods, chemical material structure determination methods [20, 21, 22, 23].

4.1.1. Diffraction methods

Diffraction methods are based on analysis of different waves, emitted by the different sources, when the structure of the material is determined by studying deviations of waves emitted by the diffractometer. In general, several basic diffractometry methods, according to the nature of the emitted waves, are distinguished such as x-ray diffraction method, electron and neutron diffraction methods [2, 22].

4.1.2. X-ray diffraction methods

X-ray diffraction can be described as a method for determination of crystalline materials structure by applying x-ray waves. X-ray waves are electromagnetic rays, which length is 10^{-2}-10^{2}Å and which are generated by a special device, that is used to study structure of the materials. The distances between crystals of atoms of silicate-crystalline materials and electromagnetic rays are of equal length. As the electromagnetic rays falls on to the crystal, diffraction occurs, and each atom, into which the electromagnetic rays fall, becomes a source of a secondary spherical wave. The model of x-ray reflection in crystal is shown in Fig. 8. Lines I, II and III represent layers and arrangement of atoms in layers [2, 22].

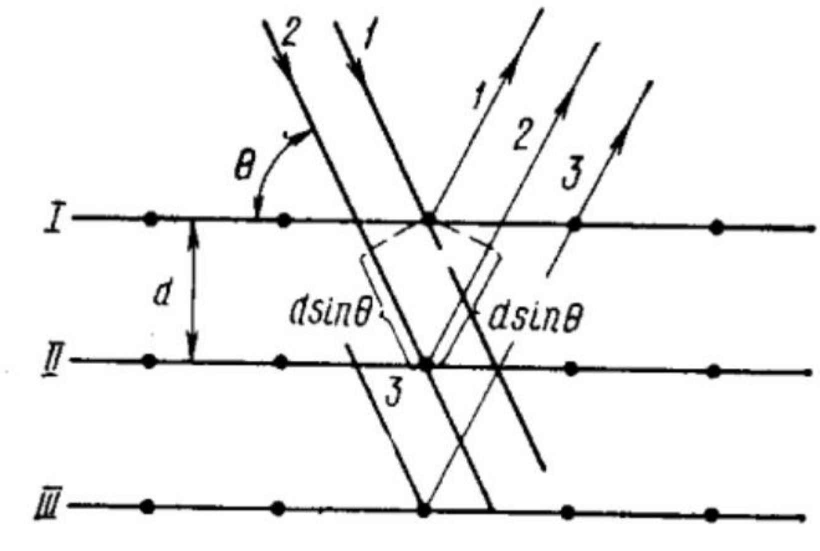

Fig. 8. X-ray reflection in crystal scheme [2]

X-ray diffraction devices used for determination of crystalline materials structure are called x-ray diffractometers. X-ray diffractometers are divided into diffractometric and photographic devices, according to the data recording method [2, 22].

Electron diffraction method is based on the effect of electron flux on atoms, which is scattered by the effect of the electrostatic field of the atoms. The electron diffraction method allows to determine the planar distance between the crystals and arrangement of free atoms in the lattice.

X-ray neutron diffraction method for determination of silicate materials structure is used relatively rarely [2, 22]. In order to determine the structure of cay mass and other raw materials or additives, samples should be dried and crushed into a powder form, further powder should be transferred into special test vessels and placed into x-ray diffractometer, which further provides detail report of the desired material structure [19, 20, 22].

4.1.3. Molybdate method

Molybdate method for determination of clay structure is the most common chemical method to determine structure of silicate materials. This method is based on chemical reactions between ortho silicon acid and ortho molybdic acid. Chemical reaction of these two acids leads to the formation of new silicon molybdic acid substance, the rate of formation of which, allows to determine the structure of clay. Chemical formula of reactions of the compounds is presented below (1).

$$H_4SiO_2 + 12H_2Mo_4 \longrightarrow H_4SiMo_{12}O_40 + 12H_2O \quad (1)$$

It was established and confirmed that silicon molybdic acid consists only of nano silicon acid therefore, in polymerized chemical compounds, formation time of silicon molybdic acid depends only on the transition time from silicon acid to the nanometric form. Lower mass silicate molecular particles reacts faster with molybdate than high mass ones, therefore, allows to determine the degree of polymerization of molecules. Confirmed that treatment of silicate materials with hydrochloric acids at 0 °C temperature gives the lowest reaction rate, therefore, tests are performed by cooling the substances. The level of substance polymerization is determined by comparing analogous curves presented in Fig. 9 [2].

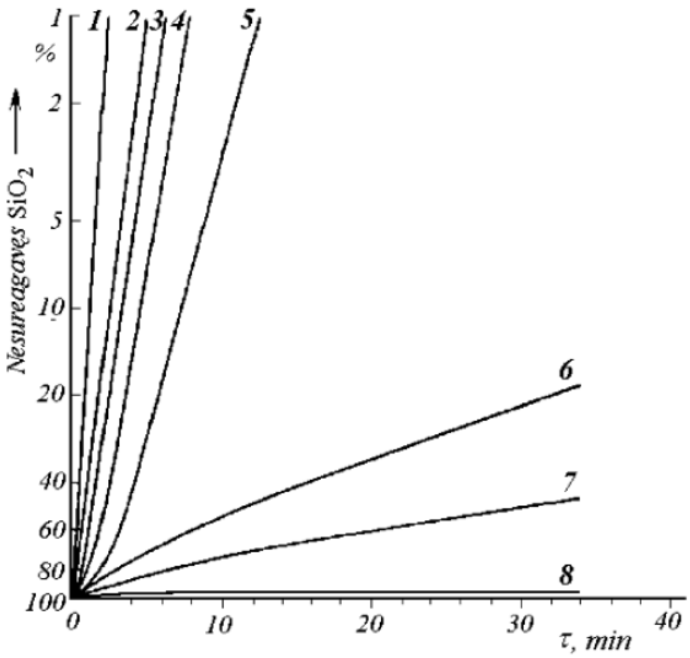

Fig. 9. SiO_2 transition velocity curves [2]

Molybdate method do not allow to perform qualitative and quantitative chemical analysis of silicate materials, as it refers to determine only the level of material polymerization. For the qualitative and quantitative analysis of silicate materials other methods should be applied such as classic chemical method for silicate materials, x-rays diffraction method, those methods are also most common methods in nowadays which are used in most of the laboratories for determination of clay chemical and mineralogical composition.

4.2. Clay melting point and firing method

As it was mentioned, clay as raw material is widely applied in the production of building materials. Determination of clay properties such as plasticity, particle size and distribution, shrinkage properties, melting point, sintering are very important while selecting optimal parameters of production process. According to the melting properties, clays are divided into the three groups which are presented in Table 7 [2, 20, 23].

Table 7. Clay melting temperatures and grouping [2, 23]

Name of the group	Clay melting temperature
Heat resistant	> 1580 °C
Hard melting	1350 °C – 1580 °C
Low melting	< 1350 °C

The plasticity of clay is a property of the clay mass, which allows form it into the different shapes and moulds without cracking it. The more plastic clay is, the higher amount of moisture it contents, the estimated and most optimal moisture content in clay, in the production of building materials, is 18 % – 23 % of clay mass [2]. Before the firing process of building materials, including clay paving bricks, moulded and dried semi-products should be placed into the tunnel, ring or zigzag kiln. The firing process begins with a preheating operation at temperature of 100 °C – 120 °C, which must be gradually achieved. During preheating operation, the amount of free moisture from moulded and dried semi-products are eliminated. As the temperature gradually rises to 750 °C, the remained water from the chemical compounds of material is removed. Further, firing process taking place at 900 °C – 1300 °C, at this temperature clay particles begins to dissolve and floods others non-molten particles. The firing operation at maximum temperature should take place for a certain calculated and selected optimal period of time. At the end of firing process products should be cooled down, by gradually reducing temperature in the kiln. The firing temperature of different clays depends on the properties of clay and the mineralogical and chemical composition of clay. For the selection of optimal firing temperature and time, also determination of others production parameters related with raw materials, specific tests are required to perform. An example of tunnel kiln is shown in Fig. 10 [23].

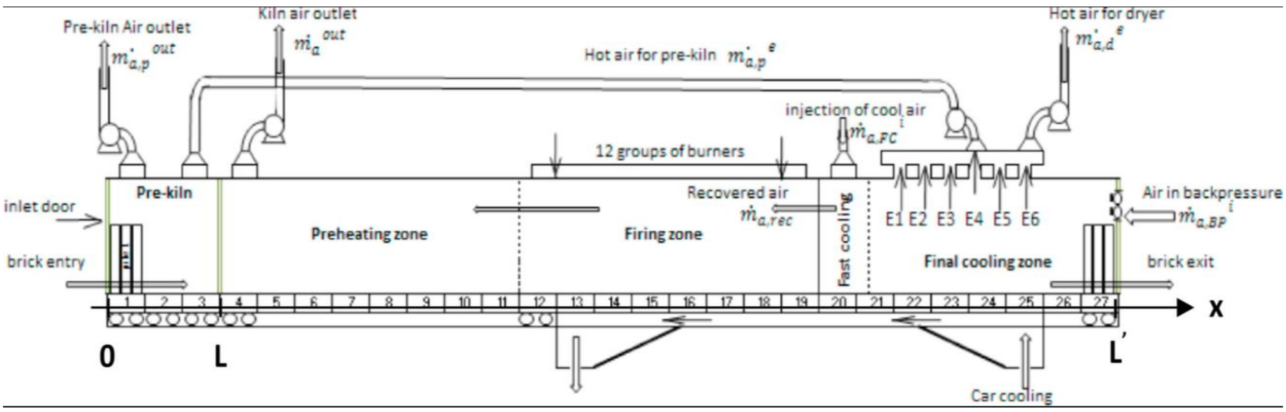

Fig. 10. Tunnel kiln drawing [24]

Liquefied gas is the most commonly used raw material for the production of heat energy in a kiln, however, other sources and materials for the production of thermal energy such as electric energy, wooden chips may be applied. Thermal energy which are released from the kiln during the firing process of building materials, can be successfully applied to maintain the climate of the production workshop premises, thus saving additional costs [24].

4.3. Mathematical surface response method for the optimization of production process

In order to optimize the use of production resources, various statistical-mathematical methods are used in the production of clay building materials. There was confirmed, that surface response mathematical method, may be successfully applied in order to optimize production process. Method allows to determine the influence of production process variables, which are assigned to a group of dependent parameters, to the process which is under the study. The effect of variables on the obtained responses are expressed through mathematical equations, based on which are determined the relationships between inputs and outputs, which allow a very accurate assessment of the entire production process [25].

In order to develop surface response method three heavy clay samples were collected for determination of chemical and mineralogical compositions and preparation of specimens. Once specimens with different additives were prepared, drying process took place at 105 ± 5 °C temperature, specimens were dried to constant mass. Further, firing process were executed at 900 °C, 950 °C and 1000 °C temperatures for 2 hours. After firing, properties of specimens such as compressive strength, water absorption were determined and recorder for further calculations. After identification of the interrelationships between substances, additives and other factors, mathematical equations were designed with modern computer soft programs "Stat Soft-Statistic" and "MATLAB" in order to determine all possible sets of parameters corelations. To determine possible positive and negative corelations between production parameters, principal component analysis was also executed. The image from material principal component analysis displayed in Fig. 11. Once positive correlations were obtained further statistical analysis was performed [25].

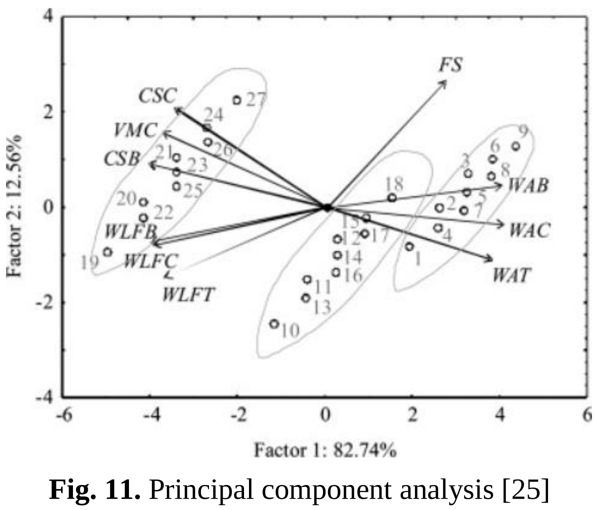

Fig. 11. Principal component analysis [25]

Analysis of variance and surface response method allowed to determine optimal production parameters, according to the calculations the best compositions of raw materials and other parameters as firing temperature and time, weigh loss during firing operation, shrinkage of production during firing operation, density, water absorption and compressive strength for hollow bricks, wall blocks and tiles were obtained and selected. The analysis also revealed, that clay samples which contained more clay particles and lower carbonates, were described as having higher physical and mechanical properties [25].

Statistical-mathematical models allows to optimize production process very accurately, however, one of the greatest advantages is that they save a lot of time and means that would be necessary to spend in order to obtain desired optimal results [25].

5. Methodological part

Clay paving bricks which are manufactured in EU must to comply with the requirements of EN 1344:2013/AC:2015 standard [26]. Mentioned standard also provides methods for determination of physical and mechanical properties of clay paving bricks.

5.1. Physical properties of clay paving bricks and test methods

Physical properties of clay paving bricks are the properties necessary to determine in order to estimate the quality of those. Physical properties could be also defined as the condition of clay paving bricks in its normal state without being subjected to any external force on them [7].

Manufacturers of clay paving bricks must ensure that their products meet the requirements of physical properties in accordance with EN 1344:2013/AC:2015. All results of the tests must be recorded strictly in accordance with the rules stated in the standard [26].

After review and evaluation of the information provided in the mentioned standard it is reasonable to state, that the most important physical properties of clay paving bricks, which are necessary to determine are freeze-thaw resistance and acid resistance, however, physical properties such as fire resistance and thermal conductivity are simply declared as certain classes without testing, as these properties are not essential due to the operational preferences of the clay paving bricks and the properties of the raw materials.

5.1.1. Method for determination of freeze and thaw resistance

According to the EN 1344:2013/AC:2015 for determination of freeze and thaw resistance, following equipment's will be necessary: 1. Water tank form steel. 2. Scales with nearest 1 gram accuracy. 3. Meter to measure heat flow. 4. Electric oven for drying of specimens, which is able to operate at constant 120 °C temperature [26].

At the beginning of test 10 specimens of clay paving bricks should be placed in-to oven and dried at 105 °C ± 5 °C temperature till constant mass. A constant mass of the specimens must be considered when the weight of the samples weighed over a period of 24 hours does not differ by more than 0.2 %. All specimens must be cooled down at ambient temperature before weighing. After drying, all specimens must be immersed into metal water tank at room temperature. Further, water temperature should be raised till 80 °C ± 3 °C gradually, over a period of 2 – 5 hours and then the specimens should remain in water for another 24 hours. Later temperature should be gradually removed, water temperature should reach room temperature. Total immersion of specimens into the water period should be between 44 and 56 hours. Before freeze and thaw process, clay paving bricks should be weighed and measures recorded in order to determine water absorption. Further, clay paving bricks according requirements must be arranged in-to the frame and freeze and thaw process shall be processed. The temperature while freezing periods must be -15 °C ± 3 °C, first freezing period should last for about 6 hours and others freezing periods should last for about 120 min. During the thawing process temperature from -15 °C ± 3 °C should be raised to 20 °C ± 3 °C gradually between 15 and 20 minutes. After clay paving bricks are thawed, water on surface of clay paving bricks must be sprayed, and freeze and thaw process repeated. After one thundered (100) freeze and thaw cycles the examination of samples by special machine should be applied. If any defects appears on clay paving bricks, they must be recorded [26].

