



Modestas KLIGYS

PRODUCTION TECHNOLOGY AND PROPERTIES OF COMPOSITE MATERIAL MADE OUT OF POROUS CEMENT PASTE AND CRUSHED EXPANDED POLYSTYRENE

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
MATERIALS ENGINEERING (08T)

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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Doctoral dissertation was prepared at Vilnius Gediminas Technical University Institute of Thermal Insulation in 2005–2009.

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Modestas KLIGYS

KOMPOZITINĖS MEDŽIAGOS
IŠ PORINGOSIOS CEMENTO TEŠLOS
IR TRUPINTO POLISTIRENINIO
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Introduction

Topicality of the problem. The European Union (EU) pays a great attention to the environmental problems and pollution. Lithuania has been a full EU member for five years, however, there was not much done for sorting and recycling waste in our country. As before, the waste expanded polystyrene (EPS) packages is simply disposed of in the dumping grounds.

One of the ways to reduce the amounts of mentioned waste is its inclusion in a new composite material with porous cement paste as matrix. The good properties of the composite material may be ensured only by crushing the waste to a required size. Even in case the required size is achieved, the application and availability is limited. Due to low density and hydrophobic nature, waste EPS is poorly coated by cement paste in the course of mixing and is apt to rise up to surface of formative mixture and segregation.

Subject of research. The subject of research of current work is composite material made out of porous cement paste and crushed waste EPS packages and also separate components of mentioned material.

Methodology of research. Experimental researches of surfactant water solutions, fresh and hardened cement paste and samples of composite material with different density were done. Empirical equations, which stand in limits of experiments, were obtained using the methods of statistical analysis.

Importance of the Work. Using surfactants, it is possible to eliminate hydrophobic nature of inclusions and to reduce density of matrix (form air voids in it). In development of such a composite material, the density and other properties of which are determined in many cases by matrix density, it is important. To the aim of developing such a lightweight composite material, one should thoroughly select compositions of formative mixtures and technological parameters of production what cannot be done without investigation of the whole composite material and its separate components.

The air voids present in the matrix also serve as inclusions. The duration of their formation and existence in the formative mixture is subject to its individual properties, as well as many technological factors. It is a complicated matter to develop the composite material with inclusions of two types dominating and to predict its properties.

Main objective – to develop a composite material with density of 150, 250 and 350 kg/m³ where porous cement paste serves as matrix and crushed waste EPS packages serve as inclusions. To select the compositions of formative

mixtures and technological parameters of production for this composite material and to investigate its properties. To achieve the objective of the work, the following *main tasks* should be solved:

1. To investigate the properties of surfactant water solutions of different type and concentration and their influence on adhesion between matrix and inclusions of composite material.
2. To investigate the influence of surfactant additives of different type and concentration and technological parameters on porosity degree of composite material matrix. Basing on research results, to select the most effective surfactant additive, its concentration, mixer type and optimal mixing time.
3. To select the compositions of formative mixtures with composite material with density of 150, 250 and 350 kg/m³ and mixing parameters.
4. To establish the properties of composite material in the samples of different density, such as density, macro- and microstructure, compressive and bending strength, behavior under point load, thickness for floating floor, thermal resistance coefficient, water absorption due capillary action, water vapour transmission coefficient, hygroscopic sorption, drying shrinkage, frost resistance and combustibility.
5. To develop a technological production scheme for the composite material out of porous cement paste and crushed waste EPS packages.

Scientific novelty. While preparing the dissertation, the following new results in material engineering science were received:

1. The properties of surfactant water solutions of different type (anionic, anionic-nonionic) and concentration (0.033–0.297%) were investigated and the work of adhesion of these solutions on hydrophobic surface of paraffin wax was estimated what enabled as well to predict the process of coating-by-matrix of hydrophobic inclusions out of waste EPS packages.
2. Basing on the research results, there was established the most effective surfactant additive (“Ufapore TCO”) and its optimal concentration (0.03% of Portland cement mass), which ensured the sufficient degree of matrix porosity and its close contact with EPS inclusions, to which the uniformity of all composite material is subject.
3. The one-stage method of hydrophilization and mixing was developed for the composite material components in the vertical type mixer.

4. The compositions of formative mixtures out of composite material with density of 150, 250 and 350 kg/m³ containing porous cement paste and waste EPS packages were developed.
5. The dependences were established between structure of composite material with different density and its other properties, such as density, compressive and bending strength, behaviour under point load, thickness for floating floor, thermal resistance coefficient, water absorption due capillary action, relative vapour resistance coefficient, hygroscopic sorption, drying shrinkage, frost resistance and combustibility.

Practical value. The composite material with density of 150, 250 and 350 kg/m³ out of porous cement paste and crushed waste EPS packages was developed. It can be used for thermal insulation of floor, wall and roof structures in living and industrial buildings. The production technology of the mentioned composite material does not require any complex equipment; therefore, the composite material of required density can be formed in the building plot while installing a layer of thermal insulation in building structures.

Defended propositions

1. The porosity degree of formative mixture of composite material matrix is determined by work of adhesion of surfactant water solution.
2. The hydrophilization of inclusions ensures their good distribution in the whole volume of composite material and their close contact with matrix.
3. It is possible to produce effective units of thermo-insulating composite material when the matrix is foamed correctly and the size and quantity of inclusions out of waste EPS packages are chosen correctly and hydrophilized.

