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RESEARCH ON SAND-LIME PRODUCTS REGARDING THEIR PHYSICAL AND MECHANICAL FEATURES

Abstract

In this article, the main goal of conducted experiments was focused on determination of physical and mechanical features of examined sand-lime building blocks and how they interact with each other. The experiment was conducted using solid sand-lime bricks of 250 x 180 x 220 mm size of the class 15 as well as modified products of the same size but different structure.

The investigation covered different kinds of fillers. From the preliminary technical and economical analysis we may state that the best ones are barite, basalt, hematite and magnetite.

Keywords: Sand-lime brick, acoustic isolation, fillers, basalt

1. Introduction

Sand-lime products are used as an engineering material of ultimate compressive strength. They are completely natural. Their main ingredients are: sand, lime and water. They are environmentally friendly. Sand-lime bricks are popular in many countries e.g. Scandinavia, Germany, the Netherlands, France, Italy, Spain, Great Britain or Russia. Moreover, thanks to their considerable weight, they are characterised by high acoustic isolation [1, 2].

Due to their strong alkaline reaction, sand-lime bricks are resistant to biological corrosion in closed places. They provide friendly climate and protect against the spread of mould and bacterial flora. They also posses very good features regarding the thermal building regulations. It is due to their ability to accumulate heat and humidity.

Based on current standards (PN-EN 772-9, 10, 11, 13, 18), various hypothesis have been formulated. They became the basis for further research on sand-lime products. One of them was formulated, if weight modification of a sand-lime product (without changing its capacity) will cause major improvement of both physical and strength features.

Another important aspect of sand-lime products is acoustic isolation (apart from water absorption, humidity, density and soaking). But the acoustic isolation clearly depends on the structure and material used. Heavy dams ensure sound absorbance. However, it is not related to dimensions of walls, but to the weight of that kind of dams. Very important is the weight possessed by used material per 1 m^2.

Another question to be answered is, if the infringement in product's structure which considers an insertion of fillers into sand-lime production had any impact and what their influence on physical parameters and strength features of modified units is. Another question to be investigated was, if an insertion of fillers into the sand-lime has an impact on physical parameters and durability of modified units.

It is commonly known, that sand-lime products belong to a group of materials characterised by very good acoustic isolation. Therefore, any interference with their inner structure (by various kinds of fillers) may cause formation of new structures and bonds. They may have an impact not only on interaction between the of certain units and its structure as a whole. That involves works on that involves the tightness and porosity of the material. They determine most of the features such as for example: ultimate compressive strength, acoustic isolation and frost-resistance.

It may happen that improvement of one of those features may cause deterioration of others. Therefore, it is necessary to consider if it is appropriate to interfere with anything that is fine and completely natural.

In this article, the aim of conducted experiments was focused on determination of physical and mechanical features of examined sand-lime building blocks. Also, how they interact with each other.

2. Examination of sand-lime products

The experiment was conducted using solid sand-lime bricks of 250 x 180 x 220 mm size of the class 15 as well as modified products of the same size but different structure.

The preliminary technical and economical analysis determined that among different kind of fillers used to improve physical and mechanical properties, the best ones to use are: barite, basalt, hematite and magnetite. It is because of the density of the final product, which is very significant.

Based on previously mentioned norms, numbers of samples were chosen for every stage of the research. Sand-lime products were subject to following tests:

– determination of water absorption caused by a capillary pull of building blocks,
– determination of humidity of examined sand-lime products,
– determination of weight of sand-lime building blocks,
– determination of impregnability of sand-lime units (water absorption with complete immersion into water).

Durability test has also been done. It is considered to be the basic mechanical feature.

Some of used aggregates are characterised by high hardness. These materials poses the hardness of 8.5 on the Mohs' hardness scale. That explains their wide usage in civil engineering. Consequently, we can deduce, that hardness of a solid depends on the energy bonds in their structure. Therefore, we used basalt aggregate of the 2-4 mm fraction. Considering that 36% (M2) and 48% (M1) of its contents will be used in the mixture of the product.

3. Research analysis

The chart above shows the relation between ultimate compressive strength and water absorption corresponding to different types of sand-lime products. The experiment proves that original sand-lime building blocks (S) are characterised by much higher water absorption that those modified (M1 and M2) (Fig. 1). This is clearly seen in the chart above. Therefore, it is appropriate to state that inner modification of the material structure, contributed to significant and proportional decrease in water absorption; and to increase in compressive strength. The analysis showed, that original sand-lime bricks were completely wet due to a capillary pull, whilst those modified were half-wet (where h = 18 cm).

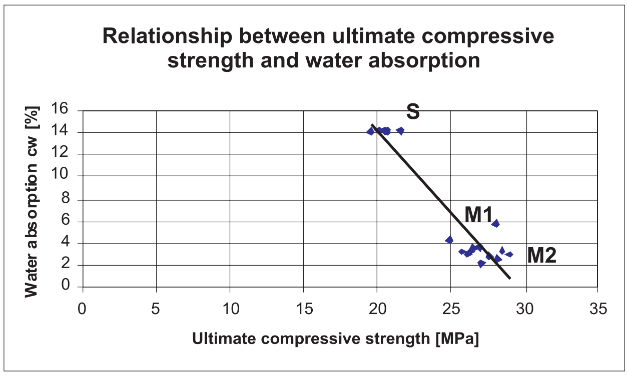

Fig. 1. Relationship between ultimate compressive strength of sand-lime products and their water absorption

Humidity test (Fig. 2) for sand-lime products proved that sand-lime building blocks of an original and intact structure (S) show proportionally lower humidity than those modified (M1 and M2). That is undoubtedly is related to the filler used. However, the difference is insignificant. Therefore, we can't state as yet, if the further increase in both of those parameters will cause refraction of the straight line.

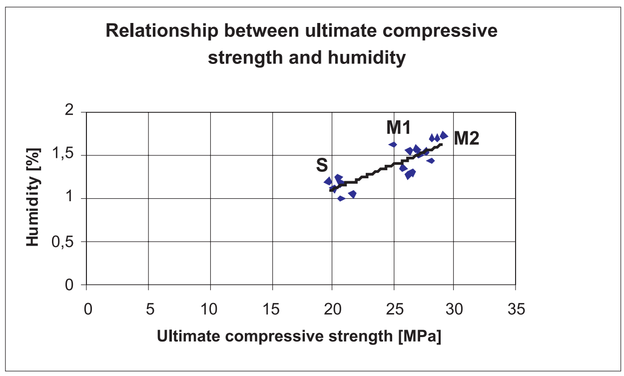

Fig. 2. Relationship between ultimate compressive strength of sand-lime products and their humidity

Due to modification in the original structure of a sand-lime product through insertion of the aggregate, impregnability of the product has improved (Fig. 3). When immersed in water, the modified material (M1 and M2) possessed proportionally lower water absorption, as compared to original sand-lime products (S). The latter one absorbs more water considerably faster (due to the capillary pull). But, consequently, the water is absorbed from the whole surface. Thus, it has the negative impact on mechanical features of these products.

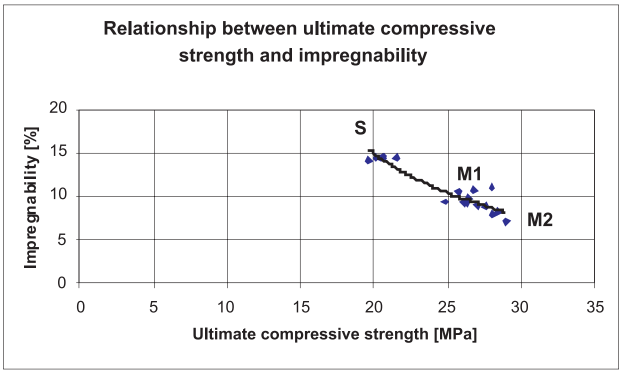

Fig. 3. Relationship between ultimate compressive strength of sand-lime products and their impregnability

Insertion of an aggregate of density from 2.70 to 3.2 T/m^3 caused weight increase of a "new" product. Higher density of sand-lime products led to improvement of their ultimate compressive strength. That was the objective of yet another experiment. Commonly, sand-lime bricks are class 15 product. Endurance test allowed to place the modified sand-lime products into a higher class (Fig. 4).

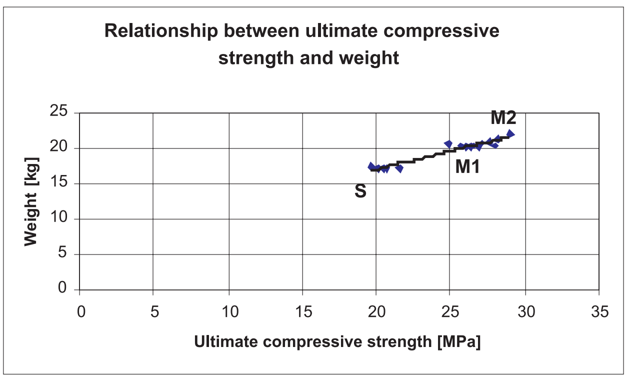

Fig. 4. Relationship between ultimate compressive strength of sand-lime products and their weight

Modification in a structure contributed to improvement of mechanical features mentioned above. But higher weight of an element with following higher density of a product has an impact on improvement of sound absorbance of sand-lime products as well.

Thanks to insertion of basalt aggregate in the production of sand-lime building blocks, it is possible to estimate the annual costs of production. And that may be very cost-effective for the mass production.

Original sand-lime products (S) with lower humidity, absorbed significantly more water due to a capillary pull than modified products (M1 and M2) (Fig. 5). Units with modified structure feature slightly higher humidity as compared with original units. But their absorption is much lower. This undoubtedly has an impact on the quality of a material.

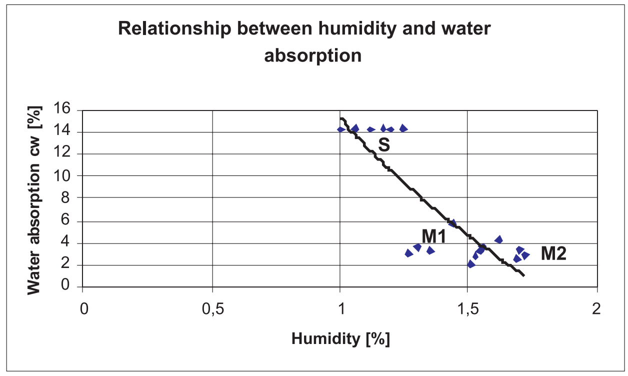

Fig. 5. Relationship between humidity of sand-lime products and their water absorption

The above curve represents the relationship between the two physical features: humidity and absorption. From the interpretation of this curve can be seen, that the higher is the humidity, the lower impregnability of the element (Fig. 6). Original sand-lime products (S) have usually higher humidity than those modified (M1 and M2). That is certainly related to an aggregate used.