Fig. 12. Defects appeared during the freeze and thaw test [27]

If no defects obtained after one hundred (100) freeze and thaw cycles, clay paving bricks classified as FP 100 Class. If any defects appears, clay paving bricks classified as FP 0 as shown in Table 8 bellow [26].

Table 8. Classification of freeze and thaw resistance [26]

Class	Freeze – thaw resistance
FP 0	No requirement
FP 100	Freeze – thaw resistant

If clay paving bricks after freeze and thaw resistance test specified as class FP 0, this means that such paving bricks can only be used indoors, because they won't be able to withstand the effect of freeze and thaw, the structure and dimensions of clay paving bricks will collapse over some period of time, likely before the end of the warranty period [26]. It has been declared that freeze and thaw resistance is very important property of clay building materials if the exploitation of materials occur in natural weather conditions, in order to increase freeze and thaw resistance of building materials many researches were conducted [28].

5.1.2. Method for determination of acid resistance

Clay paving bricks can be used next to the premises of industrial or agricultural enterprises therefore, the presence of various chemicals or acids on their surface can affect the physical properties of those. In order to ensure the resistance of clay paving bricks to the effect of various acids, manufacturers should ensure that during production process all optimal parameters of technological process would be selected and applied.

To assess the acid resistance of clay paving bricks, the following test is performed, which is also required by the standard EN 1344:2013/AC:2015. According to the mentioned standard for determination of acid resistance following materials provided in Tabe 9 are required [26]

Table 9. Required reagents to determine acid resistance [26]

Reagents	Density at 20 °C, minimum value	Density at 20 °C, maximum value
Sulfuric acid (H_2SO_4)	1.064 g/cm^3	1.068 g/cm^3
Nitric acid (HNO_3)	1.053 g/cm^3	1.056 g/cm^3
Deionised water	–	–

During the test following equipment's are also required: 1. Stainless steel sieves 150 μm, 500 μm, 800 μm, which are correspond with ISO 3310-1 standard. 2. Round bottom laboratorial flask of 500 ml capacity. 3. Reflux condenser. 4. Bath [26].

At the beginning of the test, it is necessary to select 5 samples of clay paving bricks. Once specimens is obtained, it is necessary to crush them into 12 – 10 mm size. Required quantity of crushed samples is about 1 ± 0.3 kg. Further, samples should be grained and retained through 800 μm sieve, the same process should be repeated and samples sifted through 500 μm sieve, later washing process with deionised water must be processed until clean fraction of 500 μm remains. When clean fraction of 500 μm is obtained, the drying process of samples at 110 °C temperature to constant mass is required. A constant mass should be considered, if during the drying process in two subsequent weightings with a 24 hours interval the loss in mass between the two determination is no more than 0.2 % of the total mass. After the drying, 100 ± 5 grams of the sample mass should be weighed with the accuracy of 0.01 g. Further, prepared mass should be transferred to laboratorial flask and 75 ml of 10 % sulfuric acid and 25 ml of 10 % nitric acid applied. Once reagents are applied samples should be boiled for 60 ± 2 minutes by immersing flask into bath with hot oil or by surrounding flask with electrically heated mantle. After acid treatment and boiling, the whole mass should be poured on 150 μm sieve, washed with deionized water and dried at 110 °C temperature to constant mass. Once sample mass is dried, it should be weighed with the accuracy of 0.01 gram and the loss of mass calculated and record [26].

The results of specimen mass loss should be expressed in the percentages by the accuracy of 0.1 %. According to the standard the following information of test should be stated in the report: 1. Reference to the standard. 2. Clay paving brick identification number. 3. Delivery of sample date. 4. The loss of sample mass in percentage by accuracy of 0.1 %. Classification of acid resistance according the standard is provided in Table 10 [26].

Table 10. Classification of acid resistance [26]

Class	**Loss of the mass %**
C	≤ 7

Acid resistance as well as freeze and thaw resistance are attributed to the physical properties of clay paving bricks.

5.2. Mechanical properties of clay paving bricks and test methods

Mechanical properties of clay paving bricks can be defined as the properties of a product that enable product to resist external loads or forces which are acting on them. Mechanical properties are determined and measured by applying external forces on clay paving bricks. Manufacturers of clay paving bricks in EU are obligated to test its products in accordance with the standard EN 1344:2013/AC:2015 and minimum product measures of transverse breaking load, abrasion resistance and slip and skid resistance properties must meet the minimum criteria of the standard [5, 26].

5.2.1. Method for determination of transverse breaking load

Transverse breaking load of clay paving brick could be defined as the capability of clay paving brick to withstand external force when two edges of paving brick are supported and the force applied to the centre of wearing surface. After the measurements of transverse breaking load, clay paving bricks are classified as following: 1. Class T0. 2. Class T1. 3. Class T2. 4. Class T3. 5. Class T4, where class T4 represents the highest resistance to transverse breaking load and class T0 represents clay paving brick ability to withstand the minimum force of transverse breaking load, which is required by the standard. For determination of clay paving brick transverse breaking load, the apparatus displayed in Fig. 13 is required [7, 26, 29].

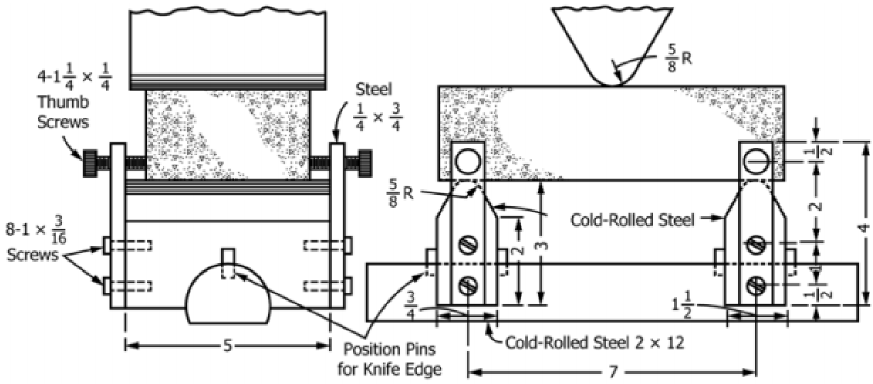

Fig. 13. Clay paving brick transverse breaking load testing apparatus [29]

10 specimens of clay paving bricks should be selected and immersed into the water at 20 ± 5 °C temperature, for minimum 16 hours but not longer than 72 hours. Further, clay paving bricks must be removed from the water and remained moisture wiped off. Before applying external force on clay paving bricks, they should be measured according requirements and all measures recorded. Later, clay paving bricks, one by one, should be placed into the apparatus which is displayed in Fig. 13, two ends of clay paving brick must be supported and external force in the middle of the fracture shall be applied. It would be important to mention, that force must be applied only to the wearing surface, if clay paving brick have 2 wearing surfaces, both them should be tested. The force on clay paving brick must be applied gradually, not exceeding 5 N/mm load per 1 second, until failure occurs and clay paving brick will break in half. The load which is applied at the time the clay paving brick breaks must be noted and recorded, further all process should be repeated with different specimens. All records of applied force should be made by the accuracy of 0.1 kN [26].

Once all specimens are tested and all measurements recorded the average value and minimum individual value of transverse braking load should be calculated, and clay paving bricks should be assigned to a particular class as provided in Table 11 [7, 26].

Table 11. Classification of clay paving bricks regarding to transverse breaking load [7]

Class	**Transverse breaking load N/mm**	
	Average value	**Minimum individual value**
T0	Not specified	Not specified
T1	≥ 30	≥ 15
T2	≥ 30	≥ 24
T3	≥ 80	≥ 50
T4	≥ 80	≥ 65

Report of transverse braking load should provide the following information: 1. Reference to the relevant EU standard. 2. Details of the manufacturer certification. 3. Samples testing date. 4. The arithmetic value and individual minimum values of transverse braking load of ten clay paving bricks with the accuracy of 0,1 kN [26].

After the transverse breaking load is measured and calculated, clay paving bricks are assigned into the appropriate classes, conclusions can be drawn as to their performance. If clay paving bricks are assigned to class T0, that kind of pavers should be used only in rigid construction zones, also to use clay paving bricks on conventional grounds would be prohibited, it is strongly recommended to lay them on a mortar bed on a stiff bottom however, if clay paving bricks are classified as class T4, they may be used anywhere, taking in-to account the relevant loads and the thickness of the clay paving bricks. [7].

According to the standard EN 1344:2013/AC:2015, calculations of transverse bending tensile load should be made according to the formula (2) bellow [26].

$$\sigma_t = \frac{3}{2} * \frac{F * s}{w * t^2} \quad (2)$$

Where:

σ_t – bending tensile strength in N/mm^2;

F – braking load in N;

s – distance between the end supports in mm;

w – width of clay paving brick in mm;

t – thickness of clay paving brick in mm.

5.2.2. Determination of dimensional differences and tolerances

Very important requirement which is defined by the EN 1344:2013/AC:2015 is related to the dimensions of the clay paving bricks. Clay paving bricks should remain of the declared dimensions however, tolerances and differences were allowed. Differences of the dimensions between clay paving bricks of the same production batch must not exceed established norms. This requirement is very important as it ensures the uniformity and precise form of clay paving bricks. [7, 26].

According to the EN 1344:2013/AC:2015 dimensions of the clay paving bricks should be determined at the following sequence. At the beginning of the measurements 10 samples of clay paving bricks from the same production batch should be randomly selected. All dirt and grime which may influence the accuracy of measurements should be removed from the selected samples. The length, width and thickness of clay paving bricks should be measured with an accuracy of 0.5 mm. Measurement methodology and technique displayed in Fig. 14 [26].

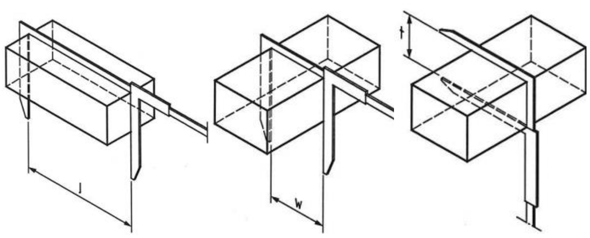

Fig. 14. Measurement of clay paving brick dimensions [26]

All obtained dimensions of specimens as length, width and thickness shall be recorded and after it shall be assessed whether the actual dimensions of the clay paving bricks do not exceed tolerances which are allowed by the standard, and which should be calculated and determined according to the formula (3) [7, 26].

$$0.4 * \sqrt{d}; \quad (3)$$

Where:

0.4 – relevant coefficient;
d – dimension of the edge.

If obtained dimensions of clay paving bricks do not exceeds the allowed tolerances from the mean values and do not exceeds permissible rage between the smallest and the greatest values, clay paving bricks should be assigned to class R1, an explanation provided in Tables 12 and 13 [7].

Table 12. Allowed dimensional deviations form the mean value [7]

Overall dimensions of clay paving brick, mm.		**Formula**	**Allowed dimensional deviations from the mean value**	**Class**
Length of the specimen	200	0.4 x √200	± 6 mm	R1
Width of the specimen	100	0.4 x √100	± 4 mm	R1
Thickness of the specimen	52	0.4 x √52	± 3 mm	R1

An additional requirement for dimensions of clay paving bricks is applied to the same batch of products, the difference between maximum and minimum measured values for each dimension shall not be greater than calculated according the formula (4) [7].

$$0.6 * \sqrt{d}; \quad (4)$$

Where:

0.6 – relevant coefficient;
d – dimension of the edge.

Table 13. Allowed dimensional range between minimum and maximum values [7]

Overall dimensions of clay paving brick, mm.		**Formula**	**Allowed rage between minimum and maximum value**	**Class**
Length of the specimen	200	0.6 x √200	± 8 mm	R1
Width of the specimen	100	0.6 x √100	± 6 mm	R1
Thickness of the specimen	52	0.6 x √52	± 4 mm	R1

From the obtained results in Tables 12 and 13 it is notable that relatively high dimensional tolerances are permissible, the main reasons could be that clay paving bricks are manufactured from raw materials as clay, water and sand, by using drying and firing operations therefore, it may be simply not possible to control dimensions within very narrow limits. However, because of the variety of dimensions and the distinctiveness of their colours clay paving bricks are unique and unrepeatable [1].

5.2.3. Clay paving brick declaration of performance

According to the information provided in the methodological part it is notable that the most important physical and mechanical properties of clay paving bricks are such as freeze and thaw resistance, acid resistance, transverse breaking load. Despite all listed physical and mechanical properties which are required for the high-quality clay paving bricks, another very important factor is the uniformity of the dimensions of the products. The overall dimensions of the clay paving bricks must comply with the established norms and not exceed the permissible values which are defined by the relevant standard. Clay paving bricks manufactured by the established and approved production methodology, with the physical and mechanical properties which meet the requirements of the EN 1344:2013/AC:2015 standard, can be successfully operated in the countries of the European Union [1, 7].

In order to ensure manufacturing process of high-quality clay paving bricks, manufacturing process should be strictly supervised and controlled, raw materials and other mentioned production parameters should be carefully evaluated and selected. A declaration of performance should be provided on each packaging of clay paving bricks however, some manufacturers may simply submit declaration of performance to the purchaser or place it on their website. After evaluation of the data provided in the declaration of performance the place of usage of clay paving bricks could be determined and selected. However, before purchasing clay paving bricks users should also consider such important factors as the thickness and shape of pavers [7].

A standard declaration of performance is provided in Table 14 however, manufacturers of clay paving bricks could also provide such important information as packaging date and details, name and address of the manufacturing company, product identification number and name, typical drawing of clay paving brick and short description of product usage [1].

Table 14. Clay paving brick declaration of performance [7]

Declaration of performance **Clay paving brick:**			
In accordance with the standard:			**EN 1344:2013**
Dimensions			
Length	mm.	200	± 6
Width	mm.	100	± 4
Thickness	mm.	52	± 3
Range of tolerances	Class	**R1**	
Durability (by frost resistance)	Class	**FP 100**	
Transverse breaking load	Class	**T4**	
Abrasion resistance	Class	**A3**	
Slip and skid resistance	Class	**U3**	
Fire resistance	Class	**$A1_{FL}$**	
Thermal conductivity	W/m K	**N/A**	
Acid resistance	Class	**C**	
Hazardous substance	-	**N/A**	

As observed during the methodological part, fire resistance and thermal conductivity are not essential properties of clay paving bricks, therefore tests to determine these properties are not mandatory. Clay paving bricks are fire resistant, so they are always declared as class $A1_{FL}$. Due to the outdoor usage properties of thermal conductivity for clay paving bricks is not relevant [7].

6. Experimental part

Review of the literature disclosed, that clay as a raw material is very important parameter in the production process of clay paving bricks. In order to determine whether the chemical composition of clay influence on the physical and mechanical properties of clay paving bricks, the experiment with different clays were conducted. During the experiment, samples of three different clays were collected, the chemical compositions of clays were determined and specimens of clay paving bricks manufactured under the same production methodology and production parameters. The physical and mechanical properties of specimens, were determined by executing laboratorial tests according to the requirements of EN 1344:2013/AC:2015 standard.