Scope of scientific work. The scientific work consists of a general characteristic of dissertation, an introduction, 6 chapters, conclusions, a list of literature and a list of publications. The total scope of dissertation makes 152 pages, 22 numbered formulas, 77 pictures and 10 tables. 191 source of literature was used while preparing the dissertation.

1. Analysis of references

Analysis of references showed that surfactants because of their unique properties are widely used in many industrial branches. Increase in effectiveness of technological processes and amelioration of quality of the final

product caused the popularity of surfactants. Research of scientific works shows that the influence of different technological factors on the hydrophilization processes of inserts of composite material, air void distribution in its matrix and quality indexes of composite material products have been estimated only experimentally, because these problems were not investigated enough.

2. Used materials and research methodology

The surfactant water solutions were prepared from distilled water and following surfactants: “Ufapore CC 85”, “Ufapore TP 707”, “Upafore CC”, “Ufapore TCO”, “PB-2000” and sulfonol with bone glue. Their concentration was 0.033, 0.099, 0.165, 0.231 and 0.297%, what corresponds the surfactant concentrations of 0.01, 0.03, 0.05, 0.07 and 0.09% in cement paste with W/C = 0.3 (counting of Portland cement mass). The concentrations of surfactant water solutions were evaluated considering the content of active material in the surfactant. The surface tension of surfactant water solutions of different type and concentration was measured by Rebinder apparatus and the contact angle by fixing the position of a drop on surface of paraffin wax by means of the projector “Varimex” and the digital camera “Canon”. The work of adhesion (W_{Ad}) of surfactant water solutions is calculated by the following formula:

$$W_{Ad} = \sigma_{lv} (1 + \cos \theta), \quad (1)$$

where σ_{lv} – liquid surface tension, N/m; θ – contact angle in the solid-liquid-vapour contact region, °

For formation of cement paste (W/C = 0.3), Portland cement CEM I 42.5 R mark from SC “Akmenės cementas” was used, as well as technical water and mentioned surfactants. The concentration of surfactants was 0.01, 0.03, 0.05, 0.07 and 0.09% (of Portland cement mass). The concentrations of surfactants were also evaluated considering the content of active material in the surfactant. The components of cement paste were mixed in the horizontal or vertical type mixer. The density of fresh cement paste (ρ_c) was established according to known methodology. The effect of surfactant on hydration of Portland cement was determined according to the research technique of corporation “Alcoa” based on EN-196. The density of hardened cement paste samples (ρ_{ca}) was also established according to known methodology. The pore volume and diameter of hardened cement paste samples were measured using the mercury pore measurer with the software “Poremaster 33”.

For formation of composite material samples, the surfactant “Ufapore TCO” of 0.03% (of Portland cement mass), and crushed waste EPS packages

from JSC “Virginijus and Co” were used as inclusions. The components of composite material were mixed in the vertical type mixer. The compositions of formative mixtures are shown in Table 1.

Table 1. Compositions of formative mixtures out of composite material

Density, kg/m ³	Size of inclusions, mm	Portland cement:inclusions (by mass), %	W/C
150	Not more than 5.0	83:17	0.80
250	Less than 20.0	91:9	0.65
350	Less than 20.0	94:6	0.50

The properties of composite material samples were established in accordance with: LST EN 1602, LST EN 826, LST EN 12089, LST EN 12430, LST EN 12431, LST EN 12664, LST EN 772-11+A1, LST EN 12086, LST EN ISO 12571, LST EN 680, LST EN 15304, LST EN ISO 11925-2, LST EN 13823 and LST EN ISO 1182 standards. The macrostructure was investigated by optical microscope with camera “Motic”. The microstructure was analyzed by scanning electron microscope “EVO 50”, and the X-ray analysis was done by the diffractometer “Dron-2” (Co anode and Fe filter).

The experimental results were analyzed by using the software packages “Microsoft Excel”, “OriginPro 7.5” and “Statistica 6.0”.

3. Investigation of surfactant water solutions

After determination of values of surface tension and contact angle in the surfactant water solutions, the work of adhesion was calculated according to formula 1 (Fig. 1).

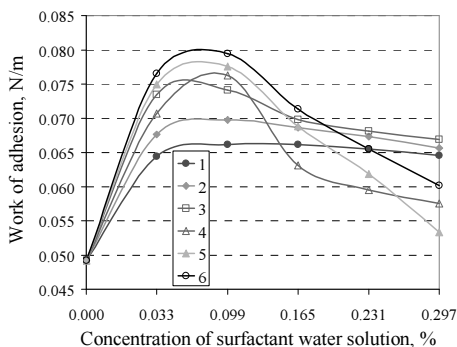


Fig. 1. Influence of surfactant type and concentration on average value of work of adhesion of water solution: 1 – sulfonol with bone glue; 2 – “Ufapore CC 85”; 3 – “PB-2000”; 4 – “Ufapore TP 707”; 5 – “Ufapore CC”; 6 – “Ufapore TCO”

The higher is the value of work of adhesion the better will be the wettability of solid by liquid. And vice versa, when the value of work of adhesion is low, the wettability of solid by liquid will be poor. It was established that the value of work of adhesion of pure distilled water is 0.049 N/m. With concentration of 0.099% for surfactants of all types, the highest values of work of adhesion were achieved. These values vary within 0.079–0.066 N/m range. Along with increase of concentration of surfactant, the values of work of adhesion decrease, but still are higher comparing with those of pure distilled water. The highest values of work of adhesion of solutions are achieved using the surfactant “Ufapore TCO” and they vary within 0.077–0.071 N/m range, while the concentration of mentioned surfactant is varying within 0.033–0.165% range.