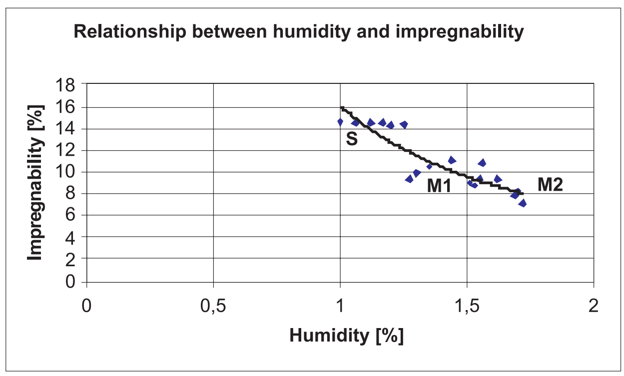

Fig. 6. Relationship between humidity and impregnability

4. Conclusions

1. Modification of the structure of sand-lime products had a positive impact on improvement of some of its physical features. These are: water absorbency, impregnability and density.
2. Humidity of a "new" sand-lime product was a little higher due to insertion of a filler. The filler was the basalt aggregate.
3. Higher humidity caused a decrease of impregnability. It significantly limited capillary pull of units at the same time.

4. Modified products showed higher ultimate compressive strength as compared to their original equivalents.
5. Higher weight of a sand-lime product, without any changes of its capacity, caused improvement of both: physical and durability features.

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Anna Stępień

Badania wyrobów silikatowych pod kątem poprawy ich cech fizykomechanicznych

1. Wstęp

Wyroby silikatowe są materiałem konstrukcyjnym charakteryzującym się znaczną wytrzymałością. Silikaty to produkty całkowicie naturalne, których składnikami są: piasek, wapno oraz woda, a więc są przyjazne dla środowiska naturalnego. Na szeroką skalę stosuje się je między innymi w krajach takich jak: Niemcy, Skandynawia, Francja, Włochy, Hiszpania, Holandia, Wielka Brytania czy Rosja. Ich duża masa sprawia, że odznaczają się wysoką izolacyjnością akustyczną.

2. Zakres i metodyka badań

W przedstawionym artykule celem przeprowadzanych doświadczeń jest określenie właściwości fizykomechanicznych badanych elementów silikatowych i ich wzajemne oddziaływania podczas ich modyfikacji. Eksperyment przeprowadzono na pełnych silikatowych elementach murowych o wymiarach: 250 x 180 x 220 mm, klasy 15 oraz na wyrobach modyfikowanych, o tych samych wymiarach, ale innej strukturze.

Wstępna analiza techniczno-ekonomiczna wykazała, że spośród różnego rodzaju wypełniaczy dla polepszenia właściwości fizykomechanicznych najkorzystniejsze będzie zastosowanie między innymi: barytu, bazaltu, hematytu, czy magnetytu. Istotną rolę odgrywa bowiem gęstość końcowego produktu.

Silikaty poddane były następującym próbom:

– określenie absorpcji wody spowodowanej podciąganiem kapilarnym elementów murowych,
– określenie wilgotności badanych silikatów,
– określenie masy elementów silikatowych,
– określenie nasiąkliwości elementów silikatowych (absorpcji wody przy całkowitym zanurzeniu wyrobów w wodzie),
– określenie wytrzymałości na ściskanie.

W związku z powyższym dla naszych badań eksperymentalnych wybrane zostało kruszywo bazaltowe o frakcji 2-4 mm we wstępnie założonej 36% i 50% jego zawartości w masie wyrobu.

3. Wnioski

1. Zmiana budowy wewnętrznej wyrobów silikatowych korzystnie wpłynęła na poprawę takich cech fizycznych, jak: absorpcja wody badanych wyrobów, nasiąkliwość i ich gęstość.
2. Na skutek dodania do produkcji elementu wypełniacza, jakim było kruszywo bazaltowe, wzrosła nieznacznie wilgotność „nowego" silikatu.
3. Wzrost wilgotności spowodował równocześnie zmniejszenie nasiąkliwości i znacznie ograniczył podciąganie kapilarne elementów.
4. Modyfikowane produkty wykazały zwiększoną wytrzymałość na ściskanie w porównaniu z ich tradycyjnymi odpowiednikami.
5. Zwiększenie masy wyrobu silikatowego, bez zmiany jego objętości spowodowało polepszenie właściwości zarówno fizycznych, jak i wytrzymałościowych.

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RESISTANCE OF THE PAVEMENT TO WATER AND FROST IN THE COLD RECYCLING TECHNOLOGY

Abstract

The road pavement structure (apart from having the required load capacity) should be water and frost resistant. This is important for pavements produced with the cold recycling technology. Foamed bitumen and, alternatively, bitumen emulsion were used for the resistance tests of the pavements. The bitumen binder content in the recycled material was 2.0%, 2.5% and 3.0%. The tests (stability against deformation, Marshall stiffness and indirect tensile strength (ITS)) showed that use of foamed bitumen is more advantageous than bitumen emulsion. That is in terms of mechanical properties of pavement. The measurements of resistance due to water and frost (according to AASHTO T283 method) and resistance to low temperature cracking (according to the PANK 4302 method) confirmed that pavement produced with the cold recycling technology is resistant to these climatic factors. The tests also showed that pavement produced with foamed bitumen is more resistant than pavement with bitumen emulsion. It is suggested, that general water resistance criterion (tensile strength retained (TRS)) of such pavement should be broadened to include e.g. the AASHTO T283 method.

The paper was presented at the International Conference on Maintenance and Rehabilitation of Pavements and Technological Control in Torino, Italy.

Keywords: pavement, base, foamed bitumen, cold recycling technology, PANK 4302, AASHTO T283

1. Introduction

The constantly deteriorating condition of asphalt roads in Poland is one of the crucial problems in road engineering. There are many reaons for accelerated degradation of pavements. Some of them are: the growing number of heavy trucks, an increase in vehicle axle loading from 100 kN to 115 kN, aging of pavement, improper design for the weather conditions, and improper maintenance.

The need to modernize the road network and the necessity to build highways led to increased demand for an aggregate. Its supply has been insufficient for years. It resulted in broad interest in alternative methods of road construction. These methods should improve the efficiency in road repairs. Technologies which reuse construction materials are of particular interest. That allows to better manage the funds allocated for road maintenance.

The use of the cold recycling technology is advantageous. For technical, economical and ecological reasons. Reusing materials taken from old pavements is lowering the exploitation rate of mineral deposits. Thus, its reducing the impact on the environment.

The cold recycling technology is the method more and more commonly used. Especially for significantly damaged asphalt surfaces where ruts and fatigue crack are seen. In Poland the technology using mineral – cement – emulsion (M-C-E) mixes is popular. However, in recent years due to demand for modernization of the road network this approach is changing approach. The emphasis is placed on improvement of the load capacity of surface construction. The foamed bitumen is used instead of bitumen emulsion. This bitumen binder enables to obtain more durable road pavements [1].

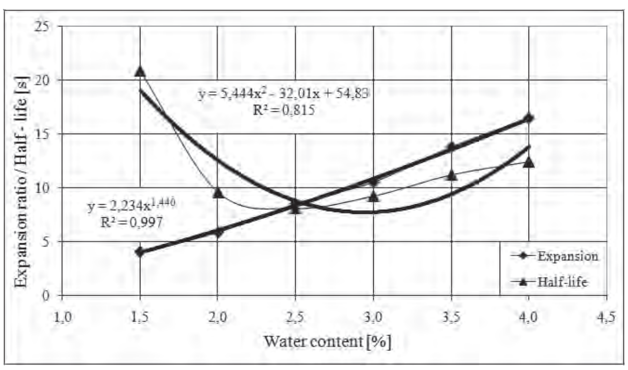
Foamed bitumen contains very little water. Its curing period is shorter then bitumen emulsion. The pavement made with this technology can almost immediately be covered by other layers. Another advantage is the 100% use of an old material from destructed pavements. And to produce a new load bearing flexible layer. It can also decrease the thickness of the upper bitumen layers. And lower the production time.

The deep recycling with foamed bitumen is widely used. Examples are: Africa and Australia. There, the impact of temperatures below 0^{o}C (frost) and water on the road construction is not significant. Consequently, only tensile strength retained (TRS) is usually done. TRS is a ratio of the values of indirect tensile strength before and after soaking pavement samples in water. However, in Poland the weather conditions are more severe (due to water and frost interaction). As far as we know, for the pavement with foamed bitumen (regarding its water and frost resistance) no detailed data is available for moderate climate. Thus, before introducing this technology on the market, it is necessary to assess its water and frost resistance. It should be done in a range which broadens the existing requirements. And should be specifically prepared for this innovative technology.

2. Tested material

2.1. Foamed bitumen tests

An important step of the tests was to preliminarily determine the suitability of bitumen applied for the foaming technology. The tests were performed on four kinds of road bitumen: 50/70 from Plock (50/70P), 160/220 from Trzebinia (160/220T) and two kinds of bitumen manufactured by the Nynas company (50/70N and Nyfoam 80). The suitability analysis focused on the basic properties and foaming parameters. The test results are presented in Figures 1a – 1d. From the analysis of the results [1, 2], we conclude that the Nyfoam 80 bitumen (Fig. 1d) has the most favourable foaming parameters. Its expansion ratio WE = 15.1 and half – life of the bitumen foam t½ = 14.4 s. Thus, its application should guarantee high physical and mechanical parameters of the pavement.



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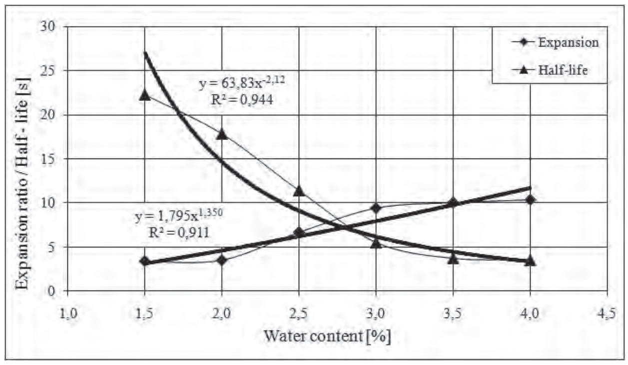

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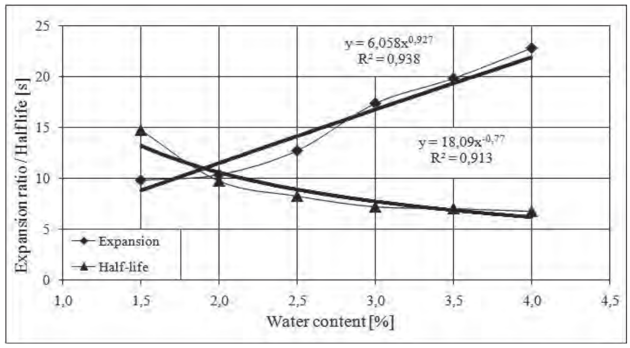

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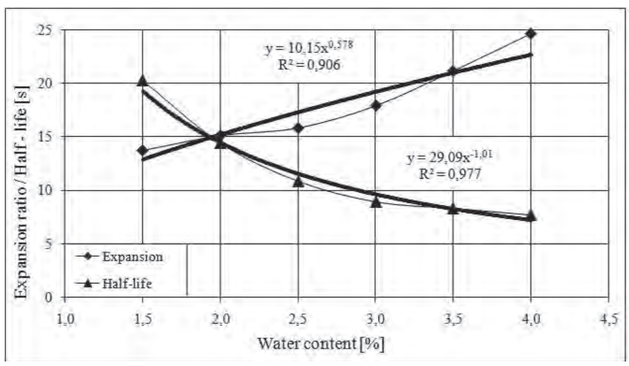

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Fig. 1. Foamed bitumen characteristics for the following kinds of bitumen: a) 50/70P, b) 160/220T, c) 50/70N, d) Nyfoam 80

2.2. The composition of the recycled pavement mixes

The laboratory tests were carried out on the mineral mix from the modernised construction layers with the addition of foamed bitumen. And, alternatively, with bitumen emulsion intended to form the pavement layer. Cement and water were also added to the recycled mix. It was done in order to obtain optimal compaction conditions.