Necessity to investigate chemical compositions of clays and the influence of chemical composition of clay on physical and mechanical properties of clay paving bricks, arose from the necessity to understand which clay raw material is the most suitable for the production those. And also, to determine which other parameters of technological process are necessary to harmonize in order to produce high quality clay pavers. The aim of this experiment was not only to determine the influence of chemical composition of clay on physical and mechanical properties of clay paving bricks, but also to analyse technological process of production and evaluate the impact of production parameters on product properties. The samples of clays collected for this experiment was extracted from the depths of the earth with bucket chain excavators and ordinary wheel loaders.

6.1. Materials and determination of clay structure

At the beginning of the experiment three different samples of clay were collected. All samples of clay were obtained from the different locations in different countries. Fist clay sample was obtained from deposit which is located in eastern Germany, clay sample were yellowish in colour, further (S1). Another sample was obtained from the deposit in northeaster Estonia and was grey in colour, further (S2). And the third sample of clay was obtained from clay deposit in western Lithuania and was dark brown and red in colour, further (S3).

After collection of clays samples, 100 grams of each sample was separated and taken in order to determine chemical compositions. For determination of chemical compositions of clays, all samples were dried in electric oven at 60 °C temperature for about 12 hours and after shredded to 2 mm particles. Further, clays specimens drying process was continued for additional 6 hours at the same temperature of 60 °C. Once clay drying process was finished, clay samples were milled to a powder and submitted for chemical analysis. The chemical composition of all clay samples was determined by applying energy dispersive x-ray spectroscopy method with microscope "Quanta 250", which was equipped with x-ray spectrometer [2]. Samples of clays in powder form before determination of chemical analysis are presented in Fig. 15.

Fig. 15. Clay samples in powder form

6.2. Production of specimens

To determine how different raw materials affects on the physical and mechanical properties of clay paving bricks, the specimens of clay paving bricks were produced under the same production circumstances and under the same production parameters. Production process of specimens covered 4 main steps presented in Fig. 16.

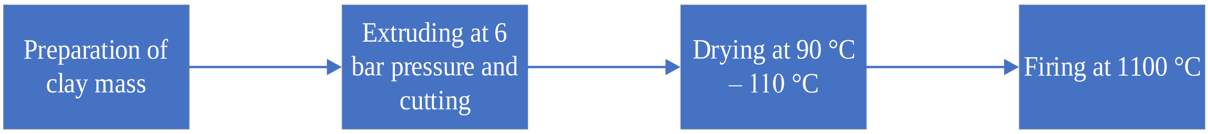

Fig. 16. Production process of specimens

6.2.1. Preparation of clay mass

Raw clay materials obtained from the quarries were not suitable for the production of clay paving brick samples, as it came in the form of pieces of various sizes and should be prepared in accordance with technological requirements. At the factory, during the raw clay preparation process, raw clays were transported by the belt conveyors. Raw clays brought from the quarries to the factory were at first shredded by reducing them to the smaller fractions. All three different samples of clay, without mixing them together, were crushed and blended with the help of crushing machine with four crushing rollers. Raw clay were poured in-to the shredder and shredded by the first coarse shredding rolls, and then pushed through a 3 – 4 mm sieve to ensure a finer clay fraction. Sieved clay to a fraction of 3 – 4 mm entered the second crushing rollers where it was crushed and sieved through a smaller than 3 mm fraction sieve, during this second clays crushing process, additional additives as water (H_2O), sand and barium carbonate ($BaCO_3$) to clay mass were added. Sand used in the preparation of clay mass complied with the requirements of the LST EN 12620:2003. Water applied during the preparation of clay mass was without acids or salts complied with requirements of LST EN 1008:2003. Some additional clay additives which were applied for preparation of clay mass, in the production of clay paving brick samples, displayed in Fig. 17 and 18.

Fig. 17. Barium carbonate

Fig. 18. Sand 0.4 fraction

After clays crushing process and addition of mentioned additives, clay mass was still not ready for the production of clay paving brick specimens. The main reason for this is that clay is a bad conductor of water therefore, water which were added in-to the clay mass is not evenly distributed throughout the clay raw material mass. Therefore, in order for the moisture to be evenly distributed, clay raw materials were left for additional 3 days to mature. During this process of clay mass maturation, clay raw materials become soft and acquired plasticity, but still were not suitable for the production of paving bricks. Clay maturation process time depends on various factors, however probably the most important factors are the type of clay and it's granulometric composition [2, 7]. Clay maturation process is presented in Fig. 19.

Fig. 19. Clay maturation process

After clay maturation process, preparation of clay mass was continued. Clay with the belt conveyors were transferred to the third crushing rollers, where it was crushed and pressed through mesh of 1.8 – 2.2 mm. After, clay mass was transferred to the fourth crushing rollers where was crushed and pressed through mesh of 0.9 – 1.2 millimetres. Transportation of clay mass with the belt conveyors and crushing – pressing through a sieves process presented in Fig. 20 and 21.

Fig. 20. Clay mass transportation process

Fig. 21. Clay crushing process

The mixtures of clays and additives were transferred to the final mixer, where they were mixed again and, if necessary, moistened in order to provide the required plasticity to the clay mass. As it was observed during analitical part of reaserch, in the procution of clay biulding materials the optimal amout of mouisture in clay mass is between 18 % and 23 % [2]. Final clay mass mixturing process, before shaping and cutting operations, is presented in Fig. 22.

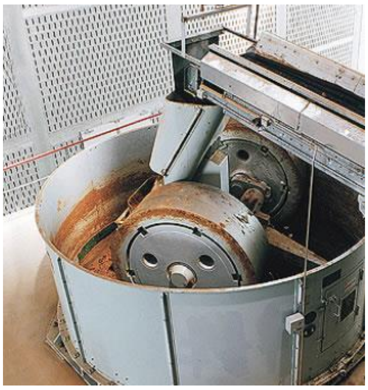

Fig. 22. Clay mass mixing process

6.2.2. Molding and cutting

After preparation of clay mass, the shaping and cutting operations were executed. With the help of belt conveyors, mass of clay raw materials were delivered to the clay shaping machine, for the shaping operation. Before clay shaping operation, the entire line was adjusted and inspected to ensure that there no pressure leaks and overflows. The main technical data of clay shaping machine is provided in Table 15.

Table 15. Technical data of clay shaping machine [31]

Model	Barrel diameter, mm.	Extrusion pressure (max.), bar	Volumetric throughput, m^3/h	Throughput capacity, t/h wet	Power requirement, kW
Handle 25a/20	200	50	0.2 – 1.9	0.3 – 3.3	19 - 45

A pressure of 6 bar was applied for the production of clay paving bricks samples, as such pressure is optimal according to the technological regulations of the production of the local factory. Clay shaping machine is presented in Fig. 23.

Fig. 23. Clay shaping machine [31]

During the clay shaping process it is necessary to ensure that shaped clay bars slide out of the press evenly, without bends, with equal edges and angles. If pressure leaks or overflows occurs during the shaping of clay mass process, it is necessary to stop the shaping line and determine the causes of the failure, fix them. During the shaping process clay bars were produced of size 200 x 100 mm. Clay extrusion and shaping process presented in Fig. 24 and 25.

Fig. 24. Extruded bar of clay S3

Fig. 25. Extruded bar of clay S2

Further, extruded and shaped clay bars were cut by automatic cutting machine to the required 52 mm thickness pieces. Before starting of cutting operation, it is necessary to ensure that cutting machine are properly adjusted and all clay bricks will be of the same thickness. The cutting wires must be free of clay and tensioned, cutting machine must ensure clean and smooth cut. Clay bars cutting machine is presented in Fig. 26. Clay paving bricks samples size of 200 x 100 x 52 mm were produced from each type of clay S1, S2, and S3.

Fig. 26. Clay bar cutting machine [7]

6.2.3. Drying of specimens

Cut pieces of size 200 x 100 x 52 were placed on drying wagons and transported to the drying chamber by a rail cross conveyor. Specimens were dried in drying chamber at temperature 90 °C – 110 °C. Heat to the drying chamber were supplied from nearby firing chamber. Samples of clay paving bricks were dried for 68 hours and then delivered to the firing site. Drying process presented in the Fig. 27.

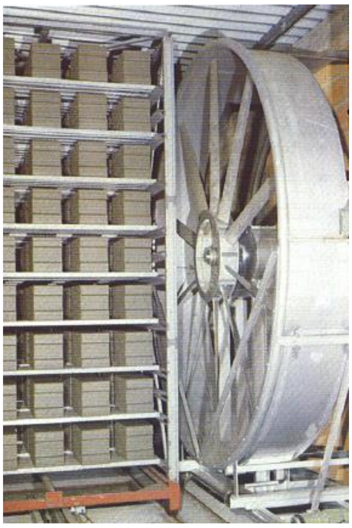

Fig. 27. Clay paving bricks in drying chamber

Clay drying process is very important factor and parameter of the technological production process, because during drying the main content of moisture is removed from the clay mass. If clay paving bricks are dried improperly the cracks and splits may appear during the firing process, thus damaging the products [7].

6.2.4. Firing of specimens

After specimens of clay paving bricks were dried, they were reloaded on the firing wagons and placed into the tunnel firing chamber. The firing process began with preheating operation at 90 °C temperature, which was gradually increased and achieved. During preheating operation, the amount of free moisture from clay paving bricks samples was removed. As the temperature gradually raised to 700 °C, remained water from the chemical compounds of clay paving brick specimens was removed. Further, firing process was performed at 1100 °C temperature and at the end of the firing process specimens remained at the end of tunnel firing chamber to cool down. Tunnel firing chamber with the injectors of liquefied gas displayed in Fig. 28.

Fig. 28. Tunnel firing chamber

Technological production process of specimens of clay paving bricks was designed and developed in accordance with the requirements of EN 1344:2013/AC:2015, physical and mechanical properties of clay paving bricks. Development for technological production process also were executed in accordance with he requirements of the following standards: ISO 3310-1:2003 requirements and test methods for sieves; ISO 3310-2000 requirements and test methods for sieves from metal wire mesh; LST EN 1745:2012 requirements for production of masonry units; LST EN 12620:2003+A1:2008 requirements for concrete aggregates; LST EN 1008:2003 requirements and test methods for water sampling and suitability; HN 33-1993 standard of Lithuanian Republic hygiene for acoustic noise; HN 51-1994 standard of Lithuanian Republic hygiene for vibrations which are acting on human body; LST EN ISO 9001:2015 quality management requirements; LST EN ISO 14001:2015 requirements for environmental management, LST EN 12620:2003 requirements and test methods for sand. All manufactured specimens of clay paving bricks were tested in accordance with requirements of EN 1344:2013/AC:2015 standard.

Detailed manufacturing process of clay paving bricks presented in Fig. 29. Barium carbonate was added in-to the clay mass in order to stabilize salts, which raw clay contents.

During the preparation process of raw materials, water to clay mass were added twice, once before clay maturation process and second time during the final clay mass mixing process, then it was necessary to ensure required plasticity of clay mass, before the shaping and cutting operations.

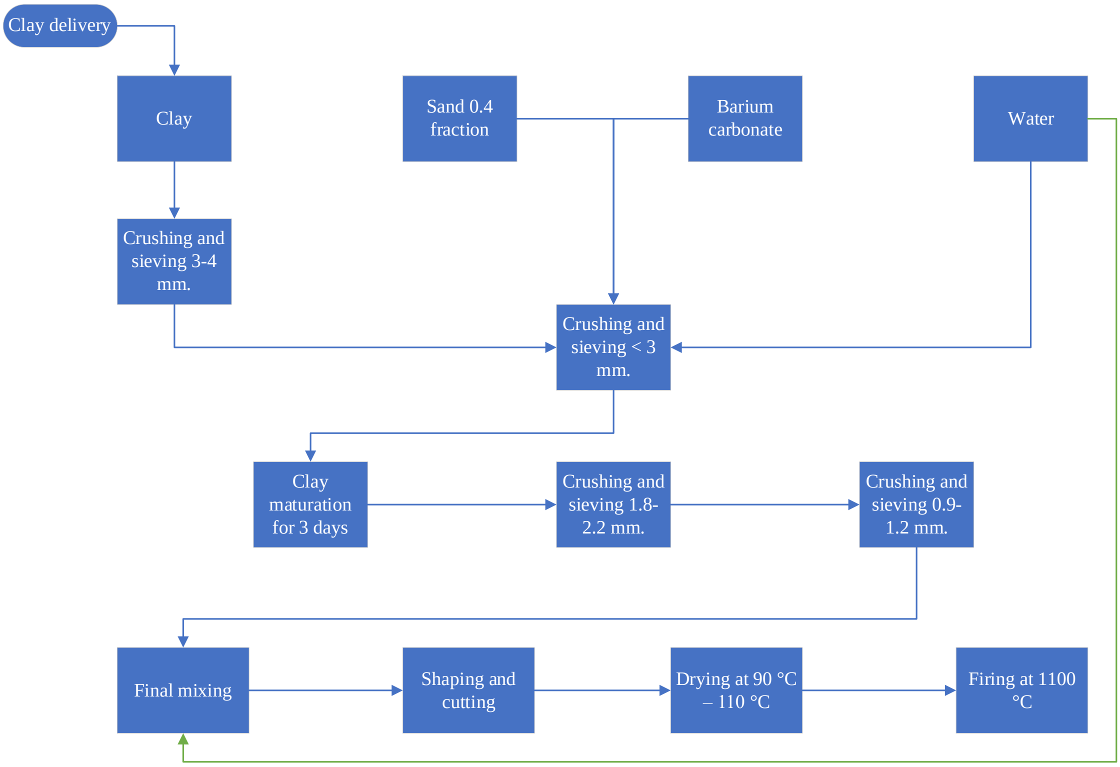

Fig. 29. Production process of specimens of clay paving bricks

Fig. 29 represents production methodology of clay paving bricks specimen's which was finally suggested only after production of all specimens from all three different types of clays. During the specimen's production process, many operations and parameters were standard and selected according to the production methodology of the local factory however, the problems related with clays plasticity was encounter in the production of specimens from different clays. It was observed that before the clay maturation process, the same amount of water which was added in-to the different types of clay mass, during the maturation process were absorbed differently. Different clay properties leaded to the different water absorption, thus one type of clay S2 had optimal plasticity and additional amount of moisture there wasn't necessary, however, another two types of clay mass S1 and S3 before shaping operation had not reached the optimal plasticity therefore, it was not possible to produce a clay bars due to the resulting of cracks during the shaping-extrusion operation. It was determined that in order to provide required plasticity to some clays, it is necessary to add an additional amount of water just before the shaping operation, during the final clay mass mixing operation. It has been observed that by adding an additional amount of water to the clay mass at this stage of the production process, the required clay plasticity parameter can be achieved very accurately. Also, no additional maturation process of the clays is required, as the particles of clay and other additives are already saturated with the required amount of moisture during the previous clay maturation process.

Proposed production methodology displayed in Fig. 29, when water is added in-to the clay mass before shaping operation is more optimal because it allows to achieve and control the optimal amount of moisture in the clay mass very accurately. In order to determine and select required amount of water which should be added in-to the clay mass for the achievement of optimal raw materials plasticity, a final mixer with scales can be integrated in-to the production line, which immediately weighs the mass of clay during the mixing process, from which the required additional amount of water can be calculated. The operation of adding additional water to the clay mass is illustrated by the green arrow shown in Fig. 29.