4. Investigation of fresh and hardened cement paste

It was established that the optimal concentration of surfactant water solutions, which ensures the maximum value of work of adhesion, is 0.099%. In cement paste (W/C = 0.30) this concentration of surfactant equals to 0.03% (counting of Portland cement mass). The curves for variation of density in fresh cement paste subject to mixing time are presented to compare and estimate the effectiveness of surfactant type and mixer design when the concentration of surfactants of all types is 0.03%. The analysis of results showed that the most effective is the surfactant “Ufapore TCO”, notwithstanding the type of mixer, horizontal or vertical (Fig. 2).

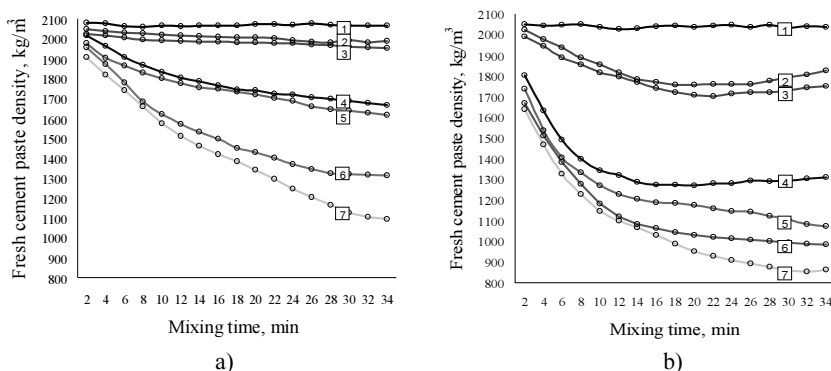


Fig. 2. Influence of surfactant type and mixing time in the horizontal (a) or vertical (b) type mixer on variation of density in fresh cement paste when the concentration of surfactant is 0.03%: 1 – without surfactant; 2 – sulfonol with bone glue; 3 – “Ufapore CC 85”; 4 – “PB-2000”, 5 – “Ufapore TP 707”, 6 – “Ufapore CC”; 7 – “Ufapore TCO”

It was also established that using any mentioned surfactant, the vertical type mixer was more effective than horizontal. With the concentration of surfactant of 0.03%, the density of fresh cement paste being mixed in the vertical type mixer for 10 minutes decreases to 1147 kg/m³. It is lower by 77.5% versus the density research results for fresh cement paste without surfactant.

The analysis of results shows that the density of fresh cement paste (ρ_{ct}) predetermines the density of hardened cement paste (ρ_{ca}). It was established that using surfactants of all types with same concentration, the decrement of density in the samples of hardened cement paste after mixing fresh cement paste in the vertical type mixer was higher versus that of samples received in the horizontal one. The interrelation of these densities, when fresh cement paste mixed in the vertical type mixer, is expressed in the following equation:

$$\rho_{ca} = -25.4327 + 0.9651 \cdot \rho_{ct}, \quad (2)$$

where ρ_{ct} – density of fresh cement paste, kg/m³; ρ_{ca} – density of hardened cement paste, kg/m³.

The standard error of estimate ($s_e = 27.21$ kg/m³) and determination ratio ($R^2 = 0.994$) of this equation show that the variation of density in hardened cement paste is subject averagely by 99% to density of fresh cement paste. The influence of fresh cement paste density on that of hardened cement paste when mixed in the vertical type mixer is shown in Fig. 3.

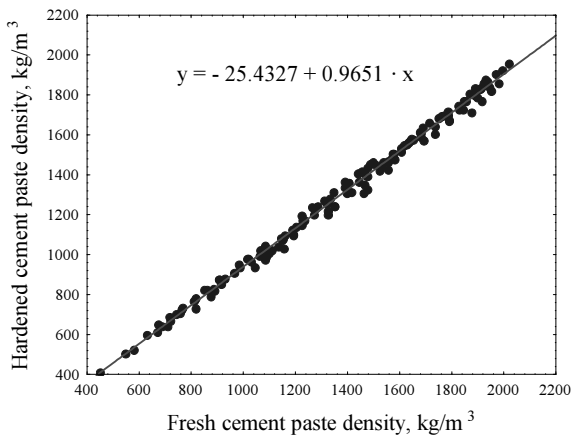


Fig. 3. Influence of fresh cement paste density on hardened cement paste density when mixed in the vertical type mixer

It was established that the surfactant “Ufapore TCO”, the concentration of which varies in fresh cement paste within 0.01–0.05% (of Portland cement mass), increases the maximal temperature of Portland cement hydration and practically does not retard the mentioned process (Fig. 4).