The designed mineral mix of the recycled pavement contained 48% of milled asphalt layers, 22% of the existing stone base and 30% of a new material –

0/4 mm dolomite aggregate. The addition of cement to the mix was based on the strength tests. It equalled 2.0% in relation to its mass. Cement was used to increase the content of the fraction below 0.075 mm in the recycled material.

The designed recycled mineral mix met the grading criteria for both: the mineral mixes in the recycling technology with foamed bitumen, and for the M-C-E mixes (Fig. 2); it also complied with requirements [3] [4].

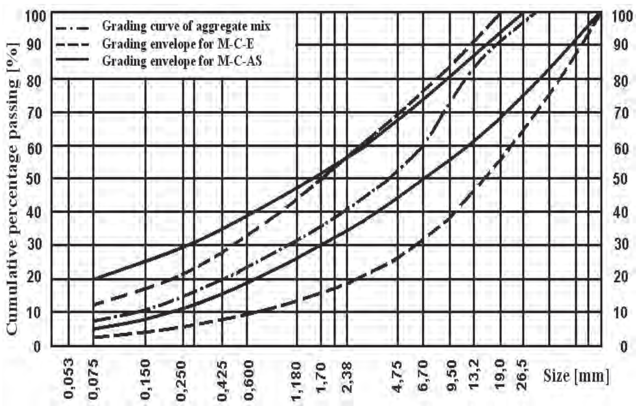


Fig. 2. Grading curves of the mineral mix for the production of pavements in the recycling technology with foamed bitumen and bitumen emulsion

The laboratory tests were performed on two kinds of mineral – bitumen mixes. In the first kind of the mineral – bitumen mix foamed bitumen from the Nyfoam 80 bitumen with a 2.0% addition of water (M-C-AS) was used. Its choice was based on the analysis of the preliminary test results. In the other mix (M-C-E) cationic slow – curing bitumen emulsion K3-60 was used. The foamed bitumen content was 2.0%, 2.5% and 3.0% (m/m). In order to properly compare the recycled pavement mix, the same amount of bitumen binder (bitumen precipitated from bitumen emulsion) as in the foamed bitumen mixes was used. However, due to the fact that measurements were conducted for K3-60 bitumen emulsion (whose bitumen content in emulsion was 60%), emulsion was added according to the technical guidelines [4]. The percentage of the added emulsion was: 3.4%, 4.2% and 5.0%. That resulted in bitumen content of 2.0%, 2.5% and 3.0%, respectively.

2.3. Methodology and analysis of the test results

The aim of this investigation was to determine the impact of foamed bitumen on the mechanical properties of pavement made with the deep cold recycling technology (M-C-AS); also to determine its water and frost resistance. Reference tests were made for the recycled mix in which bitumen emulsion (M-C-E) was used.

The experiment was carried out in two stages. The first stage was focused on the basic physical and mechanical properties with considering the kind of binder used. In the second one the water and frost resistance of the pavement was determined.

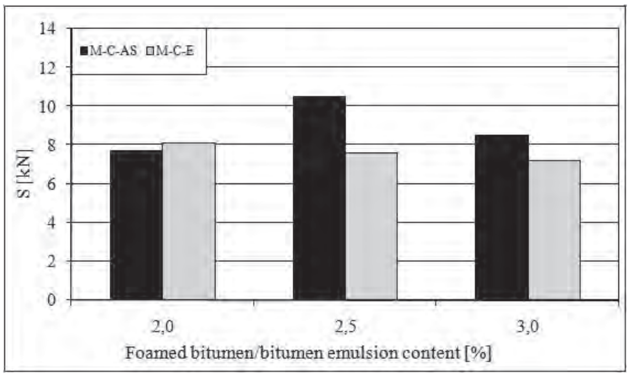
It was important to assess the homogeneity of the conducted experiment. The measurements were taken only for samples with void fraction content ranged between (V – 2s ; V + 2s), where V – mean void fraction content in the pavement, s – standard deviation. The tests were performed on series of 9 samples. The presented results are the mean values.

For the designed mixes the basic physical and mechanical properties were determined. That included: stability against deformation, Marshall stiffness, indirect tensile strength, void fraction content and static creep modulus.

The results of the laboratory tests for both mixes are presented in Figure 3. The description is as follows: Marshall stability (S), deformation (E) and stiffness (Sz), indirect tensile strength (ITS), void fraction content (Wp) and static creep modulus (MS) depending on the kind of bitumen binder.

The increase in the binder content (foamed bitumen and bitumen emulsion) led to an increase in indirect tensile strength. The use of foamed bitumen resulted in about 10% rise in indirect tensile strength as compared to binder in which bitumen emulsion was used.

The stability of the recycled pavement and foamed bitumen content is different. An increase in foamed bitumen content to 2.5% resulted in an increase in stability. However, the application of more bitumen led to a decrease in stability. In the case of bitumen emulsion pavement stability decreased when more binder was used. The pavement stability was highest for the foamed bitumen content of 2.5%; and higher than in the case of 2% bitumen emulsion content.



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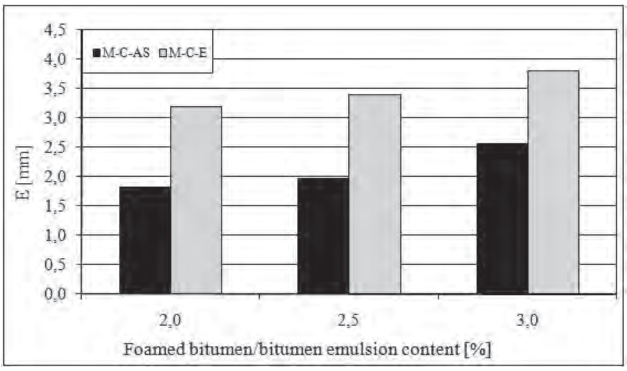

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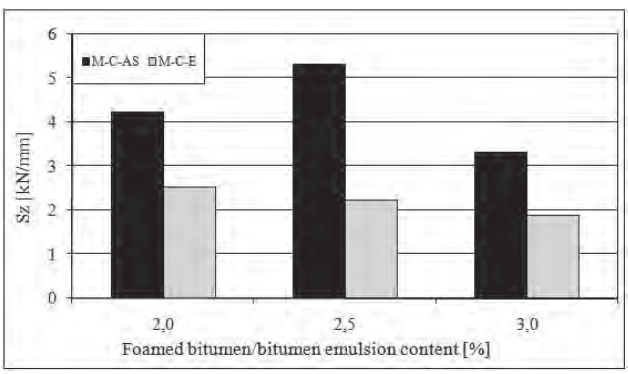

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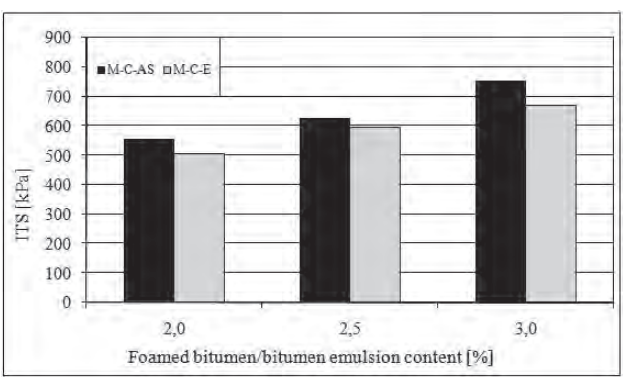

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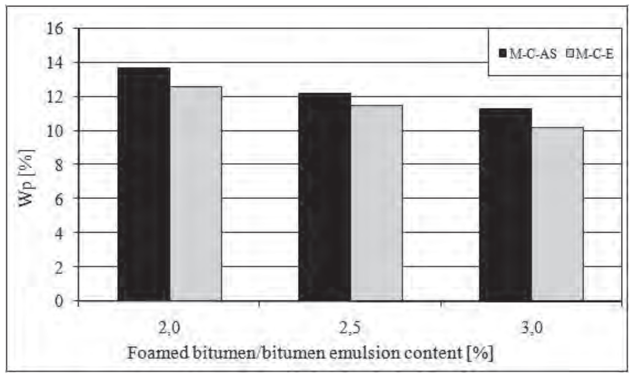

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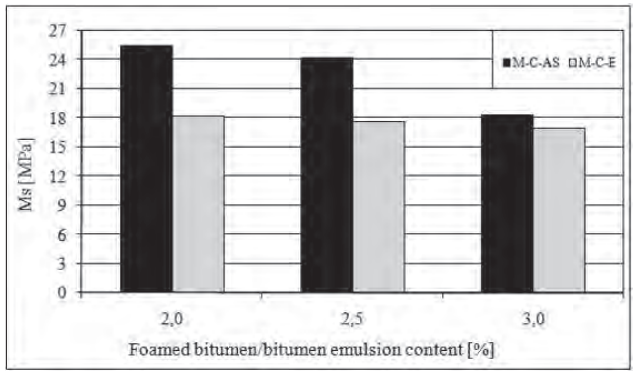

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Fig. 3. Physical and mechanical properties of the recycled pavement mixes are depending on the kind of bitumen binder: a) Marshall stability, b) Marshall deformation, c) Marshall stiffness, d) indirect tensile strength, e) void fraction content, f) static creep modulus

The pavement with foamed bitumen has lower Marshall deformations as compared to pavement with bitumen emulsion. At the same time its more resistant to plastic deformations under the traffic load. It is also confirmed with the analysis of Marshall stiffness of the pavement with foamed bitumen. The Marshall stiffness values from the tests prove that the application of this kind of bitumen binder enables to obtain the pavement structure which is more resistant. Marshall stiffness for the foamed bitumen content of 2.5% was 5.33 kN/mm in comparison to the highest value of 2.53 kN/mm for the 2.0% content of bitumen from bitumen emulsion.

These pavements have higher values of the static creep than bitumen emulsion. The values of the static creep decrease as more bitumen binder is used, regardless of its kind. The static creep does not quite depend on binder. Decreasing this concentration led to a significant increase in the values of the static creep as opposed to the case when bitumen emulsion was used.

The tests from the first stage show, that if we use the foamed bitumen, the properties of the recycled pavement are advantegous compared to bitumen emulsion.