6.3. Results and discussions

Results of chemical analysis confirmed, that the chemical compositions of all clays S1, S2, S3 was different. All clays were essentially composed of the same chemical oxides as Al_2O_3 (Aluminium oxide), SiO_2 (Silicone oxide), Fe_2O_3 (Iron III oxide), TiO_2 (Titanium oxide), MgO (Magnesium oxide) and others, however, the amounts of mentioned oxides in the clays was different. The chemical compositions of clays S1, S2, S3 provided in Table 16.

Table 16. Chemical compositions and plasticity of clays S1, S2, S3

Clay	Chemical oxides, %								Plasticity
	SiO_2 Silicone oxides	Al_2O_3 Aluminium oxides	TiO_2 Titanium oxides	Fe_2O_3 Iron III oxides	CaO calcium oxides	MgO Magnesium oxides	K_2O Potassium oxides	Na_2O Sodium oxides	H_2O, %
S1	70.05	19.52	1.35	5.35	0.30	0.50	2.30	0.30	23.51
S2	62.20	19.35	2.39	6.30	1.25	2.33	5.41	0.16	18.54
S3	48.15	12.21	3.23	4.45	7.50	4.01	4.23	4.82	20.42

From the values given in Table 16 visible, that largest differences of chemical oxides were determined in differences of silicon dioxides (SiO_2). The amount of SiO_2 in clay S1 was accounted for 70.05 %, and this content of SiO_2 is the highest comparing with the others samples of clays S2 and S3. The values in Table 16 shows, that content of silicon dioxides in clay S2 is 62.20 % and 48.15 % in clay S3. Content of aluminium oxides in clays S1 and S2 was found of 19.52 % and 19.35 %, respectively, however, content of aluminium oxides in clay S3 was significantly lower and accounted of 12.21 %. A graphical diagram of the chemical compositions of the clays S1, S2, S3 is provided Fig. 30.

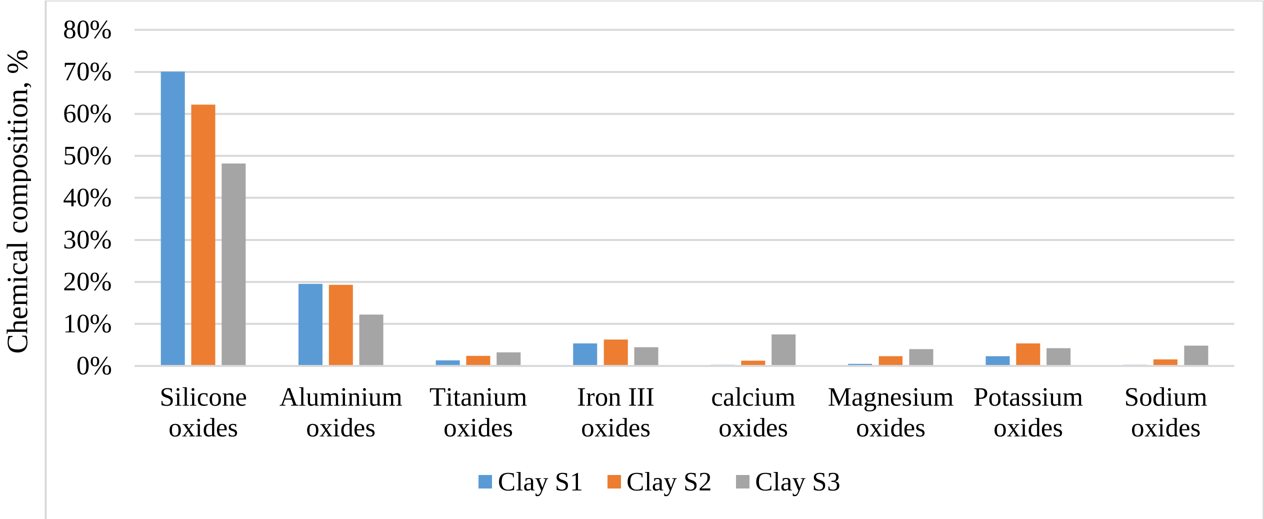

Fig. 30. Chemical compositions of clay S1, S2, S3

The plasticity parameters of clay shown in Table 16 indicates what percentage of moisture clay should content in order to obtain it best plasticity properties. As it was mentioned in previous chapters, different clays can achieve optimal plasticity at different content of moisture, the plasticity of the clay directly depends on clay minerology and particles size [2].

During the experiment, 75 specimens of clay paving bricks of size 200 x 100 x 52 mm were manufactured, followed 25 specimens of clay paving bricks from each different type of clay. All specimens of clay paving bricks were manufactured using the manufacturing methodology provided in Fig. 29, under the mentioned requirements of production standards and presented production parameters.

In order to evaluate the physical and mechanical properties of manufactured specimens of clay paving bricks, laboratory tests on clay paving bricks were performed in accordance with the requirements of EN 1344:2013/AC:2015. As it was mentioned earlier, the requirements of this standard is mandatory for all clay paving bricks, which are produced in EU.

To determine physical properties of specimens, freeze and thaw resistance and acid resistance tests were executed. In order to determine mechanical properties of specimens, transverse braking load test were performed. Also, the overall dimensions of all specimens of clay paving bricks were measured and recorded, it was assessed whether the dimensional deviations complied with the permissible norms of the EN 1344:2013/AC:2015. All manufactured specimens of clay paving bricks are presented in Fig. 31.

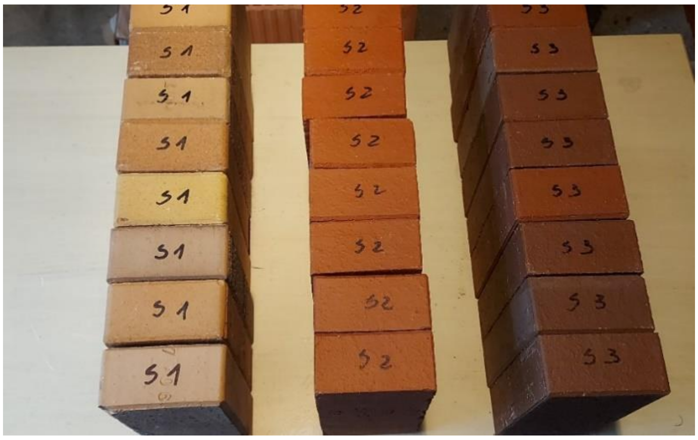

Fig. 31. Specimens of clay paving bricks

At the beginning of laboratory tests to determine physical and mechanical properties of clay paving brick specimens, all manufactured specimens was thoroughly visually inspected and no fissures or external damages was founded. The visual properties of clay paving brick specimens met the requirements of the statistical user, the colours of the clay paving bricks were rich and bright.

6.3.1. Results of dimensional differences and deviations

Before starting laboratory tests on manufactured specimens of clay paving bricks, overall dimensions of specimens were measured and recorded in accordance with the requirements of EN 1344:2013/AC:2015 standard. As it explained in previous chapters, during the experiment 10 specimens of clay paving bricks from each type of clay were randomly selected, all specimens were clean and smooth. Measured dimensions of specimens in accordance with requirements of EN 1344:2013/AC:2015 standard presented in Table 17.

Table 17. Assessment of dimensional deviations

Dimension's deviation test		**Total sample: 30 units**		**Standard: EN 1344:2013/AC:2015**
Type of clay	**No.**	**Length (d), mm**	**Width (d), mm**	**Thickness (d), mm**
		200	**100**	**52**
		Measuring point: Middle of the area		
S1	1	201.4	100.5	52.1
	2	201.0	100.6	52.2

	3	200.1	99.6	52.0
	4	201.6	100.7	51.4
	5	201.6	100.9	51.8
	6	201.7	100.9	52.4
	7	201.8	100.8	51.7
	8	201.1	100.5	52.2
	9	201.8	100.8	52.0
	10	200.1	99.5	52.1
Average value:		**201**	**100**	**52**
Allowed deviation value: **From: d-(0.4∗ $\sqrt{d}$)/To: d+(0.4∗ $\sqrt{d}$)**		**194 to 206**	**96 to 104**	**49 to 55**
Smallest value:		200	100	51
Greatest value:		202	101	52
Class R0		No requirement	No requirement	No requirement
Class R1 0.6∗ $\sqrt{d}$		8	6	4
Result:		**Assigned to class**	**R1**	
S2	1	197.2	99.0	50.2
	2	198.5	98.4	51.5
	3	200.5	99.3	50.6
	4	198.3	98.4	52.3
	5	199.2	97.9	50.3
	6	198.2	98.2	49.9
	7	198.6	97.8	50.3
	8	199.1	98.5	51.6
	9	197.8	99.1	50.8
	10	198.5	97.3	52.2
Average value:		**199**	**98**	**51**
Allowed deviation value: **From: d-(0.4∗ $\sqrt{d}$)/To: d+(0.4∗ $\sqrt{d}$)**		**194 to 206**	**96 to 104**	**49 to 55**
Smallest value:		197	97	50
Greatest value:		200	99	52
Class R0		No requirement	No requirement	No requirement
Class R1 0.6∗ $\sqrt{d}$		8	6	4
Result:		**Assigned to class**	**R1**	
S3	1	195.8	97.3	50.1
	2	196.2	96.8	50.3
	3	196.5	96.3	50.6
	4	195.1	97.1	50.0
	5	197.4	97.3	49.3
	6	196.7	96.4	49.7
	7	195.1	96.1	49.9
	8	196.4	96.3	50.6
	9	196.7	97.1	50.4
	10	196.6	96.8	49.2
Average value:		**196**	**97**	**50**
Allowed deviation value: **From: d-(0.4∗ $\sqrt{d}$)/To: d+(0.4∗ $\sqrt{d}$)**		**194 to 206**	**96 to 104**	**49 to 55**
Smallest value:		195	96	49
Greatest value:		197	97	51
Class R0		No requirement	No requirement	No requirement
Class R1 0.6∗ $\sqrt{d}$		8	6	4
Result:		**Assigned to class**	**R1**	

During the experiment 10 specimens of clay paving bricks from each type of clay were randomly selected and their overall dimensions were determined. The total number of measured specimens of clay paving bricks was 30 pcs. All measurements were conducted with a special measuring calliper, the accuracy of which was verified by the relevant authority of Lithuania Republic. From the presented results in Table 17 visible, that specimens which were manufactured from three different types of clays are all assigned to class R1 as its dimensional differences not exceeds established norms required by the EN 1344:2013/AC:2015. However, despite the fact that all specimens of clay paving bricks were the same dimensions after shaping and cutting operations, it is notable that dimensions after the firing operation have changed. The highest dimensional deviations were recorded of the specimens manufactured from clay type S3 and the most resistant to expansion and shrinkage were specimens from clay type S1. Chart of dimensional deviations of all tested specimens is presented in Fig. 32.

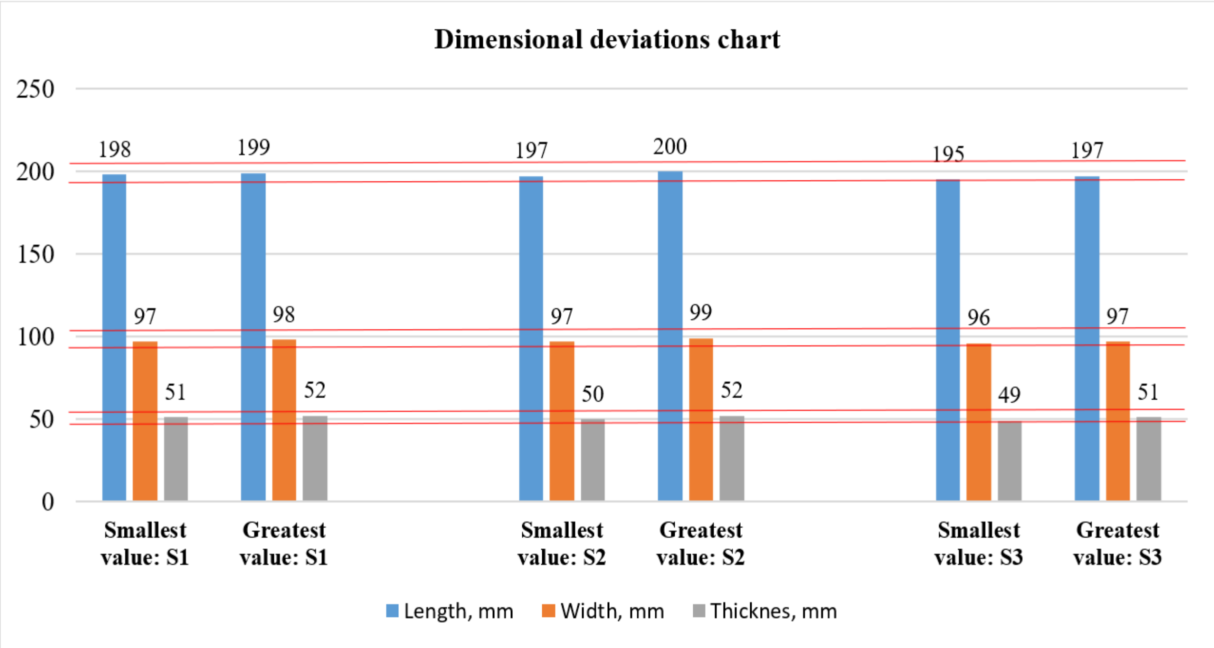

Fig. 32. Results of dimensional differences and deviations

6.3.2. Results of freeze and thaw resistance

To determine freeze and thaw resistance of manufactured specimens of clay paving bricks, tests in accordance with the requirements of EN 1344:2013/AC:2015 standard were conducted [26]. At the beginning of freeze and thaw test, 10 specimens of clay paving bricks from each clay was selected, placed in oven and dried at 105 °C ± 5 °C temperature till constant mass. A constant mass of the specimens is considered when the weight of the specimens weighed over a period of 24 hours does not differ by more than 0.2 %. All specimens was cooled down at ambient temperature before weighing. Determination of constant mass of specimens are presented in Table 18.