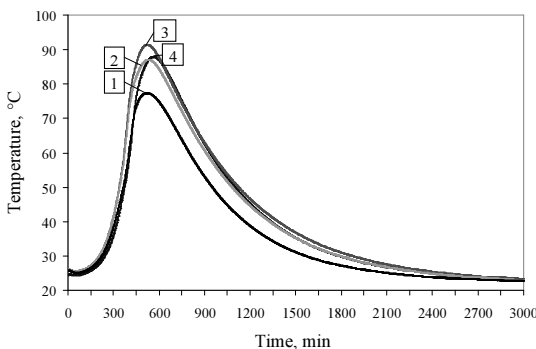


Fig. 4. Curves of exothermal reactions of hydration process of Portland cement:
1 – without surfactant; 2 – 0.01%; 3 – 0.03%; 4 – 0.05%

The analysis of results shows that the influence of surfactants of various types with same concentration on porosity of hardened cement paste differs. The research as to porosity of hardened cement paste shows that the highest theoretical porosity (58.3%) was obtained with the surfactant “Ufapore TCO” (the concentration of 0.03% for surfactants of all types in fresh cement paste, counting of Portland cement mass). Other properties of porosity in hardened cement paste with the mentioned surfactant were as follows: total intruded volume – 0.2571 cm³/g, total surface area – 6.1441 m²/g, total porosity – 21.5%. It was also found out that using the surfactant “Ufapore TCO”, the pores with 0.13–1.70 μm and 5.00–13.00 μm diameter prevailed in hardened cement paste.

5. Determination of properties of composite material

The analysis of macrostructure shows that the inclusions sized not more than 5.0 mm in the samples with the lowest density are coated by an extremely thin layer of matrix. In the matrix no air voids, which could have been formed due to used surfactants, were detected. The voids between inclusions are interconnected (Fig. 5, a). The inclusions sized less than 20.0 mm in the samples of higher density were coated by a thicker layer of matrix. The observed air voids of various diameters in the matrix have been formed due to

application of surfactant. The voids between inclusions are filled by matrix (Fig. 5, b).



Fig. 5. Macrostructure of composite material (enlarged by 25 times):
a) sample with density of 150 kg/m³; b) sample with density of 350 kg/m³

The analysis of microstructure of composite material shows that the inclusions are well coated by matrix and the contact between matrix and inclusions is close (Fig. 6, a and b).

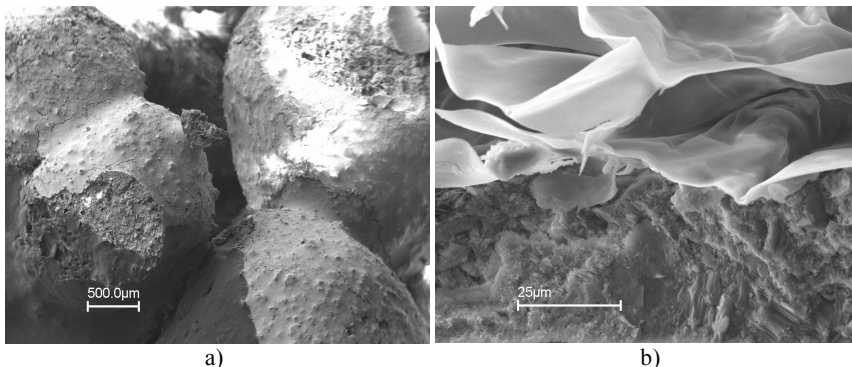


Fig. 6. Microstructure of composite material: a) inclusions coated by matrix;
b) contact region between matrix and inclusions

Basing on the stress and strain curves typical to composite material samples with density of 150, 250 and 350 kg/m³, it is possible to maintain that the strains occurring during compression are typical to elastic (Fig. 7, 1 curve), plastic (Fig. 7, 2 curve) and brittle materials (Fig. 7, curve 3).

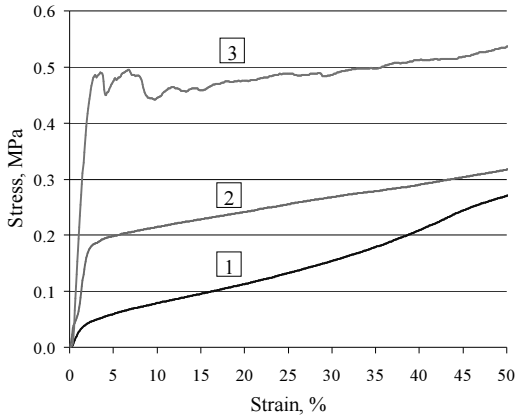


Fig. 7. Stress and strain curves of composite material samples with different density when strained by 50%: 1 – 150 kg/m³; 2 – 250 kg/m³; 3 – 350 kg/m³

The analysis of literature sources showed that the values of mechanical properties increase along with increase of density in the samples, and are more stable in the samples of lower density. This tendency is also observable with the mechanical properties of composite material samples where density was of 150, 250 and 350 kg/m³ (Fig. 8, a and b).