The favourable test results of the physical and mechanical properties of the pavement produced with the recycled technology with foamed bitumen are However, its not sufficient to introduce this road engineering technology in Poland. Asits also necessary to determine water and frost resistance of this kind of pavement. That was done in the second step of an investigation.

In order to assess water and frost resistance of mineral mixes with foamed bitumen (M-C-AS) and reference mineral – cement – emulsion mixes (M-C-E), the following parameters were determined:

– indirect tensile strength after soaking with water (ITSwoter),
– tensile strength retained TSR [5],
– resistance to low temperature cracking according to the Finnish PANK 4302 standard [6],
– indirect tensile strength after curing in water and frost according to the American guidelines, e.g. the AASHTO T283 method [7, 8].

The test results due to weather conditions are presented in Table 1 (as reference samples). The relation between indirect tensile strength at -2ºC according to PANK 4302 and the foamed bitumen and bitumen emulsion content are shown in Figure 4. Figure 5 presents the same, but for indirect tensile strength after curing only in water and in water and frost according to AASHTO T283.

Table 1. Test results of water and frost resistance of the recycled pavement with foamed bitumen and bitumen emulsion

No.	The kind of the recycled pavement mix	M-C-AS			M-C-E		
	Bitumen (AS) content / bitumen in bitumen emulsion (EA) content [%]	2.0	2.5	3.0	2.0	2.5	3.0
	Cement content [%]	2.0					
The properties of the recycled pavement mixes							
1	ITS_{water} [kPa]	404	470	604	344	421	497
2	TSR	0.73	0.75	0.82	0.68	0.71	0.74
3	Indirect tensile strength at -2ºC according to PANK 4302 [MPa]	0.7	0.8	1.1	0.7	0.9	1.0
Indirect tensile strength ratio at 20ºC according to AASHTO T283 [%]							
4a	After curing in water	71.2	78.3	79.7	67.4	69.5	71.8
4b	After curing in water and frost	62.7	70.2	72.9	59.6	62.2	65.1

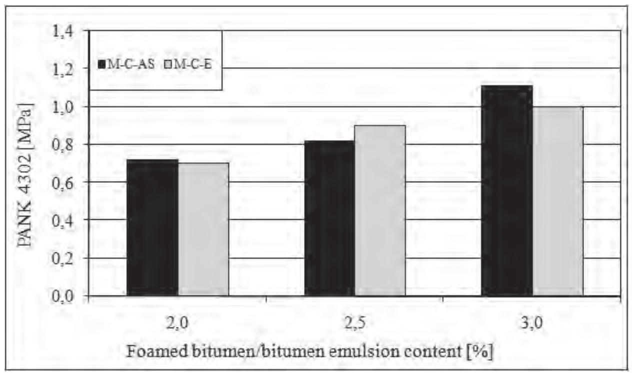

Fig. 4. Indirect tensile strength of the recycled pavement according to PANK 4302

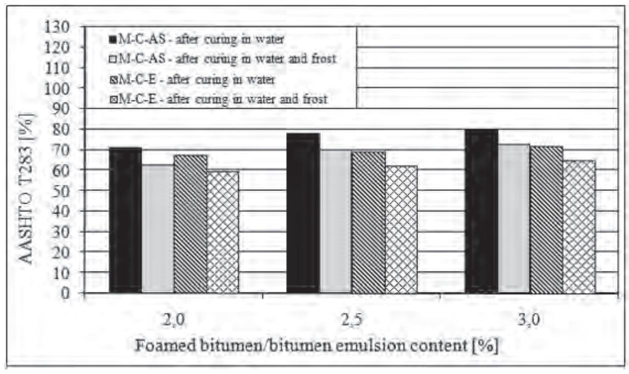

Fig. 5. Indirect tensile strength ratio of the recycled pavement according to AASHTO T283

Pavements made with foamed bitumen have higher tensile strength retained in comparison to bitumen emulsion. TSR increases with the foamed bitumen content. It should be noted that According to the criterion proposed by Jenkins [5] the recycled pavement is water resistant if TSR exceeds 0.70. This criterion is met only for the pavement with foamed bitumen. The use of bitumen emulsion does not guarantee required water resistance of the pavement. Since the TSR values are lower than 0.70.

The tests confirmed, that resistance to low temperature cracking of the recycled pavement for foamed bitumen and bitumen emulsion is comparable for the same binder contents.

A thorough assessment of water and frost resistance was performed according to AASHTO T283. The pavement with foamed bitumen turned out to be water resistant. But the pavement with bitumen emulsion did not meet the required criterion. Its indirect tensile strength ratio after curing in water was lower than 70% regardless of the emulsion content used. Similarly, the pavement with bitumen emulsion was not water and frost resistant. The indirect tensile strength ratio was below the required value of 70%. At the maximal bitumen emulsion content this ratio was only 65.1%. However the foamed bitumen content in the recycled pavement of at least 2.5% ensured its water and frost resistance. It was observed that rising foamed bitumen content led to an increase in resistance to the investigated climatic factors.

The tests of the effects of water and low temperatures on the recycled pavement prove that the use of foamed bitumen enables to ensure better resistance to these destructive factors. It can also be concluded, that the water resistance criterion of the recycled pavement based on the TSR parameter should be broadened. It should include, (for example) the proposed AASHTO T283 method.

3. Conclusions

From the laboratory tests of the recycled pavement with foamed bitumen and bitumen emulsion, the following conclusions can be drawn:

1. Only these kinds of bitumen that possess proper foaming parameters can be used in the foaming technology, for example the Nyfoam 80 bitumen.
2. An increase in the foamed bitumen content form 2.0% to 3.0% results in an increase in indirect tensile strength of the recycled pavement.
3. The stability is highest at the binder concentration of 2.5%.
4. The use of more binder results in decrease of stability in recycled pavement.
5. The recycled pavement with the 2.5% foamed bitumen content has more favourable mechanical properties, higher Marshall stability and stiffness than bitumen emulsion; that is regardless of the binder content.
6. The use of foamed bitumen ensures higher water and frost resistance than bitumen emulsion.
7. The water resistance criterion based only on the TSR parameter is insufficient; it should be broadened to include the proposed AASHTO T283 method.
8. The recycled pavement with foamed bitumen has higher static creep than bitumen emulsion.
9. The use of foamed bitumen in the deep cold recycling technology should guarantee higher resistance to plastic deformation.

The favourable laboratory tests indicate, that there is a need to continue research in this area. In particular, its necessary to verify laboratory test results in the field. More research should be done and data collected before introducing this technology on the market

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Odporność na oddziaływanie wody i mrozu podbudowy w technologii recyklingu na zimno

1. Wprowadzenie

Stale pogarszający się stan techniczny asfaltowych nawierzchni dróg jest jednym z najważniejszych problemów drogownictwa w Polsce. Zwiększający się udział pojazdów ciężkich w ogólnej strukturze ruchu drogowego, wzrost obciążenia na oś pojazdów ze 100 kN na 115 kN, starzenie się materiałów konstrukcji nawierzchni, brak przystosowania nawierzchni do warunków klimatycznych panujących w Polsce, a także wyczerpanie przez nawierzchnie zakładanego okresu eksploatacji są głównymi przyczynami przyspieszonej degradacji nawierzchni na znacznym obszarze sieci drogowej.

W przypadku mocno zniszczonych nawierzchni asfaltowych, na których występują koleiny lub pęknięcia zmęczeniowe, coraz częściej stosowaną metodą naprawy jest recykling na zimno. Obecnie w Polsce rozpowszechniona jest technologia recyklingu na zimno konstrukcji nawierzchni z zastosowaniem mieszanek mineralno-cementowo-emulsyjnych (M-C-E). Jednakże ciągły wzrost prac w zakresie modernizacji eksploatowanej sieci drogowej w naszym kraju, związany z koniecznością poprawy nośności konstrukcji nawierzchni, wskazuje na potrzebę wdrożenia do krajowego wykonawstwa bardziej nowoczesnej technologii recyklingu na zimno, w której zamiast emulsji asfaltowej stosowany jest asfalt spieniony. Wykorzystanie tego lepiszcza asfaltowego pozwala uzyskać większą trwałość konstrukcji nawierzchni drogowej przy oddziaływaniu agresywnego obciążenia ruchem i coraz bardziej niekorzystnych warunków klimatycznych [1].

2. Badany materiał

2.1. Badania asfaltu spienionego

Do technologii spienienia w drogownictwie światowym stosowane są asfalty o różnej penetracji. Istotnym elementem wykonanych badań było na wstępie określenie przydatności stosowanych w Polsce asfaltów do technologii spienienia. Badania oceny przydatności asfaltów obejmowały określenie podstawowych ich właściwości oraz parametrów spienienia. Na podstawie badań [2, 4] stwierdzono, że asfalt Nyfoam 80 charakteryzuje się najkorzystniejszymi parametrami spienienia: współczynnikiem ekspansji WE = 15,1 oraz czasem połowicznego rozpadu piany asfaltowej t½ = 14,4 s. Tym samym zastosowanie go podczas recyklingu głębokiego na zimno powinno gwarantować uzyskanie podbudowy o wysokich parametrach fizykomechanicznych.

2.2. Skład ramowy recyklowanych mieszanek podbudowy

W wykonanych badaniach laboratoryjnych zastosowano mieszankę mineralną pochodzącą z modernizowanych warstw konstrukcyjnych nawierzchni z dodatkiem asfaltu spienionego i alternatywnie emulsji asfaltowej, przeznaczoną na warstwę podbudowy w technologii recyklingu głębokiego na zimno. Recyklowana mieszanka zawierała również dodatek 2,0% cementu oraz wody w celu uzyskania optymalnych warunków zagęszczania. Zawartość asfaltu spienionego wynosiła odpowiednio 2,0%, 2,5% oraz 3,0% (m/m). Aby możliwe było prawidłowe porównywanie recyklowanych mieszanek podbudowy z asfaltem spienionym z mieszanką M-C-E, w badaniach laboratoryjnych mieszanek M-C-E stosowano tę samą ilość lepiszcza asfaltowego (asfaltu wytrąconego z emulsji) co w mieszankach z asfaltem spienionym. Jednakże ze względu na fakt, iż w badaniach wykorzystywana jest kationowa emulsja asfaltowa wolnorozpadowa K3-60 (60% asfaltu w emulsji asfaltowej), w związku z tym dozowano ją zgodnie z warunkami technicznymi [4] w ilości 3,4%, 4,2% oraz 5,0%, co w konsekwencji daje nam odpowiednio asfaltu 2,0%, 2,5% oraz 3,0%.

2.3. Metodyka oraz analiza rezultatów badań

Celem badań było określenie wpływu ilości asfaltu spienionego na właściwości mechaniczne podbudowy wykonanej w technologii recyklingu głębokiego na zimno, oraz określenie jej odporności na oddziaływanie wody i mrozu. Badania kontrolne wykonano dla mieszanki recyklowanej, w której zastosowano emulsję asfaltową.