Table 18. Determination of constant mass

Type of clay	No.	Mass after drying at (105 ± 5) °C			Loss of mass < 0.2 %	
		After 24 hours		After 48 hours		
		1, kg	2, kg	3, kg	After 24 hours	After 24 hours more
S1	1	2.308	2.300	2.300	0.35	0.0

	2	2.319	2.313	2.313	0.26	0.0
	3	2.312	2.308	2.308	0.17	0.0
	4	2.293	2.284	2.284	0.39	0.0
	5	2.301	2.292	2.292	0.39	0.0
	6	2.321	2.312	2.312	0.39	0.0
	7	2.312	2.303	2.303	0.39	0.0
	8	2.297	2.284	2.284	0.57	0.0
	9	2.305	2.296	2.296	0.39	0.0
	10	2.315	2.309	2.309	0.26	0.0
Constancy of mass achieved					**Not achieved**	**Achieved**

Type of clay	**No.**	**Mass after drying at (105 ± 5) °C**			**Loss of mass < 0.2 %**	
		After 24 hours		**After 48 hours**		
		1, kg	**2, kg**	**3, kg**	**After 24 hours**	**After 24 hours more**
S2	1	2.301	2.279	2.279	0.97	0.0
	2	2.311	2.281	2.281	1.32	0.0
	3	2.321	2.295	2.295	1.13	0.0
	4	2.305	2.286	2.286	0.83	0.0
	5	2.322	2.302	2.302	0.87	0.0
	6	2.326	2.315	2.315	0.48	0.0
	7	2.300	2.278	2.278	0.97	0.0
	8	2.304	2.295	2.295	0.39	0.0
	9	2.321	2.315	2.315	0.26	0.0
	10	2.299	2.272	2.272	1.19	0.0
Constancy of mass achieved					**Not achieved**	**Achieved**

Type of clay	**No.**	**Mass after drying at (105 ± 5) °C**			**Loss of mass < 0.2 %**	
		After 24 hours		**After 48 hours**		
		1, kg	**2, kg**	**3, kg**	**After 24 hours**	**After 24 hours more**
S3	1	2.193	2.189	2.189	0.18	0.0
	2	2.201	2.198	2.198	0.14	0.0
	3	2.185	2.183	2.183	0.09	0.0
	4	2.198	2.195	2.195	0.14	0.0
	5	2.188	2.187	2.187	0.05	0.0
	6	2.190	2.186	2.186	0.16	0.0
	7	2.205	2.201	2.201	0.18	0.0
	8	2.210	2.209	2.209	0.07	0.0
	9	2.197	2.195	2.195	0.11	0.0
	10	2.206	2.204	2.204	0.10	0.0
Constancy of mass achieved					**Achieved**	**Achieved**

Once constant mass of specimens were achieved test for determination of water absorption has began. All specimens were emersed in-to the water at room temperature. Further, water temperature were raised till 80 °C ± 3 °C gradually, over a period of 2 – 5 hours and then specimens remain in water for another 24 hours. Later, heating of water was stopped and water temperature cooled down to room temperature gradually. Total immersion period of specimens in-to the water was about 48 hours. Results are presented in Table 19.

Table 19. Determination of water absorption

Type of clay	No.	Mass in air after immersion in water, g	Mass under the water, g	Specimen density, kg/m^3	Specimen mass after drying, g	Water absorption, %
S1	1	2308.2	1274.9	2.23	2300	0.36
	2	2320.8	1282.4	2.23	2313	0.34
	3	2314.7	1298.7	2.27	2308	0.29
	4	2292.0	1264.8	2.22	2284	0.35
	5	2300.0	1269.0	2.22	2292	0.35
	6	2321.5	1281.4	2.22	2312	0.41
	7	2310.6	1276.6	2.23	2303	0.33
	8	2293.0	1259.5	2.21	2284	0.39
	9	2303.8	1269.2	2.22	2296	0.34
	10	2316.4	1304.1	2.28	2309	0.32
Average value:				**2.23**		**0.35**
S2	1	2325.3	1273.9	2.15	2279	2.03
	2	2331.5	1280.6	2.18	2281	2.21
	3	2353.3	1285.6	2.14	2295	2.54
	4	2364.2	1275.4	2.15	2286	3.42
	5	2348.5	1284.2	2.14	2302	2.02
		2338.7	1290.9	2.13	2315	1.02
	7	2348.1	1280.7	2.14	2278	3.08
	8	2345.5	1270.2	2.12	2295	2.20
		2366.3	1283.2	2.15	2315	2.22
	10	2337.6	1286.0	2.13	2272	2.89
Average value:				**2.14**		**2.36**
S3	1	2356.3	1298.5	1.95	2189	7.64
	2	2361.1	1302.3	2.02	2198	7.42
	3	2335.2	1295.4	1.96	2183	6.97
	4	2388.6	1318.6	1.95	2195	8.82
	5	2345.5	1294.3	1.95	2187	7.25
	6	2335.5	1292.3	1.96	2186	6.84
	7	2362.8	1301.1	1.95	2201	7.35
	8	2375.5	1304.1	1.97	2209	7.54
	9	2361.2	1296.8	2.01	2195	7.57
	10	2375.2	1312.6	2.03	2204	7.77
Average value:				**1.98**		**7.52**
Specimen density, average value ≥ 2.0 kg/dm^3 Individual values ≥ 1.9 kg/dm^3 **Water absorption ≤ 6 %** **Measurements performed in accordance with requirements of EN 18503 standard**						

As it notable from the results of water absorption in Table 19, specimens manufactured from clay S3 can be characterized as the most moisture absorbing, because the average percentage value of difference between dry and moistened specimens was determined of 7.52 %, which is higher than maximum value of 6 % established by the standard. Due to the determined moisture absorption value, the use of such clay paving bricks in outdoor conditions would not be recommended.

After determination of constant mass and water absorption 10 specimens from each clay were assembled in-to the frames for freeze and thaw test. The temperature while freezing periods were -15 °C ± 3 °C, first freezing period was executed for 6 hours and other freezing periods lasted for 120 min. During the thaw process temperature from -15 °C ± 3 °C were increased to 20 °C ± 3 °C gradually between 15 and 20 minutes. After thawing process, water on specimens' surface were sprayed for 120 ± 10 seconds, and process were repeated. All results are presented Table 20.

Table 20. Determination of freeze and thaw resistance

<table>
<tr><th rowspan="2">Type of clay</th><th rowspan="2">Description of damage</th><th rowspan="2">Type</th><th colspan="10">No.</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th></tr>
<tr><td rowspan="11">S1</td><td>Changes or damages</td><td>0</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Chalking crater</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Hairline crack ≤ 0.15 mm</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Crack</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Surface crack > 0.15</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Continuous crack</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Chipping</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Shuttering</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Flake off</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fracture</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Flaking</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="13">-) No changes or damages.
+) Occurrence of the violation.
Clay paving bricks of class FP 100 must not show any damage of the type or higher after 100 freeze and thaw cycles.</td></tr>
<tr><td colspan="2">Result:</td><td colspan="3">Assigned to class</td><td colspan="4">FP 100</td><td colspan="4">Freeze and thaw resistant</td></tr>
<tr><th rowspan="2">Type of clay</th><th rowspan="2">Description of damage</th><th rowspan="2">Type</th><th colspan="10">No.</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th></tr>
<tr><td rowspan="11">S2</td><td>Changes or damages</td><td>0</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>Chalking crater</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Hairline crack ≤ 0.15 mm</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Crack</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Surface crack > 0.15</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Continuous crack</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Chipping</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Shuttering</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Flake off</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fracture</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Flaking</td><td>0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="13">-) No changes or damages.
+) Occurrence of the violation.
Clay paving bricks of class FP 100 must not show any damage of the type or higher after 100 freeze and thaw cycles.</td></tr>
<tr><td colspan="2">Result:</td><td colspan="3">Assigned to class</td><td colspan="4">FP 100</td><td colspan="4">Freeze and thaw resistant</td></tr>
<tr><th rowspan="2">Type of clay</th><th rowspan="2">Description of damage</th><th rowspan="2">Type</th><th colspan="10">Number of specimens</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th></tr>
<tr><td>S3</td><td>Changes or damages</td><td>6</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>2</td><td>x</td><td>3</td><td>1</td><td>x</td></tr>
</table>

	Chalking crater	1	-	-	-	-	-	-	-	-	+	-
	Hairline crack ≤ 0.15 mm	1	-	-	-	-	-	-	-	+	-	-
	Crack	0	-	-	-	-	-	-	-	-	-	-
	Surface crack > 0.15	0	-	-	-	-	-	-	-	-	-	-
	Continuous crack	0	-	-	-	-	-	-	-	-	-	-
	Chipping	0	-	-	-	-	-	-	-	-	-	-
	Shuttering	0	-	-	-	-	-	-	-	-	-	
	Flake off	1	-	-	-	-	-	+	-	-	-	-
	Fracture	1	-	-	-	-	-	-	-	+	-	-
	Flaking	2	-	-	-	-	-	+	-	+	-	-
-) No changes or damages. +) Occurrence of the violation. Clay paving bricks of class FP 100 must not show any damage of the type or higher after 100 freeze and thaw cycles.												
Result:		**Assigned to class**			**FP 0**				**No requirement**			

From the results presented in Table 20 notable, that specimens of clay paving bricks manufactured from clay S3 do not satisfied the minimum requirements of the EN 1344:2013/AC:2015 standard which is 100 freeze and thaw cycles. First violations was noted after cycle 82. Later specimens started to collapse, many cracks and fracture damages, flaking, chipping was detected. The others specimens of clay paving bricks manufactured from clay S1 and S2 perfectly met the requirements of the standard. Specimens manufactured from clay S2 and S1 was assigned to class FP 100 which is freeze and thaw resistant, and specimens manufactured from clay S3 assigned to class FP 0 as not freeze and thaw resistant. A graphical chart of the results of freeze and thaw resistance test presented in Fig. 33.

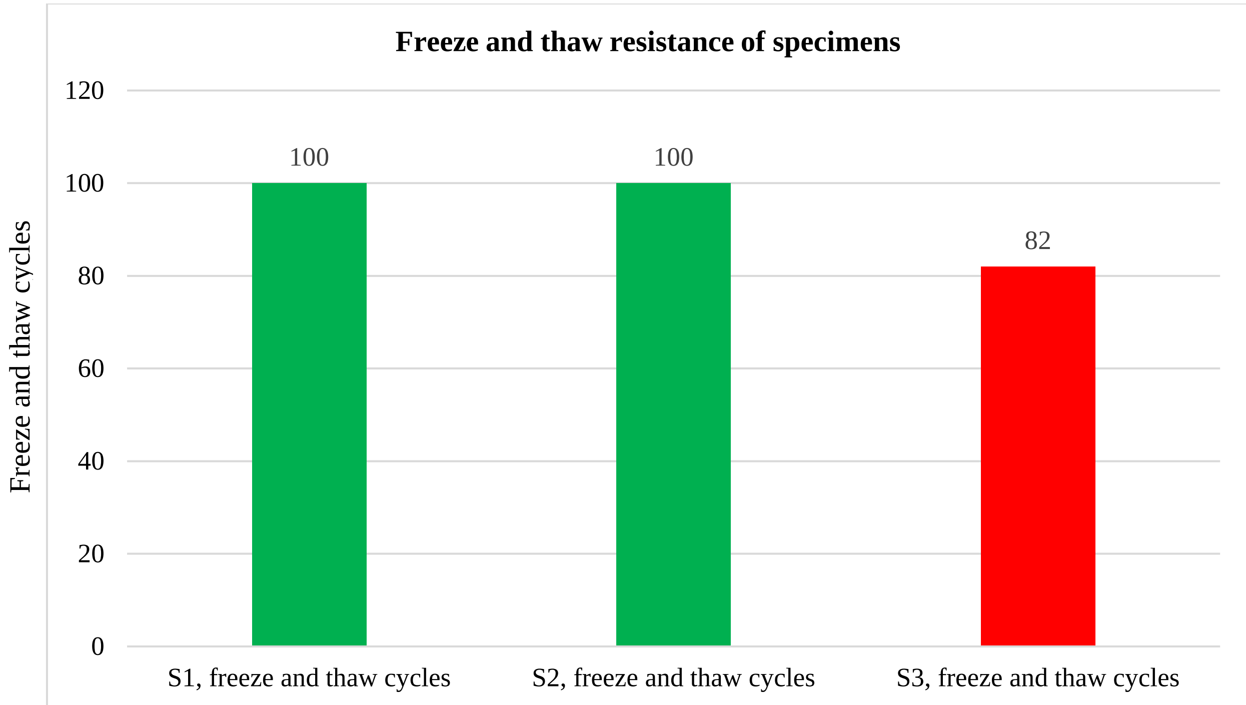

Fig. 33. Results of freeze and thaw resistance

As it was mentioned in pervious chapters resistance to freezing and thawing is one of the most important property of clay paving bricks as they are designed for outdoor usage.

6.3.3. Results of acid resistance

As it explained in previous chapters following reagents as sulfuric acid (H_2SO_4), nitric acid (HNO_3) and deionized water during experiment were used. At the beginning of the test 5 specimens was selected. Specimens was crushed in-to 12 – 10-millimeter size particles and later grained and retained through 800 μm sieve, the same process was repeated and samples sifted through 500 μm sieve, later washing process with deionised water was processed until clean fraction of 500 μm remained. Clean fraction of specimens was dried at 110 °C temperature to constant mass. A constant mass was considered, when during the drying process in two subsequent weightings with a 24 hours interval the loss in mass between the two determinations wasn't more than 0.1 %. After the drying, 100 ± 5 grams of the specimen's mass were be weighed with the accuracy of 0.01 gram. Further, specimen's mass were transferred to laboratorial flask and 75 ml of 10 % sulfuric acid and 25 ml of 10 % nitric acid applied. Once reagents were applied samples were be boiled for 60 ± 2 minutes by immersing flask into bath with hot oil. After acid treatment and boiling whole mass of specimens were poured on 150 μm sieve, washed with deionized water and dried at 110 °C temperature to constant mass. Once mass of specimens were dried all 3 specimens was weighed with the accuracy of 0.01 gram and the loss of mass calculated and recorded.

Acid resistance property of clay paving bricks may be very important especially when pavers are used outdoors during the winter period, as most of the roads and yards in winter are treated with various salts or acids in order to melt ice or snow. Also, clay paving bricks may be used next to the plants of chemical components or materials and some of them my reach the surface of pavers and cause the damage. For those reasons clay paving bricks have to comply with the requirements of the standard for acid resistance properties.

According the to requirements of EN 1344:2013/AC:2015, loos of mass after specimen's treatment with acids shall not exceed 7 %. Acid resistance results are presented in Fig. 34.

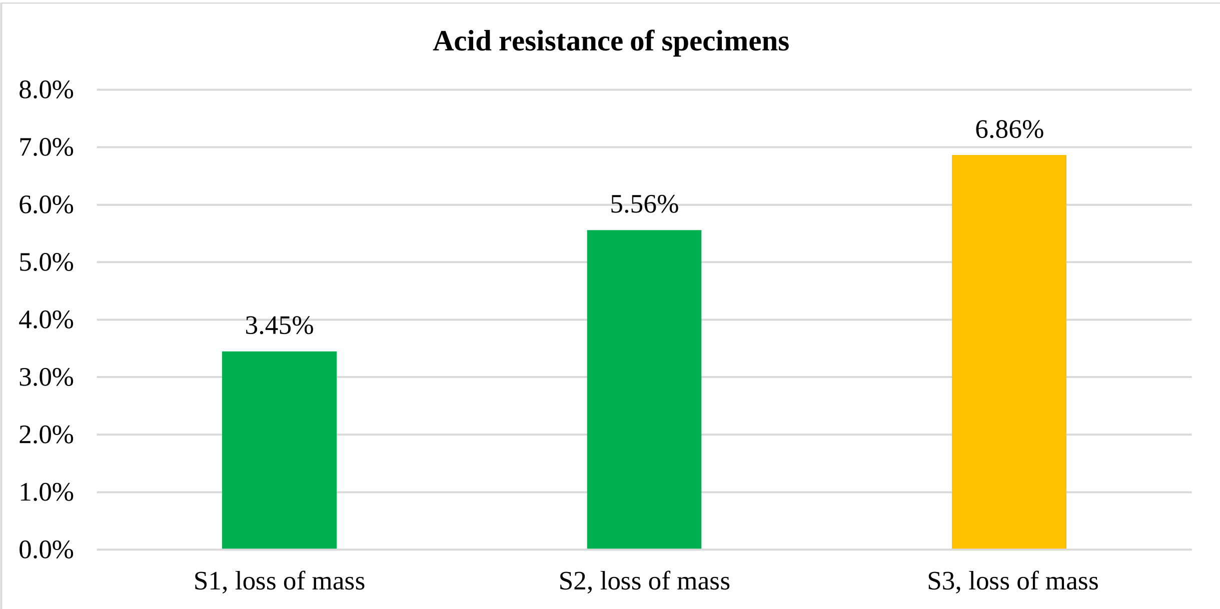

Fig. 34. Results of acid resistance

As it notable from the results presented in Fig. 34, all specimens manufactured from clay S1, S2 and S3 met the requirements of the relevant standard. However, specimens manufactured from clay S3 were already almost on the limit of 7 %.