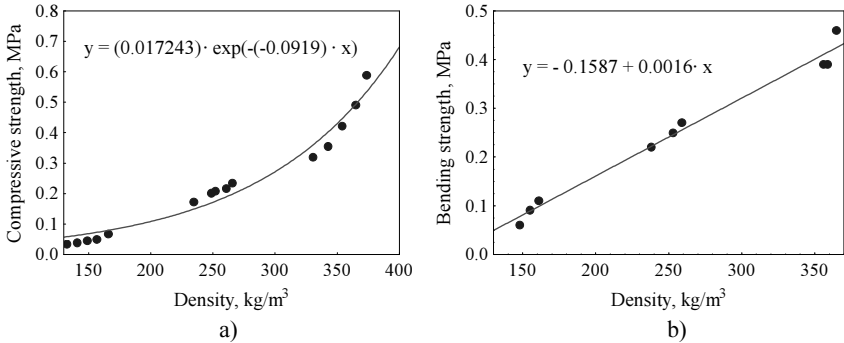


Fig. 8. Relationship between mechanical properties and density of composite material samples: a) compressive strength; b) bending strength

The operational properties of composite material samples are subject to structure and density. The fewer inclusions in the volume of samples with higher density, the higher values of thermal conductivity coefficient and relative

vapour resistance coefficient and vice versa. The interconnected voids between inclusions in the samples of lower density also predetermine lower coefficients of thermal conductivity and relative vapour resistance versus the not interconnected voids formed due to action of surfactant in the matrix of higher density ones (Fig. 9, a and b).

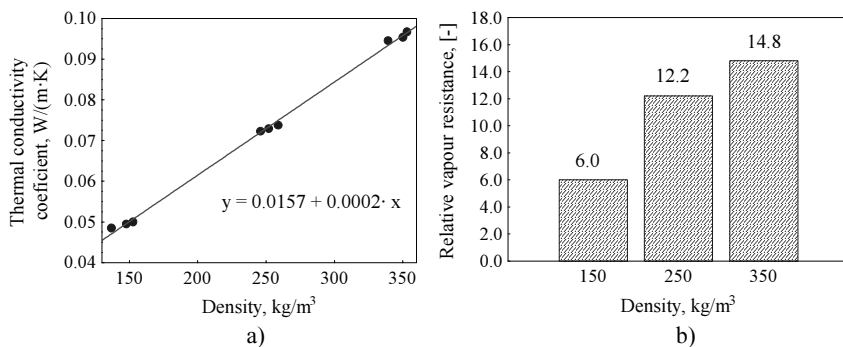


Fig. 9. Relationship between operational properties and density in the samples of composite material: a) thermal conductivity coefficient; b) relative vapour resistance coefficient

The analysis of combustibility research results showed that the samples of composite material with density of 150, 250 and 350 kg/m^3 could be allocated to combustibility class B-s1, d0 (Fig. 10).

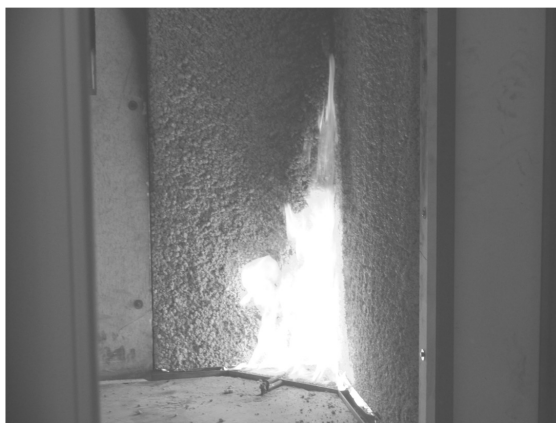


Fig. 10. Sample of composite material with density of 350 kg/m^3 during the combustibility test

6. Production technology of composite material

The two stage crushing technology and equipment for waste EPS packages was developed in pursue of the international project “EUREKA”, the program “E! 3446-SANDPLAST” (Fig. 11).



Fig. 11. Crushing line for waste EPS packages:

1 – first stage crusher; 2 – screw transporter; 3 – second stage crusher; 4 – bunker

The analysis of models of production for such a composite material showed that they consist of two stages. Mixing all components of composite material together, the production of composite material may be simplified by omitting an additional processing of EPS inclusions. The hydrophobic nature of crushed waste EPS packages is eliminated with the help of the surfactant while mixing the formative mixture of composite material.

General conclusions

1. The investigated properties of different surfactant type and concentration water solutions allowed to estimate the maximum value of work of adhesion, which ensures the good coating of hydrophobic composite material inclusions by matrix and the effective air void formation in it. The highest values for work of adhesion in surfactant water solutions were obtained at concentration of 0.099%.
2. The research results showed that all surfactants reduce the density of cement paste most intensely (by forming air voids) during first 10 minutes of mixing. It was established that subject to type of surfactant and mixing time, the effectiveness of vertical type mixer was higher versus horizontal one. The interaction between density of fresh cement paste (ρ_{ct}) and density of hardened cement paste (ρ_{ca}) when mixed in a