Dla zaprojektowanych i wykonanych recyklowanych mieszanek podbudowy z asfaltem spienionym oraz kontrolnych mieszanek mineralno-cementowo-emulsyjnych określono podstawowe właściwości fizykomechaniczne, takie jak: stabilność odkształcenie i sztywność wg Marshalla, wytrzymałość na pośrednie rozciąganie, zawartość wolnych przestrzeni oraz moduł sztywności według pełzania pod obciążeniem statycznym.

Analiza rezultatów badań recyklowanej podbudowy pozwoliła stwierdzić, że wraz ze wzrostem ilości lepiszcza (asfaltu spienionego i emulsji asfaltowej) wzrasta jej wytrzymałość na pośrednie rozciąganie. Należy zaznaczyć, że zastosowanie w podbudowie asfaltu spienionego powoduje około 10-procentowy wzrost jej wytrzymałości na pośrednie rozciąganie, przy takiej samej zawartości lepiszcza, niż kiedy stosowano emulsję asfaltową. Inny charakter przybiera zależność stabilności recyklowanej podbudowy od ilości asfaltu spienionego. Zanotowano istotną zależność – wzrost koncentracji asfaltu spienionego do 2,5% powoduje wzrost stabilności podbudowy, a dalsze jego zwiększenie powoduje obniżenie wartości badanej charakterystyki. Natomiast zastosowanie emulsji asfaltowej powoduje, że stabilność podbudowy maleje wraz ze zwiększeniem koncentracji lepiszcza.

Istotnym efektem badań jest stwierdzenie, że w zakresie stosowanych koncentracji lepiszcza asfaltowego podbudowa z asfaltem spienionym charakteryzuje się mniejszym odkształceniem wg Marshalla od podbudowy z emulsją asfaltową. Tym samym będzie ona bardziej odporna na deformacje plastyczne pod wpływem oddziałującego na nawierzchnię obciążenia ruchem pojazdów. Właściwość tę potwierdza również analiza sztywności wg Marshalla podbudowy z asfaltem spienionym. Określone wartości sztywności wg Marshalla podbudowy z asfaltem spienionym dla stosowanych w badaniach koncentracji wskazują jednoznacznie, że zastosowanie tego rodzaju lepiszcza asfaltowego pozwala uzyskać większą odporność tego rodzaju podbudowy na oddziaływanie ruchu pojazdów niż kiedy w jej składzie stosowano emulsję asfaltową.

Dla oceny odporności na oddziaływanie wody oraz mrozu mieszanek mineralnych z asfaltem spienionym oraz kontrolnych mieszanek mineralno-cementowo-emulsyjnych (M-C-E) przeznaczonych na warstwę podbudowy w technologii recyklingu głębokiego na zimno wykonano oznaczenia: wytrzymałość na pośrednie rozciąganie po nasączeniu wodą, wskaźnik odporności na oddziaływanie wody TSR, odporność na spękania niskotemperaturowe zgodnie z fińską normą PANK 4302 [6] oraz wskaźniki wytrzymałości na pośrednie rozciąganie po procesie pielęgnacji w wodzie i mrozie, zgodnie z procedurami amerykańskimi, wg metody AASHTO T283 [7, 8].

Wykonane badania pozwoliły stwierdzić, że podbudowa wykonana w technologii recyklingu z asfaltem spienionym, w badanym zakresie lepiszcza charakteryzuje się większymi wartościami wskaźnika TSR niż kiedy stosowano emulsję asfaltową. Wartości wskaźnika wzrastają wraz z koncentracją asfaltu spienionego.

Kompleksową ocenę odporności na oddziaływanie wody i mrozu badanych podbudów uzyskano na podstawie oznaczeń wg AASHTO T283. Podbudowa z asfaltem spienionym okazała się odporna na oddziaływanie wody, a podbudowa z emulsją asfaltową niestety nie spełniała tego kryterium, ponieważ jej wskaźnik wytrzymałości na rozciąganie pośrednie po pielęgnacji w wodzie był mniejszy od 70%, niezależnie od ilości zastosowanej emulsji. Podbudowa z emulsją asfaltową wykazała również brak odporności na oddziaływanie wody i mrozu, gdyż wartości wskaźnika wytrzymałości na rozciąganie pośrednie były mniejsze od wymaganej wartości 70%. Należy podkreślić, że przy maksymalnej koncentracji emulsji asfaltowej wynosił on tylko 65,1%. Natomiast zastosowanie w recyklowanej podbudowie co najmniej 2,5% asfaltu spienionego zapewniło jej odporność na oddziaływanie wody i mrozu. Wraz ze wzrostem zawartości asfaltu spienionego odporność podbudowy na badane czynniki klimatyczne wzrasta.

Wykonane badania w zakresie oddziaływania wody i niskich temperatur na recyklowaną podbudowę pozwalają stwierdzić, że zastosowanie w jej składzie asfaltu spienionego pozwala zapewnić na wyższym poziomie jej odporność na te czynniki niszczące niż zastosowanie emulsji asfaltowej. Można również wnioskować, że kryterium odporności recyklowanej podbudowy na oddziaływanie wody tylko na podstawie wskaźnika TSR jest niewystarczające i należy je rozszerzyć na przykład o zaproponowaną metodykę AASHTO T283.

3. Wnioski

Na podstawie wykonanych badań laboratoryjnych recyklowanej podbudowy z asfaltem spienionym oraz emulsją asfaltową można sformułować następujące wnioski:

structure

1. Do technologii spienienia można stosować tylko te asfalty, które charakteryzują się odpowiednimi parametrami spienienia, do takich asfaltów można zaliczyć np.: asfalt Nyfoam 80.
2. Wraz ze zwiększeniem koncentracji asfaltu spienionego od 2,0% do 3,0% następuje wzrost wytrzymałości na pośrednie rozciąganie recyklowanej podbudowy, natomiast stabilność uzyskuje największą wartość przy koncentracji 2,5% lepiszcza, dalsze zwiększenie jego zawartości powoduje spadek stabilności recyklowanej podbudowy,
3. Recyklowana podbudowa z asfaltem spienionym przy jego zawartości 2,5% charakteryzuje się korzystniejszymi właściwościami mechanicznymi, większą stabilnością i sztywnością wg Marshalla niż w przypadku, kiedy zastosowano emulsję asfaltową.
4. Zastosowanie asfaltu spienionego powoduje wzrost wytrzymałości na pośrednie rozciąganie recyklowanej podbudowy w porównaniu z zastosowaniem w jej składzie emulsji asfaltowej, niezależnie od koncentracji lepiszcza.
5. Asfalt spieniony zapewnia odporność na oddziaływanie wody i mrozu recyklowanej podbudowy na znacznie wyższym poziomie niż stosowanie emulsji asfaltowej.
6. Kryterium odporności recyklowanej podbudowy na oddziaływanie wody tylko na podstawie wskaźnika TSR jest niewystarczające i należy je rozszerzyć o zaproponowaną metodykę AASHTO T283.
7. Recyklowana podbudowa charakteryzuje się większym modułem statycznym pełzania wtedy kiedy w jej składzie stosowano asfalt spieniony niż gdy wykorzystano emulsję asfaltową.
8. Zastosowanie asfaltu spienionego podczas recyklingu głębokiego na zimno powinno zapewnić uzyskanie podbudowy o wyższej odporności na deformacje plastyczne, niż kiedy stosuje się emulsję asfaltową.

Uzyskane pozytywne wyniki badań laboratoryjnych wskazują na konieczność kontynuowania dalszych prac w zakresie trwałości recyklowanej podbudowy z asfaltem spienionym. Nieodzowna jest również weryfikacja rezultatów badań laboratoryjnych w terenowych warunkach pracy tego rodzaju podbudowy. Pozwoli to na zgromadzenie bazy danych umożliwiających wdrożenie tej technologii do polskiego wykonawstwa.

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PROGRESSIVE METHODOLOGY FOR DETERMINATION OF CONCRETE PLANTS PRODUCTIVITY

Abstract

The mathematical model for estimation of building machines productivity can have various forms of processing. When choosing the appropriate one, it becomes the qualitative tool for making optimal decisions. In this article, a nomogram for graphical determination of a concrete plant operational productivity is presented. It illustrates methods of its formation and instruction for the usage.

Keywords: concrete plant, productivity, nomogram

1. Introduction

Pertinent information related to theoretical productivity of machines is presented by their producers. It should be calculated by the mathematical formula. However, conscious and unconscious mistakes and the biased information (related to marketing of the products) may appear at some point. Thus, the information about the theoretical productivity of the machines may be – at some point – somewhat misleading. More complex situation emerges, when it comes to the estimation of the building machines real productivity. That can be significantly lower than their estimated theoretical productivity. Unfortunately, the producers generally tend not to reveal that kind of information. Therefore it is significant, especially for building and designing companies, to complete and verify the missing information. This is often a very difficult task [1].

The aim of this research was to propose the form of data processing regarding productivity of building machines. This is helpful, since it delivers quick and relatively correct technique. Thus one may obtain information about technical productivity and simultaneously be able to estimate operational productivity (under specified conditions) during the building process. The results of this investigation led to design of the nomogram. This nomogram may be used for estimation of technical and operational productivity of concrete plants. In order to compose a particular model, detailed analysis of technical and technological parameters of concrete plants was necessary. This information is required by machines' building companies and used as the input data. Many factors having significant impact on operational productivity were also considered in this analysis.

2. Mathematical modelling of building machines productivity

Mathematical modelling of the productivity in the process of building machines and machines assemblies is one of the significant tools. It enables to make the optimal decisions regarding projects of machines assemblies and schedules in building processes [3].

Generally one may state that: 'building companies do not want the formulas!'.

This does not necessarily implies, that building companies reject mathematical modelling. They only deny working with models.

Mathematical formulas are needed for preparation of building processes and composition of machines line-ups. They are also required for static calculations and project's documentation. They posses many disadvantages too, e.g.:

- ignorance or lack of a suitable mathematical formula,
- incorrect measure units in substitution of some parameters,
- mistakes regarding exact value,
- mistakes referring 'mathematical symbol',
- the necessity of a calculator or a computer (calculation without aid is ineffective),
- the amount of 'valid numbers' in the final value depends on the calculator and does not present an exact value for obtained information,
- the analysis of model sensitivity in relation to changes of entered parameters is expressed only via mathematical aid and is often invisible,
- the practical interpretation of numerically expressed data, which is obtained by calculation is missing.

The methods of data processing regarding the following model are important for building companies.

The mathematical model can be expressed in various ways, e.g. in tabular or graphical form (not only via mathematical way). These methods provide information about the values of sensitivity analysis considering parameters changes of entered information. Furthermore, this model enables a backward look at analysis of sensitivity values. When applying this model it is possible to decide which parameter values should be entered when using the pre-determined values of productivity.

The mathematical model of operational productivity of concrete plants and a new, progressive form of its processing allows to eliminate the disadvantages of the mathematical formulas. It became the qualitative tool for making optimal decisions in various technological processes. For example: during the projects of machines assembly for production, transportation and treating of fresh concrete.

3. Productivity of concrete plants

The real and operational productivity are still lower than their theoretical productivity. The reason for that is that theoretical productivity refers to both fresh concrete and ideal operational conditions.