6.3.4. Results of transverse breaking load

At the beginning of transverse braking load test 10 specimens of clay paving bricks were selected and as it required by the standard was immersed in-to the water for 48 hours at 20 °C ± 5 °C temperature. After immersion in-to the water all specimens one by one were placed into the apparatus which is displayed in Fig. 13. Two ends of clay specimens were supported, fixed and external force in the middle of the fracture were applied. External force on specimens were applied gradually, not exceeding 5 N/mm load per 5 seconds, until failure occurred and clay paving bricks were breaking in half. After determination of breaking loads of specimens, calculations of transverse breaking load and tensile bending strength were executed. All results are presented in Table 21.

Table 21. Results of transverse braking load

Type of clay	No.	Width, mm	Thickness, mm	Distance between end supports, mm	Breaking load, N	Transverse breaking load, N/mm	Tensile bending strength, N/mm^2
S1	1	100.5	52.1	170	12582	**132**	13
	2	100.6	52.2	170	10306	**107**	10
	3	99.6	52.0	170	12062	**126**	12
	4	100.7	51.4	170	12474	**133**	13
	5	100.9	51.8	170	11549	**119**	12
	6	100.9	52.4	170	13088	**138**	13
	7	100.8	51.7	170	12513	**132**	12
	8	100.5	52.2	170	12551	**133**	12
	9	100.8	52.0	170	12216	**128**	12
	10	99.5	52.1	170	12967	**137**	13
Average value:						**129**	12
Minimum value:						**107**	10
Assigned to class:						**T4**	
Type of clay	**No.**	**Width, mm**	**Thickness, mm**	**Distance between end supports, mm**	**Breaking load, N**	**Transverse breaking load, N/mm**	**Tensile bending strength, N/mm^2**
S2	1	99.2	50.6	170	8685	**88**	9
	2	98.1	51.3	170	8253	**84**	8
	3	99.5	50.7	170	9253	**93**	9
	4	98.7	52.4	170	8173	**83**	8
	5	97.5	50.2	170	8789	**90**	9
	6	98.6	49.4	170	8078	**82**	9
	7	97.9	50.5	170	7987	**82**	8
	8	98.4	51.7	170	8347	**85**	8
	9	99.5	50.9	170	8574	**86**	9
	10	97.4	52.6	170	8465	**87**	8
Average value:						**86**	9
Minimum value:						**82**	8
Assigned to class:						**T4**	
Type of clay	**No.**	**Width, mm**	**Thickness, mm**	**Distance between end supports, mm**	**Breaking load, N**	**Transverse breaking load, N/mm**	**Tensile bending strength, N/mm^2**
S3	1	97.3	50.1	170	4568	47	5

	2	96.8	50.3	170	3864	40	4
	3	96.3	50.6	170	3989	41	4
	4	97.1	50.0	170	4130	43	4
	5	97.3	49.3	170	4677	48	5
	6	96.4	49.7	170	4324	45	5
	7	96.1	49.9	170	4257	44	5
	8	96.3	50.6	170	3745	39	4
	9	97.1	50.4	170	3961	41	4
	10	96.8	49.2	170	4337	45	5
Average value:						**43**	5
Minimum value:						**39**	4
Assigned to class:						**T2**	

From the results presented in Table 21 it is visible, that specimens of clay paving bricks manufactured from clay types S1 and S2 assigned to class T4, because calculated average value of transverse breaking load is higher than 80 N/mm and minimum value higher than 65 N/mm. However, specimens of clay paving bricks manufactured from clay type S3 was assigned to class T2, because transverse breaking load average value was determined of 43 N/mm and minimum value 39 N/mm. After identification of breaking loads values of specimens, the transverse braking loads values were calculated according to the standard by the formula (5) below.

Transverse braking load = breaking load [N] / width of specimen [mm] (5)

Tensile bending strength values were calculated according to the formula (2) which was presented in previous chapter.

As it was mentioned in analytical part, transverse breaking load property is very important because during the exploitation of clay paving bricks they are affected by various external forces and must be able to withstand certain loads, which are defined by the standard. Column chart of the results of specimen’s transverse breaking loads values is presented in Fig. 35.

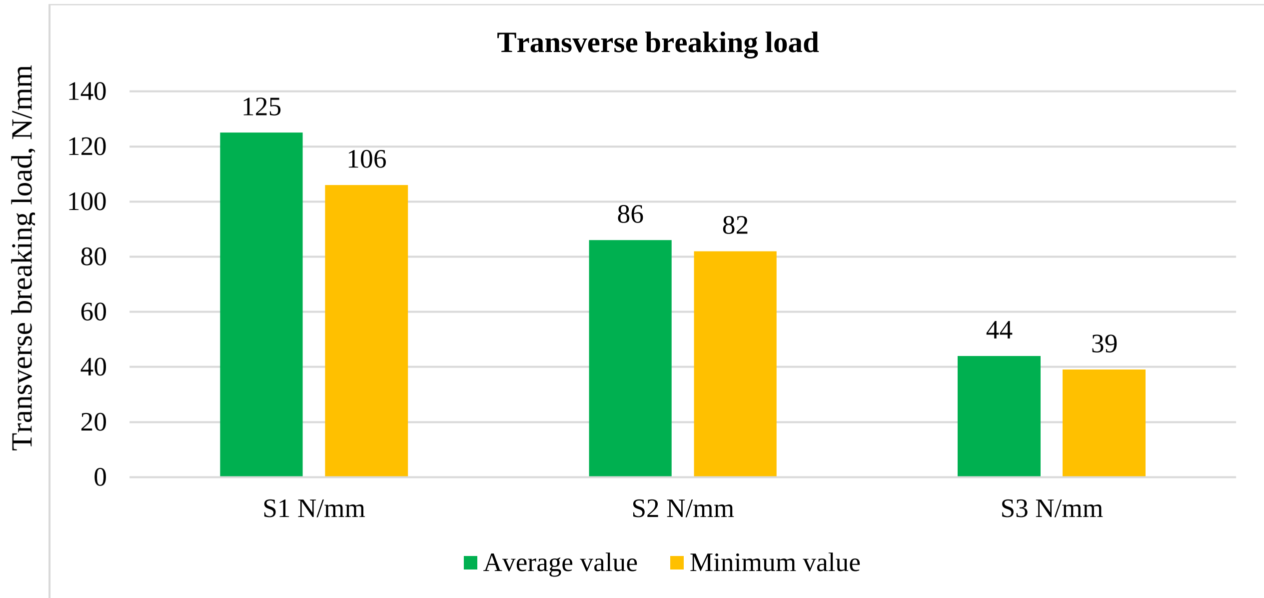

Fig. 35. Results of transverse braking load

From the results presented in column chart it is visible that all specimens of clay paving bricks are within the rage of the requirements of EN 1344:2013/AC:2015 for transverse breaking load.

6.3.5. Summary of results

During the experiment, four laboratory tests on clay paving bricks specimens were performed to determine physical and mechanical properties and dimensional deviations. However, the main objective of this experiment was to determine how different parameters of technological production process correlates with each other and effects on final physical and mechanical properties of clay paving bricks. As it was observed during the production process of specimens, there are many production parameters which are influencing the quality of final products. As it was determined form the obtained results of experiment, one of the most important production parameters is raw material. From the results presented in Table 22 it is visible, that specimens manufactured from clay S1 and S2 which contained higher amounts of silicon oxides and aluminium oxides, had higher physical and mechanical properties.

Table 22. Summary of experiment results

Summary of results	Content		
Chemical oxide	**Clay type S1**	**Clay type S2**	**Clay type S3**
SiO_2	High	7.85 % lower	21.90 % lower
Al_2O_3	High	0.17 % lower	7.31 % lower
Properties			
Freeze and thaw resistance	High resistance	High resistance	18.0 % lower from minimum value
Acid resistance	High resistance	61.15 % higher in loss of mass	98.8 % higher in loss of mass
Transverse breaking load [N/mm]	High	31.2 % lower	65.6 % lower

However, in order to confirm that lower values of specimens physical and mechanical properties are always caused by the lower content of silicon and aluminium oxides further investigations are necessary, as it may simply be due to the poor selection of other parameters of technological process such as wrong selection of material compression force during the extrusion-shaping operation, wrong firing temperature and atmosphere in the firing chamber, wrong raw material plasticity. As it was observed during the analytical part of this project, clay particle size, clay melting point and plasticity differs [2], for those reasons it is always necessary to determine the optimal parameters of technological production process.

According to the production methodology of specimens of clay paving bricks and obtained tests results of specimens physical and mechanical properties, it can be presumed that positive corelations of parameters of technological process were determined for specimens from clay types S1 and S2, as those specimens of clay paving bricks demonstrated physical and mechanical properties which fully compiled with the requirements of EN 1344:2013/AC:2015 standard. Specimens of clay paving bricks S1 and S2, manufactured according to the production methodology and under parameters of technological process presented in Fig. 29, were able to withstand 100 freeze and thaw cycles, were acid resistant, its values of transverse breaking loads and dimensional deviations were within the rage of the limits established by the relevant standard.

According to the results of the experiment, modern production line of clay paving bricks with an exclusive digitized clay mass weighing and mixing hopper is proposed and presented in Fig. 36.

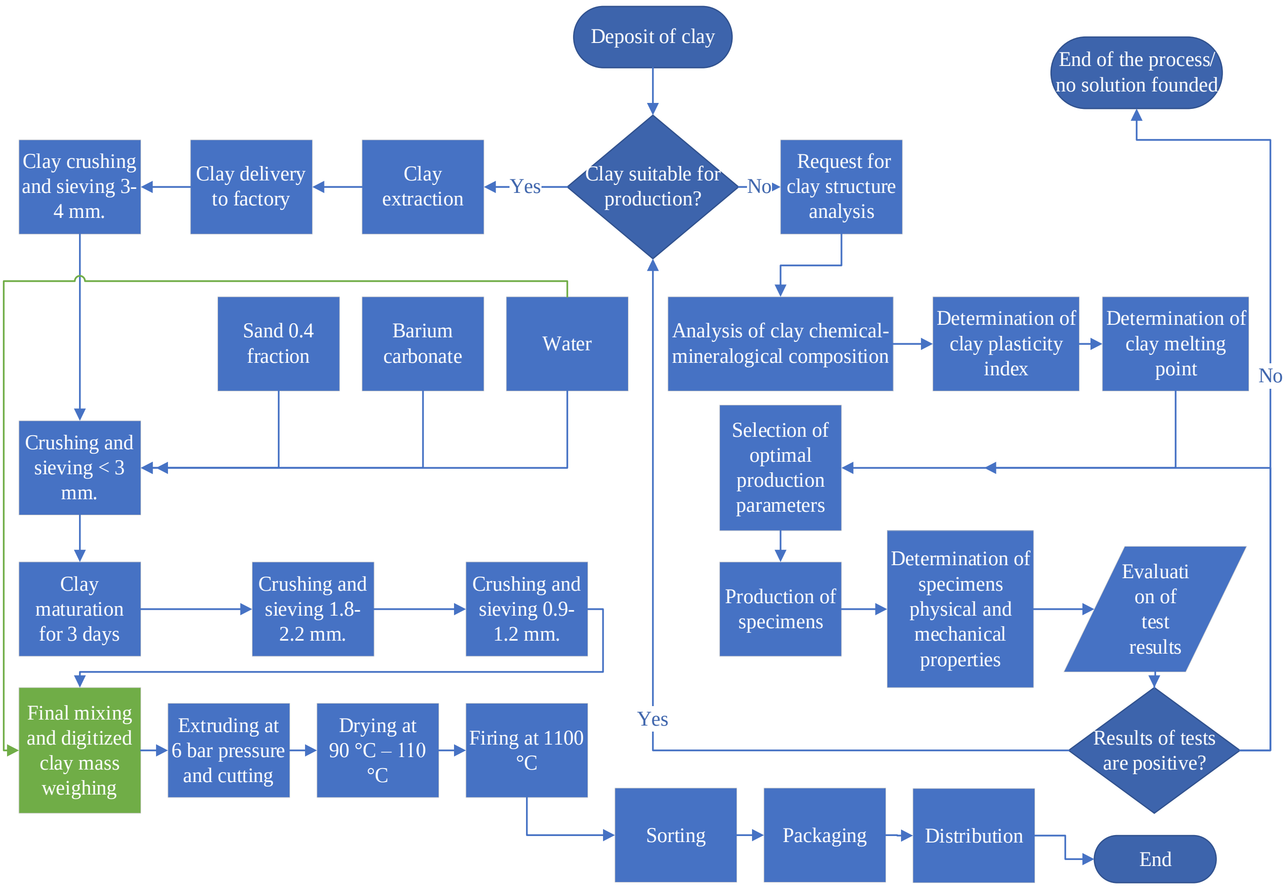

Fig. 36. Proposed technological production process of clay paving bricks

As it was observed and discussed during the analytical part of the project, structure of clay raw materials often differs, that is way the same parameters of technological production process may be not optimal solution. As it presented in Fig. 36, before the beginning of the production process it is necessary to determine raw material suitability. Once structure of raw clay is determined, other parameters of technological process must be selected. As it was discussed in previous chapters [2] clay structure, melting point, clay particle size and plasticity, firing temperature are crucial factors, which provides direct effect on physical and mechanical properties of clay paving bricks.

In order to ensure, that clay acquires optimum plasticity during the clay paving bricks manufacturing process, modern solution of determination of clay weight was suggested. As it presented in Fig. 36 in green square, modern and digitalized clay mass scales was suggested and implemented in-to the final mixing hopper of clay, in order to determine weight of clay mass and calculate the necessary and exact amount of water for the achievement of optimal raw materials plasticity. Based on the obtained exact mass of clay, computer software program automatically calculates the required amount of water, which is necessary to add in-to the clay mass. Water is added straight to the clay mixing hopper, as shown by the green arrow in Fig. 36.

Proposed technological production process of clay paving bricks presented in Fig. 36, covers all manufacturing stages of clay pavers and specifies all the necessary parameters of technological process required for the production of high-quality clay paving bricks. As it was determined during the analytical and experimental parts of this project, the parameters of technological process directly influence on the physical and mechanical properties of clay paving bricks.

7. Economical part

In nowadays production process of clay paving bricks is highly mechanized, automated and complex, however, the innovative production solutions allows to achieve high and precise quality of the final products. Also, modernization of the equipment's and production machines allows to reduce energy consumptions and costs, enables to produce and deliver to the market clay paving bricks of various sizes, shapes and colours. However, probably the most important that high technologies and innovations allows to increase the capacity of the production and even provides a competitive advantage which allows to produce more products at lower costs and negative impact to environment. For those reasons, production processes, methodologies, equipment's and machinery's are rapidly being modernized and improved.