- more effective type mixer may be expressed in the following equation:
 $\rho_{ca} = -25.4327 + 0.9651 \cdot \rho_{ct} \ (R^2 = 0.994, s_e = 27.21 \text{ kg/m}^3)$.
3. The compositions were selected for formative mixtures of composite material with density of 150, 250 and 350 kg/m³ and the one stage mode of production was developed what enabled to omit an additional processing of hydrophobic surface of inclusions. The following technological parameters for that composite material are recommended:
 - vertical type mixer and mixing time of 8 minutes;
 - content of 0.03% of surfactant “Ufapore TCO” (of Portland cement mass);
 - V/C of 0.80, 0.65 and 0.50 according to density of samples;
 - size of inclusions, not more than 5.0 mm for samples with density of 150 kg/m³ and less than 20.0 mm for those with density of 250 and 350 kg/m³.
 4. The composite material was developed, the density of 150, 250 and 350 kg/m³, and porous cement paste served as matrix, while crushed waste expanded polystyrene (EPS) packages served as inclusions. The research into structure of samples showed that the mentioned surfactant and mixer ensured the good distribution of hydrophobic inclusions through the whole volume of sample, as well as the close contact between matrix and inclusions.
 5. The properties of composite material samples with density of 150, 250 and 350 kg/m³ were investigated what enable during the design to evaluate the technical parameters of the mentioned material for application of it in enclosure structures for buildings. The main properties of samples with mentioned density are the following:
 - compressive strength – 0.05, 0.20 and 0.42 MPa;
 - bending strength – 0.08, 0.25 and 0.39 MPa;
 - thermal conductivity coefficient – 0.0493, 0.0730 and 0.0955 W/m·K;
 - water absorption due capillary action coefficient varies within (269.6–104.3), (137.7–59.6) and (55.1–24.2) g/m²·s^{0.5} ranges;
 - relative vapour resistance coefficient – 6.0, 12.2 and 14.8;
 - the samples may be allocated to combustibility class B-s1, d0.
 6. The technological scheme for production of the new composite material was developed and the two stage crushing line for waste EPS packages was implemented. These factors permit to offer cheaper products for market of thermal insulation materials comparing with other analogous products.

List of published works on the topic of the dissertation
In the reviewed scientific periodical publications

Kligys, M.; Laukaitis, A.; Sinica, M.; Sezemanas, G. 2007. The influence of some surfactants on porous concrete properties, *Materials Science (Medžiagotyra)* 13(4): 310–316. ISSN 1392-1320 (Inspec).

Kligys, M.; Laukaitis, A.; Sinica, M.; Sezemanas, G.; Dranseika, N. 2008. Investigations into the fire hazard of a composite made from aerated concrete and crushed expanded polystyrene waste, *Mechanics of Composite Materials* 44(2): 173–180. ISSN 0191-5665 (Springer).

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KOMPOZITINĖS MEDŽIAGOS IŠ PORINGOSIOS CEMENTO TEŠLOS IR TRUPINTO POLISTIRENINIO PUTPLASČIO GAMYBOS TECHNOLOGIJA IR SAVYBĖS

Tiriamoji problema. Lietuva jau 5 metus yra visateisė Europos Sąjungos narė, kurioje skiriama daug dėmesio aplinkosaugai, tačiau darbų, skatinančių atliekų rūšiavimą ir jų perdirbimą, mūsų šalyje atlikta nedaug. Polistireninio putplasčio (PPS) pakavimo taros atliekos tiek anksčiau, tiek dabar vežamos į šalies sąvartynus.

Vienas iš būdų, leidžiančių mažinti minėtų atliekų kiekį, gali būti jų, kaip intarpų, panaudojimas naujoje kompozitinėje medžiagoje, kurioje matrica yra poringoji cemento tešla. Norint užtikrinti geras jos gaminių savybes, galima šias atliekas smulkinti iki reikiamo dydžio. Net ir tinkamai susmulkintų minėtų atliekų panaudojimas, o kartu ir populiarumas, yra ribotas. Maišymo metu dėl mažo tankio ir hidrofobiškumo jos blogai dengiasi cemento tešla, iškyla į formavimo mišinio paviršių, todėl jis išsisluoksniuoja.

Tyrimo objektas. Darbo tyrimo objektas yra kompozitinė medžiaga iš poringosios cemento tešlos ir trupintų PPS pakavimo taros atliekų ir atskiros jos sudedamosios dalys.

Tyrimo metodika. Atlikti APM vandeninių tirpalų, cemento tešlos ir cemento akmens bei skirtingo tankio kompozitinės medžiagos bandinių eksperimentiniai tyrimai. Statistinės analizės metodais gautos empirinės lygtys, galiojančios eksperimento ribose.

Darbo aktualumas. Aktyviųjų paviršiaus medžiagų (APM) naudojimas padeda panaikinti tarpų hidrofobę prigimtį ir sumažinti matricos tankį (formuojant oro tuštumas joje). Tai svarbu kuriant kompozitinę medžiagą, kurios tankį ir kitas savybes daugeliu atvejų lemia būtent matricos tankis. Norint sukurti tokią lengvą kompozitinę medžiagą, reikia kruopščiai parinkti optimalias formavimo mišinių sudėtis ir gamybos technologinius parametrus. To neįmanoma padaryti be jos sudedamųjų dalių ir visos kompozitinės medžiagos tyrimo.

Matricoje esančios oro tuštumos taip pat yra tarpai. Jų susidarymas ir egzistavimo trukmė formavimo mišinyje priklauso nuo individualių mišinio savybių ir daugelio technologinių veiksnių. Sukurti tokią kompozitinę medžiagą, kurioje vyrauja dviejų rūšių tarpai, ir prognozuoti jos savybes yra labai sudėtinga.