3.1. Real productivity of concrete plants

The operational productivity of concrete plants is still lower than its estimated technical (theoretical) productivity [2]. Real productivity of concrete plants is calculated by multiplying the technical productivity by correction variables.

$$V_S = V_T \prod_{i=1}^{n} k_i$$

where:
V_S – operational productivity of a concrete plant, $m^3 \cdot h^{-1}$;
V_T – theoretical productivity of a concrete plant, $m^3 \cdot h^{-1}$;
k_i – i-th correction variable;
n – number of correction variables.

The operational productivity of a concrete plant depends on its technical productivity and following variables:

- variable of working productivity of a concrete mixer ($\boldsymbol{k_{pú}}$) – presents standard conditions of a manufacture process,
- variable of concrete mixer filling ($\boldsymbol{k_{pm}}$) – presents measures for net (useful) capacity of a concrete mixer,
- variable of operational time of a concrete plant ($\boldsymbol{k_{ho}}$),
- variable ($\boldsymbol{k_{tm}}$) – presents the extension of the fresh concrete mixing time, which is necessary in case of adding some ingredients and mixtures to concrete.

Operational productivity of machines, is derived from their technical productivity multiplied by ($\boldsymbol{k_{pú}}$), which is the working productivity variable. This variable varies from 0.7 to 0.85 in standard conditions of a concrete plant.

The under-used full capacity of a concrete mixer decreases its productivity during the mixing of concrete components. On the other hand, overflow a concrete mixer can affect its incomplete mixing. Eventually, the devastation of fresh concrete or damages in some parts of the mixer may occure as a consquence.

The concrete production depends directly on its sales. Fresh concrete is ready to use as soon as the process of mixing begins. Therefore, it is not possible to produce fresh concrete 'in stock'. Batches of fresh concrete mixture, which are placed under the mixer, are able to partially counterbalance the unsteadiness of concrete. Therefore, it is only possible to serve continuous filling for transportation. But it is difficult to store fresh concrete temporarily. The variable of unsteadiness time of concrete required from the concrete plant ($\boldsymbol{k_{ho}}$) varies from 1.4 to 2.2. For example, the variable k_{no} = 2 means, that during the 8-hour shift, it has been required for concrete to flow only 4 hours. For the next 4 hours, the concrete mixer should have a downtime. In this case, concrete plants produce and supply just a half of concrete capacity compared to its operational productivity. We can also estimate an average time of concrete production per shift during the calculation of concrete plants operational productivity.

Next aspect that has a significant impact on production is the addition of a different ingredient(s) into concrete. Interaction between some ingredients is activated by mixing. Therefore the producers recommend extending the time of mixing in a concrete mixer from 30 to 120 seconds. That time depends on a type of the mixer and the technical facilities. The mixing time consists of its filling, mixing and discharge. For example, extension of the mixing time from 30 to 120 seconds, prolongs then the previous mixing time of a concrete mixer from 60 to 150 seconds. As a result, mixing centre productivity changes at only 40% ($\boldsymbol{k}_{tm}$ = 0.4) as compared to the previous production.

The real conditions of concrete production (alongside with an impact of those factors that have a significant impact on concrete plant real productivity), are necessary to be considered in order to plan the process of concrete production.

For building companies, it is desirable to determine operational productivity of concrete plants in particular condition. The reason is that the outage and supplies of fresh concrete during the ***planning and management of building construction*** concrete process may cause serious problems or delays in the schedule. Therefore, the nomogram is the suitable tool for making optimal decisions.

4. Nomogram for determination of concrete plants operational productivity

The procedure of determination of concrete plant productivity includes five stages [4]. The presented sequence is illustrated in a **graphical version of a mathematical model** as the nomogram.

1. The net capacity of a concrete mixer is the basic information needed for the calculation. Also, the recommended concrete volume per one batch (2/3 of net capacity of a concrete mixer) is presented. In case when one batch possesses capacity lower than recommended, the following step should be estimated, considering lower concrete volume. The graphical model presents concrete volume per one batch in m^3. Typical sizes of concrete mixers that are used are: 150, 375, 500, 750, 1000, 1125, 1500, 2000, 2500 and 3000 litres.
2. The time of each mixing cycle (filling, mixing, and discharge of a concrete mixer) has a significant impact on theoretical productivity of a concrete mixer. Smaller mixers have a minimal time of 60s per each cycle and 70s for bigger one. In fact, concrete plants usually work with longer production cycle. Certainly, the needed mixing time can be extended due to a longer mixing time. This is required when some additional mixtures are added into fresh concrete. The cycle time varies from 60 to 300s in the graphical model.
3. The operational productivity of a concrete mixer is calculated by multiplying technical productivity of a concrete mixer by variable of working productivity (k_{pu}). The value of working productivity variable varies from 0.6 to 0.85. This is presented from 0.1 to 1.0 in the graphical model below.
4. The operational productivity of a concrete mixer is usually not the same as the operational productivity of a concrete plant. In fact, concrete is not available for production 'in stock'. The number of hours necessary for concrete production during one shift can be significantly lower than the length of the shift. In the graph, the dependency function is presented as 0, 1, 2, ..., 7 and 8 hours of concrete production during one shift.
5. The final value represents an average operational productivity of a concrete plant in $m^3 \cdot h^{-1}$ and operational productivity of a concrete plant per one shift.

It is possible to estimate technical productivity of a mixer from the nomogram. It depends on the net capacity of a concrete mixer (or volume of concrete mixture in one batch) and a particular time of a concrete mixer working cycle (compound from filling time, mixing time and discharge time of a concrete mixer). It is possible to estimate operational productivity of a concrete mixer, following the expected value of variables of working productivity. Considering an expected time of concrete production per one shift it is also possible to establish real productivity of a concrete plant and average time.

The procedure regarding estimation of concrete plant technical and real productivity is presented in nomogram (Fig. 1). It can be seen that when the time of mixing extends from 30s to 120s (some concrete admixtures demand the minimum 2 min of mixing time) the accurate mixing cycle time appears to be 150s. Moreover, during the relatively high value variable and amount of hours of concrete production per one shift, the final productivity of a concrete plant does not reach the third of its value, which derives from the technical productivity of a concrete plant. That is taken from guidebooks.

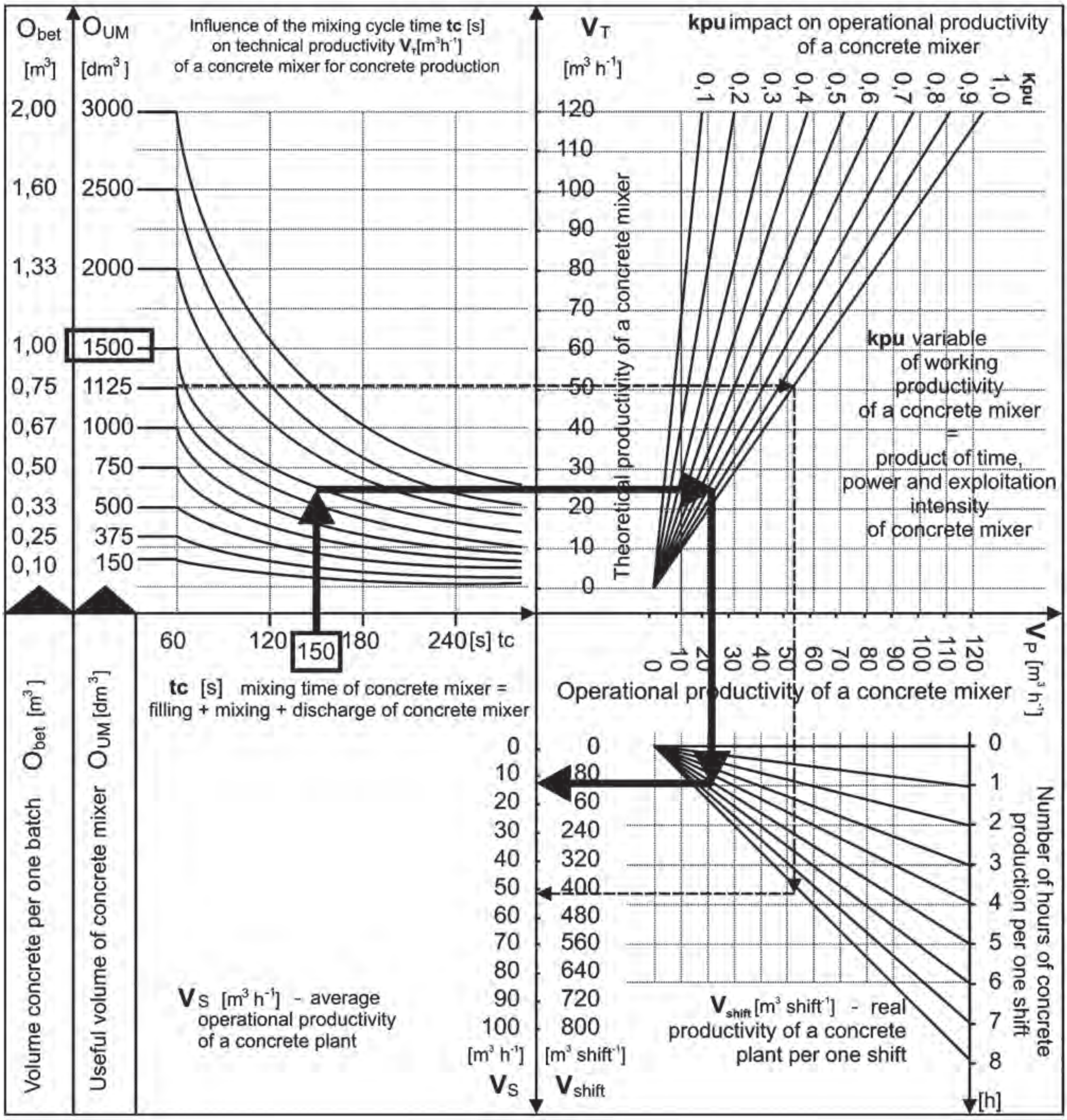

Fig. 1. The nomogram for estimation of operational productivity of a concrete plant

It is possible to use this nomogram "backwards" – 'with backward procedure of obtaining values'. For instance, we can establish what kind of a concrete mixer is necessary for required daily concrete plant productivity. This information is significant when designing the production facilities (i.e. before the plant is built).

Considering mathematical modelling, correct and precise information is very important. The measure of information accuracy (input or output), which is processed in the model above, have to be known in advance. It is also necessary to take into account the usage purpose of this model.

In the presented nomogram, the correctness measure of obtained information for lower capacity of concrete mixers is relatively low. However, in this case, it is acceptable to obtain approximate values (in case when we need the exact value, it would be possible to estimate particular values using a calculator and following simple calculation procedures from the nomogram. Values from the graph can be used as a "guard" of correctness for the values substitution in particular units). At last, the nomogram provides clear information about crucial factors and their significant impact on operational productivity of a concrete plant. That fact can accelerate and improve the decision process when objective information is needed.