On a global scale it is possible to discover developed terms as industry 4, cyber-physical systems, mobile clouds, smart objects, the internet of thing, and many more. All those developed innovations and philosophies allows to make major improvements to the daily productions of many products and also in the production of clay paving bricks.

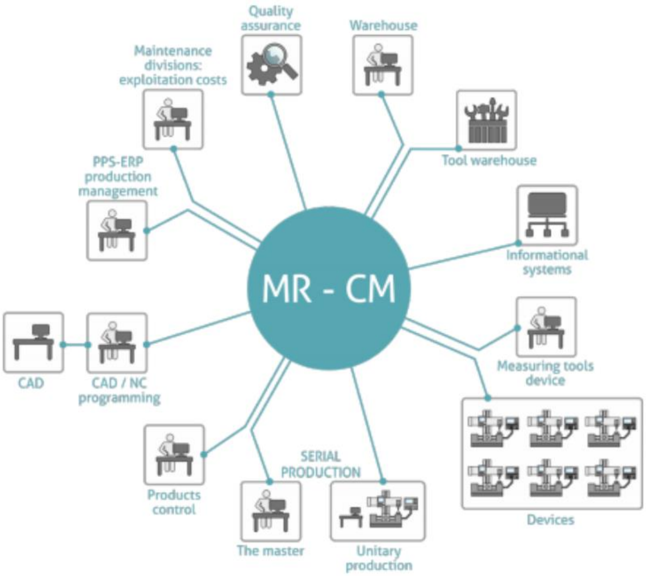

Fig. 37. Smart data management platform [32]

7.1. Production line modernization investment project

In order to achieve optimal plasticity of clay mass during the production process of clay paving bricks, it is necessary to add precise amount of water into the clay mass during the final clay mixing process, however, for that reason it is necessary to know exact weight of clay mass. To solve the occurred issue a modern clay mixing and weighing hopper were suggested.

Clay mass with others raw materials which enters in-to the final mixing hopper is mixed and weighed automatically. All relevant data of clay mass weight and achieved plasticity are transferred to the computer software, where calculations are performed to determine the required amount of water for the achievement of optimal clay mass plasticity. After determination of the required data, the necessary amount of water is automatically fed to the hopper and mixing process of clay mass is continued till optimal plasticity is achieved. When the optimal plasticity is reached raw materials travels to the extruder, where the clay mass shaping process begins. Modern clay mass mixing and weighting hopper is presented in Fig. 38.

Fig. 38. Modern clay mixing and weighting hopper [33]

To assess the rationality and payback of such an investment, the investment valuation model has been developed and presented.

7.2. Initial data and financial ratios

The financial data from annual reports and balance sheets of one of the world's largest producers of clay paving bricks and other building materials from clay, were used to estimate the return on investment. Annual financial reports and balance sheets are presented in appendixes and calculated financial ratios shown in Table 23.

Table 23. Financial ratios of clay paving bricks producer, calculated from annual financial reports

Ratio	FY 2016 31/12/2016	FY 2017 31/12/2017	FY 2018 31/12/2018
Current ratio	1.28	1.38	1.61
Quick ratio	0.54	0.60	0.65
Cash ratio	0.24	0.24	0.25
Networking capital to total assets	0.22	0.28	0.38
Interval measure	564.95	529.20	492.99
Total debt ratio	0.49	0.48	0.48
Debt/Equity	0.97	0.91	0.93
Equity multiplier	1.97	1.91	1.93
Long - term debt ratio	0.21	0.21	0.27
Times interest earned ratio	6.06	4.79	6.58
Cash coverage ratio	9.29	7.14	7.91
Inventory turnover	2.80	2.82	2.82
Day's sales in inventory	130.37	129.28	129.53
Receivable turnover	14.74	14.56	15.31
Day's sales in receivables	24.77	25.07	23.84
Payable turnover	6.64	6.51	6.57
Day's sales in payables	54.94	56.05	55.59
NWC turnover	10.93	8.67	6.82
Fixed assets turnover	1.25	1.33	1.34
Total assets turnover	0.82	0.85	0.88
Profit margin	5.0 %	5.1 %	6.2 %
Return on assets (ROA)	4.0 %	4.5 %	5.0 %
Return on equity (ROE)	8.6 %	7.5 %	10.0 %

7.3. Calculations of weighted average costs of capital

The cost of capital is the return that company needs to make capital budgeting project. Usually, it is weighted averages of company's cost of equity and cost of debt altogether. Capital costs is a rate that is needed to be overcome before value can be generated by the company. The calculations are performed by using the weighted average cost of capital (WACC) formula, that considers both equity capital and debt. Weighted average cost of capital (WACC) formula presented below (6).

$$WACC = w_d \times k_d \times (1 - T) + w_p \times k_p + w_s \times k_s + w_e \times k_e \quad (6)$$

Where:

w_d – weight of debt;

k_d – cost of debt;

T – tax rate;

w_p – weight of preferred stock;

k_p – cost of preferred stock;

w_s – weight of undivided profit;

k_s – cost of undivided profit;

w_e – weight of common stock;

k_e – cost of common stock.

According to the balance sheets of the clay paving bricks producer, the calculations of w_d for 3 periods by dividing total liabilities by total liabilities and equity were performed:

$$w_{d_{2016}} = \frac{1788221}{3637177} = 0.492$$

$$w_{d_{2017}} = \frac{1748625}{3659864} = 0.478$$

$$w_{d_{2018}} = \frac{1803830}{3742910} = 0.482$$

By using balance sheet again, w_e were calculated by dividing total equity by total liabilities and equity:

$$w_{e_{2016}} = \frac{1848956}{3637177} = 0.508$$

$$w_{e_{2017}} = \frac{1911239}{3659864} = 0.522$$

$$w_{e_{2018}} = \frac{1939080}{3742910} = 0.518$$

Values k_e are taken from Table 23, where return on equity's were calculated for each period:

$$k_{e_{2016}} = 0.086$$

$$k_{e_{2017}} = 0.075$$

$$k_{e_{2018}} = 0.100$$

Value k_d is taken from income statement, where interest expense is divided by number of borrowings, both long term and short term summed:

$$k_{d_{2016}} = \frac{35936}{481383 + 399924} = 0.040$$

$$k_{d_{2017}} = \frac{38714}{493197 + 320422} = 0.048$$

$$k_{d_{2018}} = \frac{40525}{709835 + 126684} = 0.048$$

The last value *T* is calculated by dividing current income tax by pre-tax income, both values are taken from income statement:

$$T_{2016} = \frac{40481}{158549} = 0.255$$

$$T_{2017} = \frac{45038}{144878} = 0.311$$

$$T_{2018} = \frac{58120}{195345} = 0.298$$

All obtained values were set in-to the formula (6) and weighted average cost of capital for 3 periods calculated. Results are presented below:

$$WACC_{2016} = 0.059 = 5.9\%$$

$$WACC_{2017} = 0.055 = 5.5\%$$

$$WACC_{2018} = 0.069 = 6.9\%$$

Average weighted average cost of capital value also calculated and presented below:

$$WACC_{avg} = 0.061 = 6.1\%$$

7.4. Investment, depreciation costs and description of forecasted cash flows

According to the received information from the producer of modern clay mixing and weighting hoopers, the necessary amount of investment for the acquisition of new equipment would be 250000 euros with delivery and installation costs, estimated period of exploitation 10 years.

Calculation of depreciation costs is presented below.

Depreciation costs = 250000 (investment) /10 (exploitation years) = 25000 euro each year.

The cash flows were calculated according to the formula (7) below.

CF = Depreciation costs + Net profit (7)

Depreciation costs was calculated above and its equal to 25000 euro for each exploitation year during the period of 10 years. The Net profit value was calculated according to the formula (8). The return on assets average value (ROA_{Av}) was calculated from the annual ROA values presented in Table 23, the average ROA_{Av} value of 3 years periods in % was obtained of 4.5 %.

Net profit = Investment * ROA_{Av} (8)

Where:

Investment – 250000 euro;
ROA_{Av} – 4.5 %.

Calculations of Net profit presented below:

Net profit = 250000 * 4.5 % = 11250 euro each year.

Once Net profit and depreciation values were obtained, the calculations of cash flows executed according to the formula (8). The calculations and cash flows value presented below.

CF_{1-10} = 25000 + 11250 = 36250 euro

According the calculations above, the annual cash flow for investment project is 36250 euro, including depreciation and average return on assets ratio. Selected usage period of modern clay mixing and weighting hooper is 10 years, for that reason 36250 value were placed for ten times for further calculations.

7.5. Valuation of investment

As it mentioned required investment to obtain a modern clay mixing and weighting hooper is 250000 euros therefore, in the first-year investment is calculated as company costs which occurred during acquisition of the equipment. Average weighted cost of capital (WACC) value of three periods was obtained 6.1 %. Cash flows for all ten periods calculated of 36250 euro for each period. All cash flows and discounted cash flows are presented in Table 24. Discounted cash flows were calculated by valuing the average weighted cost of capital value.

Table 24. Cash flow forecasting and investment valuation in Euro

No.	Year	Cash flows	Sum of cash flows	Discounted CF	Sum of discounted CF
1	0	**-250000**			
2	1	36250	36250	34166	34166
3	2	36250	72500	32202	66367
4	3	36250	108750	30350	96718
5	4	36250	145000	28605	125323
6	5	36250	181250	26961	152284
7	6	36250	217500	25411	177694
8	**7**	36250	**253750**	23950	201644
9	8	36250	290000	22573	224217
10	9	36250	326250	21275	245492
11	**10**	**36250**	362500	**20052**	**265544**

The sum of cash flows was calculated by adding the values of different periods as presented below.

1 period – 36250;

2 period – 36250 + 36250 = 72500;

3 period – 7250 + 36250 = 108750;

4 period – 108750 + 36250 = 145000 and so on.

Discounted cash flows values were calculated by valuing average cost of capital values as presented below.

1 period – 36250 / (1 + 6.10 %) ^{1} = 34166;

2 period – 36250 / (1 + 6.10 %) ^{2} = 32202;

3 period – 36250 / (1 + 6.10 %) ^{3} = 30350;

4 period – 36250 / (1 + 6.10 %) ^{4} = 28605 and so on.

The sum of discounted cash flows were calculated by adding the values of different periods as presented below.

1 period – 34166;

2 period – 34166 + 32202 = 66367;

3 period – 30350 + 66367 = 96718;

4 period – 28605 + 96718 = 125323 and so on.

Once cash flows, discounted cash flows and sums of cash flows and discounted cash flows were obtained the investment project valuation ratios calculated and presented below.

Payback of investment (PB) = 7 + (250000 – 253750) / 36250 = 6.89 years.

Payback of discounted investment (dPB) = 10 + (250000 – 265544) / 20052 = 9.22 years.

Net present value (NPV) = 265544 – 250000 = 155440 euro.

Profitability index (PI) = 265544 / 250000 = 1.062

Internal rate of return (IRR) = 19.78 %

7.6. Summary of the results

As indicated in calculations, the investment in equipment, modern clay mixing and weighting hopper, will pays back in 6.89 years. Discounted pay back of investment were calculated of 9.22 years and is less than depreciation period of 10 years.

From calculated net present value (NPV) it is notable that after 10 years of cash flows the profit of 155440 euro could be generated. If NPV > 0, investment project should be accepted because it contributes rationally to the development of the factory and company.

Profitability index of 1.062 indicates, that suggested investment project for acquisition of modern clay mixing and weighting hopper is profitable, because PI value is higher than 1. If PI value is higher than 1 investment project should be accepted, if PI value bellow 1 investment project should be rejected.

Internal rate of return (IRR) were calculated by using MS Excel software and is 19.78 %, which indicates that investment project should be accepted, as its IRR value higher than 10 %.

Calculations confirmed that suggested investment project is profitable and should be accepted, however despite the financial justification, acquisition of the equipment will allow to run production process more smoothly and avoid failures which are related with plasticity of raw materials.

Conclusions

1. Specimens manufactured according to the production methodology presented in the project from clay types S1 and S2 under parameters of technological process: moulding at 6 bars pressure, drying at 90 °C – 110 °C, firing at 1100 °C, were able to withstand 100 freeze and thaw cycles, were acid resistant, its values of transverse breaking loads and dimensional deviations were within the rage of the limits established by the EN 1344:2013/AC:2015.

2. From the results of clays chemical analysis in the experimental part it is notable that clay type S1 had the highest content of SiO_2 and Al_2O_3, however, compared to clay types S2 and S3, the content of the mentioned oxides was lower by: S2 – 7.85 % and 0.17 %, S3 – 21.90 % and 7.31 % respectively.

3. From the results obtained after the water absorption test can be considered, that specimens manufactured from clay type S3 were most water absorbing, as water absorption percentage were determined of 7.52 %. Water absorption for specimens manufactured from clay types S1 and S2 were determined of 0.35 % and 2.36 %, respectively.

4. Freeze and thaw test results showed that specimens manufactured from clay S1 and S2 which contents higher amounts of chemical oxides SiO_2 and Al_2O_3 were 21.95 % more freeze and thaw resistant comparing with specimens manufactured form clay S3. Specimens manufactured from clay types S1 and S2 were able to resist 100 freeze and thaw cycles, however, the violations on specimens manufactured from clay type S3 were noted after 82 freeze and thaw cycles. After acid resistance test determined, that specimens of clay paving bricks manufactured from clay type S1 characterized by the most resistant properties to acids, the loss of mass after acid resistance test was 3.45 %. Specimens manufactured form clay type S2 characterized by mass loss of 5.56 % and specimens manufactured from clay type S3 by 6.86 % of mass loss. All specimens satisfied minimum requirement of EN 1344:2013/AC:2015 which is 7 %.

5. Results of transverse breaking load test confirmed, that specimens manufactured from clay type S1 could be able to resists higher loads compared with specimens manufactured from clay types S2 and S3, the values of transverse braking load of specimens from clay types S2 and S3 were lower by 31.2 % and 65.5 % respectively, compared with specimen's form clay type S1.

6. Calculations and valuations of investment project showed, that proposed modernization of production line of clay paving bricks, by acquiring modern clay mixing and weighing hopper is economically justified and rational solution, as pay back of investments were calculated of 6.89 years, discounted pay back 9.22 years, net present value was obtained 155440 Euro and profitability index 1.062, which means that investment project is profitable and should be accepted.