Darbo tikslas – sukurti 150, 250 ir 350 kg/m³ tankio kompozitinę medžiagą, kurioje matrica yra poringoji cemento tešla, o tarpai – trupintos (PPS) pakavimo taros atliekos. Parinkti minėtos kompozitinės medžiagos formavimo mišinių sudėtis, gamybos technologinius parametrus ir iširti jos bandinių savybes. Darbo tikslui pasiekti reikia spręsti šiuos **uždavinius**:

1. Ištirti skirtingos rūšies ir koncentracijų vandeninių APM tirpalų savybes ir jų poveikį sukibčiai tarp kompozitinės medžiagos matricos ir tarpų.
2. Ištirti skirtingos rūšies ir koncentracijų APM priedų ir technologinių veiksnių poveikį kompozitinės medžiagos matricos porizacijai. Remiantis tyrimų rezultatais parinkti patį efektyviausią APM priedą ir jo koncentraciją bei maišymo įrenginį ir optimalią maišymo trukmę jame.
3. Parinkti 150, 250 ir 350 kg/m³ tankio kompozitinės medžiagos formavimo mišinių sudėtis ir maišymo parametrus.
4. Nustatyti skirtingo tankio kompozitinės medžiagos bandinių savybes: tankį, makro- ir mikrostruktūrą, gniuždomąjį ir lenkiamąjį stiprį, sutelktosios apkrovos poveikį, spūdumą, šilumos laidumo koeficientą, kapiliarinės įgerties koeficientą, laidumo vandens garams koeficientą, higroskopinę sorbciją, džiūstamąjį susitraukimą, atsparumą šalčiui ir degumą.

5. Sukurti kompozitinės medžiagos iš poringosios cemento tešlos ir trupintų PPS pakavimo taros atliekų gamybos technologinę schemą.

Darbo mokslinis naujumas. Rengiant disertaciją buvo gauti šie medžiagų inžinerijos mokslui nauji rezultatai:

1. Ištirtos skirtingos rūšies (anijoninės, anijoninės-nejoninės) ir koncentracijų (0,033–0,297 %) vandeninių APM tirpalų savybės ir apskaičiuotas jų sukibties darbas ant hidrofobinio parafino paviršiaus, leidžiantis numatyti taip pat hidrofobinių intarpų iš PPS pakavimo taros atliekų dengimą matrica.
2. Remiantis tyrimų rezultatais nustatytas efektyviausias APM priedas („Ufapore TCO“) ir optimali jo koncentracija (0,03 %, skaičiuojant nuo portlandcemenčio masės), užtikrinantys pakankamą matricos porizaciją ir gerą jos sąlytį su PPS intarpais, nuo kurio priklauso visos kompozitinės medžiagos vienalytiškumas.
3. Sukurtas vienos stadijos kompozitinės medžiagos sudedamųjų dalių hidrofilizacijos ir sumaišymo vertikalioje maišyklėje būdas.
4. Sukurtos 150, 250 ir 350 kg/m³ tankio kompozitinės medžiagos iš poringosios cemento tešlos ir PPS pakavimo taros atliekų formavimo mišinių sudėtys.
5. Nustatytos priklausomybės tarp skirtingo tankio kompozitinės medžiagos struktūros ir kitų jos savybių: tankio, gniuždomojo ir lenkiamojo stiprių, sutelktosios apkrovos poveikio, spūdumo, šilumos laidumo koeficiento, kapiliarinės įgerties koeficiento, laidumo vandens garams koeficiento, higroskopinės sorbcijos, džiūstamojo susitraukimo, atsparumo šalčiui ir degumo.

Darbo rezultatų praktinė reikšmė. Sukurta 150, 250 ir 350 kg/m³ tankio kompozitinė medžiaga iš poringosios cemento tešlos ir trupintų PPS pakavimo taros atliekų, kuri gali būti naudojama gyvenamųjų ir pramoninių pastatų grindų, sienų ir stogų konstrukcijų apšiltinimui. Jos gamybos technologija nereikalauja sudėtingų gamybos įrenginių, todėl pastatuose, įrengiant šilumos izoliacijos sluoksnį, reikiamo tankio kompozitinę medžiagą galima suformuoti statybos aikštelėje.

Ginamieji teiginiai

1. Kompozitinės medžiagos matricos formavimo mišinio porizacijos laipsnį lemia APM tirpalo sukibties darbas.
2. Intarpų hidrofilizacija užtikrina gerą jų pasiskirstymą kompozitinės medžiagos tūryje ir glaudų sąlytį su matrica.

3. Tinkamai porizavus matricą ir parinkus tam tikro dydžio interpus iš trupintų PPS pakavimo taros atliekų bei jų kiekius ir šiuos interpus hidrofilizavus, galima pagaminti efektyvius termoizoliacines kompozitines medžiagos gaminius.

Disertacijos struktūra. Disertaciją sudaro įvadas, šeši skyriai, bendrosios išvados, naudotos literatūros ir autoriaus publikacijų disertacijos tema sąrašai. Darbo apimtis – 152 puslapiai, tekste panaudotos 22 numeruotos formulės, 77 iliustracijos ir 10 lentelių. Rašant disertaciją panaudotas 191 literatūros šaltinis.