5. Conclusions

It is possible to eliminate the risk during the process of realisation by correct estimation of operational productivity of machine assemblies. Accuracy and precision in provided information about concrete plants are one of the problems that many building companies encounter during the concrete process and realization of monolithic constructions. New material and new technologies often pose higher demands when it comes to the quality of fresh concrete mixture. They might have the negative impact on the mixing time. Nevertheless, this is just one of the many factors that have a significant impact on operational productivity of a concrete plant. There are many other factors that have to be taken into consideration such as unsteadiness, requirements for concrete during the working shift, etc.

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Renáta Bašková
Ryszard Dachowski

Deterministyczna metodologia określania wydajności betonowni

1. Wprowadzenie

Celem niniejszych badań jest propozycja sposobu określania wydajności maszyn budowlanych, co w rezultacie pozwoli na szybkie i relatywnie bardzo dokładne uzyskanie informacji nie tylko o wydajności technicznej, ale i głównie oszacowanie wartości wydajności eksploatacyjnej maszyn w poszczególnych warunkach produkcji budowlanej. Jednym z wyników badań częściowych przedłożonego projektu jest nomogram dla określenia technicznej i eksploatacyjnej wydajności betonowni.

Matematyczne modelowanie wydajności maszyn budowlanych i montażowych stanowi jedno ze znaczących narzędzi ułatwiających podejmowanie optymalnych decyzji podczas projektowania maszyn budowlanych i planu realizacji procesu budowlanego.

Układ modelu matematycznego wydajności eksploatacyjnej dla betonowni i nowy progresywny sposób sterowania nim, eliminujący wady stosowania wzorów matematycznych, może stać się jakościowym narzędziem dla procesu podejmowania optymalnych decyzji podczas projektowania maszyn do produkcji i transportu świeżej mieszanki betonowej.

2. Zakres i metodyka badań

Procedura obliczania wydajności betonowni została podzielona na pięć etapów. Przedstawiona sekwencja została również przedłożona w wersji graficznej modelu matematycznego do formy nomogramu.

1. Podstawowa wielkość, która jest niezbędna dla kompletnych obliczeń, to objętość użyteczna betoniarki. Zalecana objętość betonu dla jednej porcji wynosi 2/3 objętości użytecznej betoniarki. W przypadku gdy jedna porcja jest mniejsza niż zalecana objętość, kolejny etap jest liczony z prezentowaną niższą objętością betonu. Objętość betonu na jedną porcję w m^3 jest przedstawiona w modelu graficznym. Użyte są typowe rozmiary betoniarek: 150, 375, 500, 750, 1000, 1125, 1500, 2000, 2500 i 3000 litrów.

2. Czas cyklu mieszania (napełnianie, mieszanie, opróżnianie betoniarki) ma znaczący wpływ na wydajność techniczną betoniarki. Mniejsze betoniarki betonowni posiadają minimalny czas jednego cyklu 60 s, większe betoniarki 70 s. Jednakże, betonownie zwykle pracują z dłuższym czasem cyklu mieszania. Potrzebny czas mieszania może być wydłużony poprzez wymagany dłuższy czas mieszania przy użyciu niektórych domieszek do świeżej mieszanki. Czas cyklu waha się od 60 do 300 s dla tego modelu graficznego.
3. Wydajność eksploatacyjna betoniarki jest obliczana przez pomnożenie wydajności technicznej betoniarki przez zmienną wydajności (k_{pu}). Wartość zmiennej wydajności waha się od 0,6 do 0,85. Na modelu graficznym wartość $k_{pú}$ jest przedstawiona od 0,1 do 1,0.
4. Wydajność eksploatacyjna betoniarki nie musi się równać wydajności eksploatacyjnej betonowni. Mieszanka betonowa cyklicznie produkowana jest w betonowni i fakt, że nie może być ona składowana „na zapas" oznacza, że ilość roboczogodzin produkcji mieszanki podczas jednej zmiany może być znacząco niższa niż długość zmiany roboczej. Na wykresie, zależność jest przedstawiona przez funkcję dla 0, 1, 2, ..., 7 i 8 godzin produkcji mieszanki betonowej podczas jednej zmiany.
5. Powstała w procesie wartość jest średnią wydajnością eksploatacyjną betonowni w $m^3 \cdot h^{-1}$ i wydajnością eksploatacyjną betonowni przypadającą na jedną zmianę.

3. Podsumowanie

Eliminacja ryzyka w procesach realizacji jest możliwa dzięki poprawnemu oszacowaniu wydajności eksploatacyjnej maszyn budowlanych i przez rozważenie ich w planie procesu budowlanego. Konieczność uzyskiwania danych o wydajności betonowni jest jednym z problemów, które firmy budowlane napotykają podczas planowania betonowania i realizacji konstrukcji monolitycznych. Użycie nowych materiałów i nowych technologii do produkcji i pielęgnacji świeżej mieszanki betonowej stawia często wysokie wymagania w stosunku do jakości mieszanki betonowej, co może mieć zły wpływ na potrzebny czas mieszania w betoniarce. To tylko jeden z czynników, które mają znaczący wpływ na wydajność eksploatacyjną betonowni.

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THE IMPACT OF AGING ON WATER AND FROST RESISTANCE OF ASPHALT CONCRETE WITH LOW – TEMPERATURE BITUMEN

Abstract

The application of low – viscosity (low – temperature) bitumen in asphalt concrete results in an improvement of its mechanical properties (Marshall stability and deformation, static creep modulus and indirect tensile strength). The tests conducted with the procedures LTOA (long term aging) and STOA (short term aging) according to SHRP methodology prove that use of low – temperature bitumen results in slowing down the aging process of asphalt concrete. The dynamics of this process is slower than in case of traditional bitumen. The measurements of water and frost resistance (according to AASHTO T283) of asphalt concrete and of its resistance to low – temperature cracking (according to PANK 4303) have showed that the use of low – temperature bitumen results in higher resistance to weathering than that of the road bitumen 35/50 as a binder.

The paper was presented at the International Conference on Maintenance and Rehabilitation of Pavements and Technological Control in Torino, Italy.

Keywords: asphalt concrete, low viscosity bitumen, asphalt weather resistance, LTOA, STOA, AASHTO T283, PANK 4303

1. Introduction

Asphalt pavements are subject to various defects. They are the results of the combined impact of traffic and weather factors. This impact causes the constant changes in stress, deformations, temperature and humidity. Bitumen and asphalt concrete are thermoplastic materials. Temperature causes changes in their consistency. High temperature leads to lower viscosity, cohesion and adhesion. When temperature falls the binder and asphalt concrete become stiffer. The materials become breakable and prone to cracking as a result of contraction in low temperatures. The efficiency of mixes produced in „hot" technology depends on many factors. Some of them are: the interaction between durability of the mixes due to the effects of traffic and weather resistance (water and frost). The mixes made from best materials and modern technology will not perform well if they are subject to water and frost. Therefore the water and frost resistance tests are important factors in design of the composition of an asphalt concrete.

Asphalt concrete should also meet other functionality criteria, such as: fatigue crack, thermal crack, hydraulic conductivity and workability during disintegration and compaction processes. To obtain asphalt concrete which is resistant to the formation of ruts the amount of bitumen needs to be reduced. But then the number of created voids is higher and the energy consumption increases. Maintaining this relation reduces, however, the resistance of the mix to cracking and reduces water and frost resistance. The lack of durability to water and frost is caused by two factors: an excessive number of voids and the insufficient amount of the plastic mass. The aging process needs to be considered too. Regardless of the kind of mix it has an impact in the production and operation processes. Limiting the aging process requires the reduction in the void fraction and thicker coating. Therefore the compromise between the mineralogical composition and the amount of bitumen should be found.

One of the ways of solving these problems is the use of low – viscosity bitumen. Other components which lower viscosity in higher temperatures have been added. They are aliphatic hydrocarbons of long chains. Bitumen of this kind has higher softening point and lower viscosity at 25^{o}C [4].

The significant number of fractured grains and limited amount of plastic mortar form the mix which is difficult to compact. The mixes with low compaction temperature have lower internal friction. Thus, there is a reduction in the compaction resistance at temperatures of 20°C. When the aging processes are considered and temperature induced intensification of the first stage is reduced, it's possible to produce mixes of proper water and frost resistance and low susceptibility to changes in the againg process.

2. Tests on low – viscosity bitumen

The Olexobit 30 NV bitumen was used to determine the impact of aging on water and frost resistance of asphalt concrete. The traditional 35/50 bitumen from Petrochemia Płock (Poland) was used as reference. The basic properties of the bitumen undergoing the tests have been presented in Table 1.

Table 1. The basic properties of the bitumen used in the tests

No.	Property	Unit	Olexobit 30 NV	35/50 btumen	Test methodology
1.	Penetration at 25°C	0.1 mm	33	44	PN-EN 1426:2001
2.	Softening point according to PiK	°C	65.5	55.0	PN-EN 1427:2001
3.	Elastic recovery	%	60	10	PN-EN ISO 13398:2005
4.	Ductility at 15°C	cm	79	–	PN-85/C04132
5.	Breaking point	°C	-15.0	-14.0	PN-EN 12693:2004
6.	Change of mass after evaporation in a thin film	% (decrease)	0.38	0.51	PN-EN 126071:2004
7.	Increase in softening point after evaporation in a thin film	°C	6	4	PN-EN 12607-1:2004 PN-EN 1427:2001
8.	Change of penetration after evaporation in a thin film	0.1 mm	6	9	PN-EN 12607-1:2004
9.	Elastic recovery after evaporation in a thin film	%	55	–	PN-EN ISO 13398:2005

The analysis of the above test results proves that the parameters of the low – viscosity bitumen are better than those of the 35/50 bitumen. The penetration value of Olexobit 30 NV is 50% lower and its softening point 10°C higher than the 35/50 bitumen. A significant elastic recovery is an additional advantage of the low – viscosity bitumen, while the value of the elastic recovery in case of the traditional bitumen is very low.

It needs to be emphasised that during the tests on Olexobit 30 NV almost no emissions of volatile bitumen components were detected, while such emissions were observed during the measurements conducted on the 35/50 bitumen [Iwański, Mazurek 2008].

3. Design of the asphalt concrete composition

In order to determine water and frost resistance of asphalt concrete the tests were performed on asphalt concrete whose grading was 0/12.8 mm, which is used to produce the wearing coarse of the road surface loaded with KR5 type traffic. Such asphalt concrete is used in Poland for national and transit roads. An assessment of the impact of the kind of mineral aggregate on the properties of the asphalt concrete produced with the mentioned bitumen was also an important element of the tests. Asphalt concrete with the main diabase aggregate (BA-D), quarzite aggregate (BA-K) and gabbro aggregate (BA-G) was designed. A dolomite mix 0/4 and granite fractured sand was used to increase the fine fraction content. The composition of the mineral mixes of the tested asphalt concrete has been presented in Table 2.