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Appendices

Appendix 1. Company balance sheets

Wienerberger AG (WIE AV) - Standardised				
In thousands of EUR except per share; 12 months ending		FY 2016	FY 2017	FY 2018
Total Assets				
Cash, Cash Equivalents & STI	C&CE_AND_STI_DETAILED	236737.00	223802.00	196331.00
Cash & Cash Equivalents	BS_CASH_NEAR_CASH_ITEM	197016.00	169259.00	163080.00
ST Investments	BS_MKT_SEC_OTHER_ST_INVEST	39721.00	54543.00	33251.00
Accounts & Notes Receive	BS_ACCT_NOTE_RCV	201809.00	214277.00	215838.00
Accounts Receivable, Net	BS_ACCTS_REC_EXCL_NOTES_REC	201809.00	214277.00	215838.00
Notes Receivable, Net	NOTES_RECEIVABLE	0.00	0.00	0.00
Inventories	BS_INVENTORIES	718359.00	741597.00	761659.00
Raw Materials	INVTRY_RAW_MATERIALS	127437.00	142626.00	153968.00
Work in Process	INVTRY_IN_PROGRESS	94262.00	98039.00	97402.00
Finished Goods	INVTRY_FINISHED_GOODS	495194.00	498559.00	508515.00
Other Inventory	BS_OTHER_INV	1466.00	2373.00	1774.00
Other ST Assets	OTHER_CURRENT_ASSETS_DETAILED	94545.00	125696.00	106141.00
Derivative & Hedging Assets	BS_DERIV_&_HEDGING_ASSETS_ST	13019.00	24465.00	9561.00
Assets Held-for-Sale	BS_ASSETS_HELD_FOR_SALE_ST	5380.00	0.00	—
Taxes Receivable	BS_TAXES_RECEIVABLE_SHORT_TERM	9868.00	2297.00	4144.00
Total Current Assets	**BS_CUR_ASSET_REPORT**	**1251450.00**	**1305372.00**	**1279969.00**
Property, Plant & Equip, Net	BS_NET_FIX_ASSET	1564727.00	1521572.00	1575709.00
Property, Plant & Equip	BS_GROSS_FIX_ASSET	4146537.00	4180520.00	4282696.00
Accumulated Depreciation	BS_ACCUM_DEPR	2581810.00	2658948.00	2706987.00
LT Investments & Receivables	BS_LT_INVEST	99651.00	82626.00	96989.00
LT Investments	BS_LONG_TERM_INVESTMENTS	99651.00	82626.00	96989.00
Other LT Assets	BS_OTHER_ASSETS_DEF_CHRG_OTHER	721349.00	750294.00	790243.00
Total Intangible Assets	BS_DISCLOSED_INTANGIBLES	690440.00	690897.00	712719.00
Goodwill	BS_GOODWILL	497477.00	484679.00	488487.00
Other Intangible Assets	OTHER_INTANGIBLE_ASSETS_DETAILED	192963.00	206218.00	224232.00
Deferred Tax Assets	BS_DEFERRED_TAX_ASSETS_LT	17367.00	44049.00	54076.00
Derivative & Hedging Assets	BS_DERIV_&_HEDGING_ASSETS_LT	—	0.00	0.00
Investments in Affiliates	BS_INVEST_IN_ASSOC_CO	13542.00	11371.00	22100.00
Misc. LT Assets	OTHER_NONCURRENT_ASSETS_DETAILED	0.00	3977.00	1348.00
Total Noncurrent Assets	**BS_TOT_NON_CUR_ASSET**	**2385727.00**	**2354492.00**	**2462941.00**
Total Assets	**BS_TOT_ASSET**	**3637177.00**	**3659864.00**	**3742910.00**

Liabilities & Shareholders' Equity				
Payables & Accruals	ACCT_PAYABLE_&_ACCRUALS_DETAILED	373849.00	398238.00	409916.00
Accounts Payable	BS_ACCT_PAYABLE	302718.00	321533.00	326890.00
Accrued Taxes	BS_TAXES_PAYABLE	71131.00	76705.00	83026.00
Other Payables & Accruals	BS_ACCRUAL	0.00	0.00	0.00
ST Debt	BS_ST_BORROW	399924.00	320724.00	126907.00
ST Borrowings	SHORT_TERM_DEBT_DETAILED	399924.00	320422.00	126684.00
ST Lease Liabilities	ST_CAPITALIZED_LEASE_LIABILITIES	0.00	302.00	223.00
ST Finance Leases	ST_CAPITAL_LEASE_OBLIGATIONS	0.00	302.00	223.00
Other ST Liabilities	OTHER_CURRENT_LIABS_SUB_DETAILED	205579.00	226617.00	258549.00
Deferred Revenue	ST_DEFERRED_REVENUE	6788.00	6049.00	8450.00
Derivatives & Hedging	BS_DERIVATIVE_&_HEDGING_LIABS_ST	—	0.00	0.00
Misc. ST Liabilities	OTHER_CURRENT_LIABS_DETAILED	198791.00	220568.00	250099.00
Total Current Liabilities	**BS_CUR_LIAB**	**979352.00**	**945579.00**	**795372.00**
LT Debt	BS_LT_BORROW	481434.00	493948.00	710590.00
LT Borrowings	LONG_TERM_BORROWINGS_DETAILED	481383.00	493197.00	709835.00
LT Lease Liabilities	LT_CAPITALIZED_LEASE_LIABILITIES	51.00	751.00	755.00
LT Finance Leases	LT_CAPITAL_LEASE_OBLIGATIONS	51.00	751.00	755.00
Other LT Liabilities	OTHER_NONCUR_LIABS_SUB_DETAILED	327435.00	309098.00	297868.00
Accrued Liabilities	BS_ACCRUED_LIABILITIES	0.00	0.00	0.00
Pension Liabilities	PENSION_LIABILITIES	171488.00	154992.00	136432.00
Deferred Revenue	LT_DEFERRED_REVENUE	3656.00	3430.00	2762.00
Deferred Tax Liabilities	BS_DEFERRED_TAX_LIABILITIES_LT	80759.00	71630.00	75021.00
Total Noncurrent Liabilities	**NON_CUR_LIAB**	**808869.00**	**803046.00**	**1008458.00**
Total Liabilities	**BS_TOT_LIAB2**	**1788221.00**	**1748625.00**	**1803830.00**
Preferred Equity and Hybrid Capital	BS_PFD_EQTY_&_HYBRID_CPTL	265985.00	265985.00	265969.00
Share Capital & APIC	BS_SH_CAP_AND_APIC	1203544.00	1203544.00	1192949.00
Common Stock	BS_COMMON_STOCK	117527.00	117527.00	117527.00
Additional Paid in Capital	BS_ADD_PAID_IN_CAP	1086017.00	1086017.00	1075422.00
Treasury Stock	BS_AMT_OF_TSY_STOCK	4862.00	4862.00	49858.00
Retained Earnings	BS_PURE_RETAINED_EARNINGS	586961.00	674923.00	760389.00
Equity Before Minority Interest	**EQTY_BEF_MINORITY_INT_DETAILED**	**1829125.00**	**1887748.00**	**1938494.00**
Minority/Non-Controlling Interest	MINORITY_NONCONTROLLING_INTEREST	19831.00	23491.00	586.00
Total Equity	**TOTAL_EQUITY**	**1848956.00**	**1911239.00**	**1939080.00**
Total Liabilities & Equity	**TOT_LIAB_AND_EQY**	**3637177.00**	**3659864.00**	**3742910.00**

Appendix 2. Company income statements

Wienerberger AG (WIE AV) - Adjusted				
In thousands of EUR except per share. 12 months ending		12/31/2016	12/31/2017	12/31/2018
Revenue	**SALES_REV_TURN**	**2973829.00**	**3119707.00**	**3305079.00**
Growth (YoY)	SALES_REV_TURN	0.050	4.905	5.942
Growth (Seq)	SALES_REV_TURN	0.050	4.905	5.942
Sales & Services Revenue	IS_SALES_AND_SERVICES_REVENUES	2973829.00	3119707.00	3305079.00
Growth (YoY)	IS_SALES_AND_SERVICES_REVENUES	0.050	4.905	5.942
Cost of Revenue	IS_COGS_TO_FE_AND_PP_AND_G	2011241.00	2093708.00	2146319.00
Growth (YoY)	IS_COGS_TO_FE_AND_PP_AND_G	-0.817	4.100	2.513
Cost of Goods & Services	IS_COG_AND_SERVICES_SOLD	2011241.00	2093708.00	2146319.00
Growth (YoY)	IS_COG_AND_SERVICES_SOLD	-0.817	4.100	2.513
Gross Profit	**GROSS_PROFIT**	**962588.00**	**1025999.00**	**1158760.00**
Growth (YoY)	GROSS_PROFIT	1.909	6.588	12.940
Growth (Seq)	GROSS_PROFIT	1.909	6.588	12.940
Other Operating Income	IS_OTHER_OPER_INC	30303.00	31243.00	26520.00
Growth (YoY)	IS_OTHER_OPER_INC	92.657	3.102	-15.117
Operating Expenses	IS_OPERATING_EXPN	808530.00	900343.00	947660.00
Growth (YoY)	IS_OPERATING_EXPN	-0.543	11.356	5.255
Selling, General & Admin	IS_SG&A_EXPENSE	760029.00	798884.00	854721.00
Growth (YoY)	IS_SG&A_EXPENSE	0.023	5.112	6.989
Selling & Marketing	IS_SELLING_EXPENSES	574347.00	595562.00	637162.00
Growth (YoY)	IS_SELLING_EXPENSES	-0.494	3.694	6.985
General & Administrative	IS_GENERAL_AND_ADMINISTRATIVE	185682.00	203322.00	217559.00
Growth (YoY)	IS_GENERAL_AND_ADMINISTRATIVE	1.657	9.500	7.002
Research & Development	IS_OPEX_R&D	14878.00	10980.00	15882.00
Growth (YoY)	IS_OPEX_R&D	-13.691	-26.200	44.645
Prov For Doubtful Accts	IS_PROVISION_DOUBTFUL_ACCOUNTS	1745.00	1474.00	305.00
Growth (YoY)	IS_PROVISION_DOUBTFUL_ACCOUNTS	9.131	-15.530	-79.308
Other Operating Expense	IS_OTHER_OPERATING_EXPENSES	31878.00	89005.00	76752.00
Growth (YoY)	IS_OTHER_OPERATING_EXPENSES	-6.942	179.205	-13.767
Operating Income (Loss)	**IS_OPER_INC**	**184361.00**	**156899.00**	**237620.00**
Growth (YoY)	IS_OPER_INC	25.126	-14.896	51.448
Non-Operating (Income) Loss	IS_NONOP_INCOME_LOSS	32032.00	34134.00	44593.00
Growth (YoY)	IS_NONOP_INCOME_LOSS	-42.849	6.562	30.641
Interest Expense, Net	IS_NET_INTEREST_EXPENSE	30442.00	32762.00	36116.00
Growth (YoY)	IS_NET_INTEREST_EXPENSE	-20.502	7.621	10.237
Interest Expense	IS_INT_EXPENSE	35936.00	38714.00	40525.00
Growth (YoY)	IS_INT_EXPENSE	-20.310	7.730	4.678
Interest Income	IS_INT_INC	5494.00	5952.00	4409.00
Growth (YoY)	IS_INT_INC	-19.230	8.336	-25.924
Other Investment (Inc) Loss	IS_OTHER_INVESTMENT_INCOME_LOSS	-1050.00	-1169.00	-983.00

Growth (YoY)	IS_OTHER_INVESTMENT_INCOME_LOSS	-186.104	-11.333	15.911
Foreign Exch (Gain) Loss	IS_FOREIGN_EXCH_LOSS	-466.00	6672.00	2051.00
Growth (YoY)	IS_FOREIGN_EXCH_LOSS	—	—	-69.260
(Income) Loss from Affiliates	INCOME_LOSS_FROM_AFFILIATES	-6666.00	-4209.00	-1701.00
Growth (YoY)	INCOME_LOSS_FROM_AFFILIATES	-65.862	36.859	59.587
Other Non-Op (Income) Loss	IS_OTHER_NON_OPERATING_INC_LOSS	9772.00	78.00	9110.00
Growth (YoY)	IS_OTHER_NON_OPERATING_INC_LOSS	-34.231	-99.202	11579.487
Pretax Income (Loss), Adjusted	**PRETAX_INC**	**152329.00**	**122765.00**	**193027.00**
Growth (YoY)	PRETAX_INC	66.859	-19.408	57.233
Abnormal Losses (Gains)	IS_ABNORMAL_ITEM	-6220.00	-22113.00	-2318.00
Growth (YoY)	IS_ABNORMAL_ITEM	60.453	-255.514	89.517
Merger/Acquisition Expense	IS_MERGER_ACQUISITION_EXPENSE	502.00	—	—
Disposal of Assets	IS_GAIN_LOSS_DISPOSAL_ASSETS	-26028.00	-25343.00	-26184.00
Growth (YoY)	IS_GAIN_LOSS_DISPOSAL_ASSETS	-36.094	2.632	-3.318
Asset Write-Down	IS_IMPAIRMENT_ASSETS	19748.00	-1055.00	8430.00
Growth (YoY)	IS_IMPAIRMENT_ASSETS	285.553	—	—
Impairment of Goodwill	IS_IMPAIRMENT_GOODWILL_INTANGIBL	6892.00	6339.00	—
Growth (YoY)	IS_IMPAIRMENT_GOODWILL_INTANGIBL	—	-8.024	—
Impairment of Intangibles	IS_IMPAIR_OF_INTANG_ASSETS	-4303.00	-1055.00	—
Growth (YoY)	IS_IMPAIR_OF_INTANG_ASSETS	—	75.482	—
Gain/Loss on Sale/Acquisition of Business	IS_SALE_OF_BUSINESS	-243.00	—	—
Growth (YoY)	IS_SALE_OF_BUSINESS	84.620	—	—
Restructuring	IS_RESTRUCTURING_EXPENSES	—	—	16100.00
Sale of Investments	IS_GAIN_LOSS_ON_INVESTMENTS	—	-368.00	-130.00
Growth (YoY)	IS_GAIN_LOSS_ON_INVESTMENTS	—	—	64.674
Unrealized Investments	IS_UNREALIZED_INVESTMENTS	35.00	28.00	—
Growth (YoY)	IS_UNREALIZED_INVESTMENTS	-35.185	-20.000	—
Insurance Settlement	IS_INSURANCE_SETTLEMENTS	-2823.00	-659.00	-534.00
Growth (YoY)	IS_INSURANCE_SETTLEMENTS	-605.750	76.656	18.968
Other Abnormal Items	IS_OTHER_ONE_TIME_ITEMS	—	—	—
Growth (YoY)	IS_OTHER_ONE_TIME_ITEMS	—	—	—
Pretax Income (Loss), GAAP	**PRETAX_INC**	**158549.00**	**144878.00**	**195345.00**
Growth (YoY)	PRETAX_INC	48.149	-8.623	34.834
Income Tax Expense (Benefit)	IS_INC_TAX_EXP	43222.00	4244.00	48475.00
Growth (YoY)	IS_INC_TAX_EXP	16.173	-90.181	1042.201
Current Income Tax	IS_CURRENT_INCOME_TAX_BENEFIT	40481.00	45038.00	58120.00
Growth (YoY)	IS_CURRENT_INCOME_TAX_BENEFIT	19.554	11.257	29.047
Deferred Income Tax	IS_DEFERRED_INCOME_TAX_BENEFIT	2741.00	-40794.00	-9645.00
Growth (YoY)	IS_DEFERRED_INCOME_TAX_BENEFIT	-18.057	—	76.357

Appendix 3. Certificate of attendance in international young researcher's conference

International Young Researchers Conference

Nr. V24-11-1

INDUSTRIAL engineering 2021

Certificate

This certificate confirms that

Rolandas Avizovas

attended in International Young Researchers Conference
"Industrial Engineering 2021" and published the paper

The Influence of Clay Chemical Composition on Freeze and Thaw Properties of Clay Paving Bricks

in the conference notification material

Dean of the Faculty of
Mechanical Engineering
and Design
dr. Andrius Vilkauskas

ktu
faculty of mechanical engineering and design