Įvadiniamame skyriuje aptariama tiriamoji problema, tyrimo objektas ir tyrimo metodika, darbo aktualumas, formuluojamas darbo tikslas bei uždaviniai, aprašomas darbo mokslinis naujumas, nurodoma darbo rezultatų praktinė reikšmė, įvardijami ginamieji teiginiai, pristatomos disertacijos tema autoriaus paskelbtos publikacijos ir pranešimai konferencijose ir nurodoma disertacijos struktūra. Pirmasis skyrius skirtas literatūros apžvalgai. Antrajame skyriuje aprašyta naudotų žaliavų savybės, formavimo mišinių paruošimas ir bandinių eksperimentams formavimas, tyrimų metodikos. Trečiajame skyriuje pateikiami vandeninių APM tirpalų savybių tyrimai. Ketvirtajame skyriuje pateikiami APM rūšies ir koncentracijos bei maišyklės konstrukcijos ir maišymo trukmės poveikio cemento tešlos ir cemento akmens tankio pokyčiui tyrimai. Penktajame skyriuje pateikiami 150, 250 ir 350 kg/m³ tankio kompozitines medžiagos bandinių savybių tyrimai. Šeštajame skyriuje pateikiama kompozitines medžiagos gamybos technologija.

Bendrosios išvados

1. Ištirtos skirtingos rūšies ir koncentracijų vandeninių aktyviųjų paviršiaus medžiagų (APM) tirpalų savybės leido nustatyti maksimalų sukibties darbą, užtikrinantį gerą hidrofobinių kompozitines medžiagos tarpų dengimą matrica ir efektyvų oro tuštumų formavimą joje. Didžiausios vandeninių APM tirpalų sukibties darbo vertės gautos jų koncentracijai esant 0,099 %.
2. Tyrimų rezultatai rodo, kad visos APM intensyviausiai mažina cemento tešlos tankį (jį porizuoja) per pirmąsias 10 maišymo minučių. Nustatyta, kad, priklausomai nuo APM rūšies ir maišymo trukmės, vertikalios maišyklės efektyvumas yra didesnis nei horizontalios. Cemento tešlos tankio (ρ_{ct}) ir cemento akmens tankio (ρ_{ca}) tarpusavio ryšys, maišant efektyvesne maišykle, išreiškiamas $\rho_{ca} = -25,4327 + 0,9651 \cdot \rho_{ct}$ lygtimi ($R^2 = 0,994$, $s_e = 27,21 \text{ kg/m}^3$).

3. Parinktos 150, 250 ir 350 kg/m³ tankio kompozitinės medžiagos formavimo mišinių sudėtys ir sukurtas vienos stadijos jos gamybos būdas, leidžiantis atsisakyti papildomo hidrofobinių intarpų paviršiaus apdirbimo proceso. Rekomenduojami tokios kompozitinės medžiagos gamybos technologiniai veiksniai yra šie:
 - vertikali maišyklė ir maišymo trukmė joje – 8 min.;
 - „Ufapore TCO“ APM kiekis – 0,03 % (skaičiuojant nuo portlandcemenčio masės);
 - V/C – 0,80, 0,65 ir 0,50 atitinkamai bandinių tankiui;
 - intarpų dydis – ne didesnis kaip 5,0 mm – 150 kg/m³ tankio bandiniams ir mažesnis kaip 20,0 mm – 250 ir 350 kg/m³ tankio bandiniams.
4. Sukurta 150, 250 ir 350 kg/m³ tankio kompozitinė medžiaga, kurioje matrica – poringoji cemento tešla, o intarpai – trupintos polistireninio putplasčio (PPS) pakavimo taros atliekos. Jos bandinių struktūros tyrimai rodo, kad naudojant minėtą APM ir maišyklę yra užtikrinamas geras hidrofobinių intarpų pasiskirstymas visame bandinio tūryje ir gaunamas glaudus sąlytis tarp matricos ir intarpų.
5. Atlikti 150, 250 ir 350 kg/m³ tankio minėtos kompozitinės medžiagos bandinių savybių tyrimai leidžia projektuojant įvertinti jos techninius rodiklius, sprendžiant panaudojimo skirtingose pastatų atitvarų konstrukcijose galimybes. Pagrindinės minėto tankio bandinių savybės yra šios:
 - gniuždomasis stipris – 0,05, 0,20 ir 0,42 MPa;
 - lenkiamasis stipris – 0,08, 0,25 ir 0,39 MPa;
 - šilumos laidumo koeficientas vidutinėje 10 °C temperatūroje – 0,0493, 0,0730 ir 0,0955 W/m·K;
 - kapiliarinės įgerties koeficientas kinta atitinkamai (269,6–104,3), (137,7–59,6) ir (55,1–24,2) g/m²·s^{0,5} ribose;
 - santykinės garinės varžos koeficientas – 6,0, 12,2 ir 14,8;
 - bandinius galima priskirti B-s1, d0 degumo klasei.
6. Sukurta naujos kompozitinės medžiagos gamybos technologinė schema ir įdiegta PPS pakavimo taros atliekų trutinimo technologinė linija. Šie veiksniai sudaro galimybę termoizoliacinių medžiagų rinkai pasiūlyti pigesnius gaminis lyginant su kitais rinkoje esančiais analogiškais gaminiais.

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PRODUCTION TECHNOLOGY AND PROPERTIES OF
COMPOSITE MATERIAL MADE OUT OF POROUS CEMENT PASTE
AND CRUSHED EXPANDED POLYSTYRENE

Summary of Doctoral Dissertation
Technological Sciences, Materials Engineering (08T)

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IR SAVYBĖS

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