Table 2. The composition of the asphalt concrete mineral mixes

No.	BA-G		BA-K		BA-D	
	Components	MMA	Components	MMA	Components	MMA
1.	Limestone powder	6.0	Limestone powder	6.0	Limestone powder	6.0
2.	Granite fractured Sand	19.0	Granite fractured sand	19.0	Granite fractured sand	24.0
3.	Dolomite mix 0/4	26.0	Dolomite mix 0/4	24.0	Dolomite mix 0/4	23.0
4.	Gabbro 2/5	11.0	Quarzite 2/6.3	18.0	Diabase 2/6.3	23.0
5.	Gabbro 5/8	13.0	Quarzite 6.3/10	33.0	Diabase 6.3/10	24.0
6.	Gabbro 8/11	26.0	–	–	–	–
	Total	100%	Total	100%	Total	100%

To ensure the required adhesion between bitumen and aggregate grains of the mineral mix an adhesive agent Teramin 14 was used. Its amount was of 0.2% in relation to bitumen for the tested asphalt concrete with gabbro and diabase chippings. The amount of the adhesive agent for asphalt concrete with quarzite chippings was higher. It equalled to 0.4%. The determination of the required amount of bitumen, was based on the strength measurements (according to Marshall method). Asphalt concrete produced with the traditional bitumen was compacted at 145°C. The asphalt concrete with the low – viscosity bitumen at 125°C [Iwański, Mazurek 2008].

The mineral mixes of asphalt concrete with gabbro, quarzite and diabase aggregate were designed in such a way that the void fraction contents for different kinds of bitumen, but the same kind of chippings, were similar.

It enables to properly assess and compare the test results of the analysed asphalt concrete. A statistical analysis of the void fraction content of samples with the traditional bitumen and low – viscosity bitumen was done. The hypothesis of the identity of mean values of the void fraction content was verified. The results of the analysis are presented in Table 3.

Table 3. Test results of identity of void fraction content's mean values

	BA-K[Z,O]	BA-D[Z,O]	BA-G[Z,O]
Total variance	0.040508333	0.046136667	0.063373333
Observations	6	6	6
Df	10	10	10
t Stat	2.165778992	-1.854664488	1.90355
Test t	2.228138842	2.228138842	2.228138842

The t-values are within the acceptable range. They do not contradict the hypothesis stating, that the void fraction contents are equal.

To have similar values of the void fraction content in the samples of asphalt concrete and low – viscosity bitumen, it was necessary to decrease the amount of bitumen. In the samples with the traditional bitumen of 0.2% at most for mixes with quarzite aggregate (from 5.5% to 5.3%) and diabase aggregate (from 5.4% to 5.2%). The content of bitumen in mixes with gabbro aggregate remained at the level of 5.2%.

4. Methodology and analysis of the results

The measurements were taken only for samples whose void fraction content ranged between V – 2s; V + 2s), where: V – is a mean void fraction content value in asphalt concrete, s – standard deviation. On this basis the identity of mean void fraction content values of the samples were assessed.

Based on strength tests in different temperature ranges it was determined that the samples with the low – viscosity bitumen would undergo short – term aging at 125°C. While asphalt concrete with the traditional bitumen would undergo long – temperature aging (LTOA) according to the SHRP method at 145°C. Asphalt concrete, in which the traditional 35/50 bitumen was used, was denoted with a letter Z e.g. BA-Z (similarly, concrete produced with the Olexobit 30 NV bitumen was designated with a letter O e.g. BA-O).

The tests were carried out to determine the basic physical and chemical parameters of the investigated kinds of asphalt concrete. These measurements were conducted for non – aged samples (NS) produced with the 35/50 bitumen and Olexobit 30 NV bitumen to find out the basic physical and mechanical parameters. The test results are presented in Figure 1 and 2.

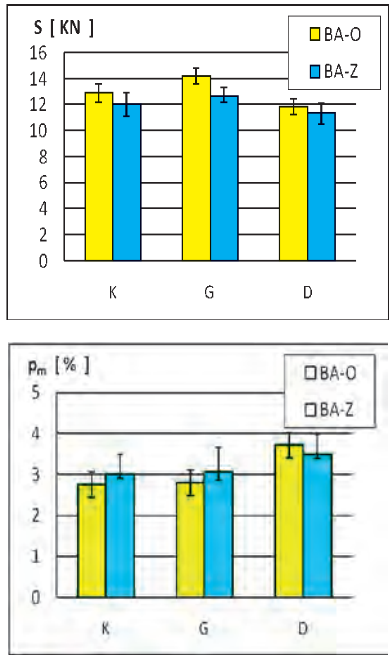


Fig. 1. Marshall stability and void fraction content in asphalt concrete for different kinds of binder

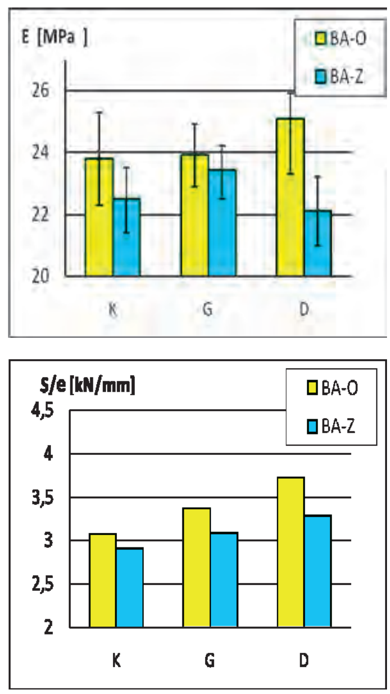


Fig. 2. Static creep modulus and Marshall stiffness of asphalt concrete for different kinds of binder

The test results of non – aged samples of Marshall stability and static creep modulus prove that the mechanical properties of asphalt concrete with low – viscosity bitumen as binder are more advantageous than that of traditional bitumen. Such asphalt concrete is more resistant to permanent deformations. The use of the low – viscosity bitumen resulted in significant increase in stability of asphalt concrete. A considerable difference between static modulus and Marshall stiffness of asphalt concrete with diabase chippings is the increased void fraction content.

In the graphs presenting changes of the physical and mechanical parameters under the aging process, asphalt concrete with the traditional 35/50 bitumen was denoted with the letter Z e.g. BA-DZ (asphalt concrete with diabase aggregate and the 35/50 bitumen) and with the letter O e.g. BA-DO when the Olexobit 30 NV bitumen was used.

The analysis of the results of stability changes of diabase, quarzite and gabbro asphalt concrete after the aging process and changes of its parameters are presented in Figure 3.

During the short and long term aging an increase in stability of asphalt concrete is observed (regardless of the kind of bitumen and aggregate). However, the increase in stability of asphalt concrete produced from the low – viscosity bitumen during the aging process (STOA/NS, LTOA/NS and LTOA/STOA) occurs more slowly than in case of the traditional bitumen. The increase in stability of asphalt concrete with the low – viscosity bitumen (regardless of the aging stage) is between ca. 10 – 15% of the stability increase as compared to asphalt concrete produced from the traditional bitumen. Consequently, during the aging process asphalt concrete with the low – viscosity bitumen becomes less stiff than in the case of the application of the traditional bitumen. Such asphalt concrete is more durable and resistant to the effects of weathering and traffic. The parameters of changes of the static creep modulus after aging WKM are presented in Figure 4.

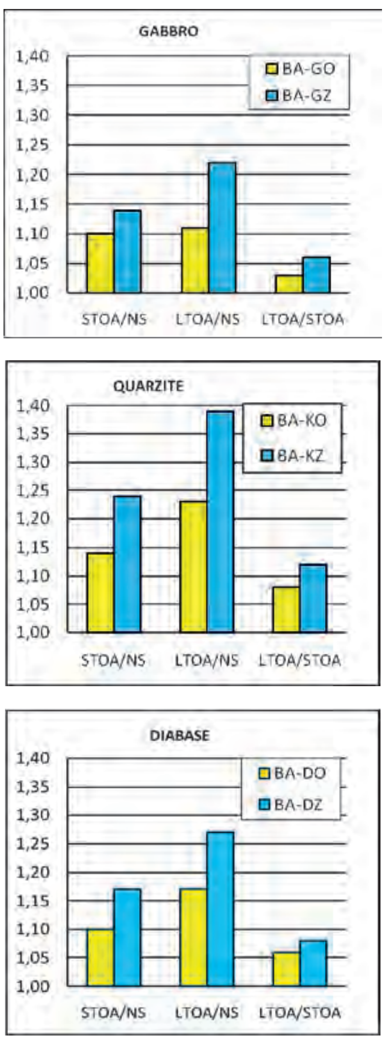


Fig. 3. The impact of aging on the stability change of asphalt concrete

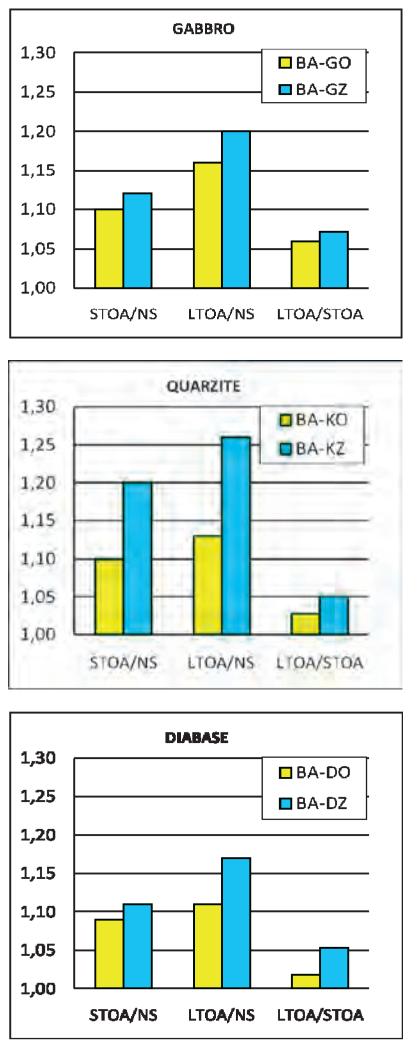


Fig. 4. The impact of aging on changes of the static creep modulus of asphalt concrete

The tests of static creep were done to verify the test results from Marshall method. The static creep modulus is determined at the temperature of 40°C under loading of 0,1 MPa for 2, 3, 5, 10, 15, 20, 30, 40, 50, 60 min with the 0.0001 mm/mm reading resolution of the deformation. From the results the following parameters are determined:

– deformation ε from the formulae:

$$\varepsilon_{max} = \Delta h / h \text{ [mm/mm]} \quad (1)$$

where: Δh = the difference between the initial height and the height after the loading period, and *h* = the initial height:

– the static creep modulus from the formulae (measurement error up to 0.1 MPa)

$$M_s = \delta_s / \varepsilon_{max} \quad (2)$$

where: δ_s = compressive stress, which equalls 0.1 MPa; and ε_{max} = deformation after 1 *h* of loading.

Changes of static creep of asphalt concrete after aging (with regard to the kind of bitumen and aggregate) are similar to the results of Marshall stability after aging. However, the dynamics of the changes of the static creep of asphalt concrete with the low – viscosity bitumen is lower than in the case when the stability change of asphalt concrete after aging was tested. During the STOA and LTOA aging the static creep of asphalt concrete with the Olexobit 30 NV bitumen was at most 10% lower (when the quarzite aggregate was used) than the static creep of asphalt concrete with the 35/50 bitumen.

The intensity of changes of the static creep of asphalt concrete with both the low – viscosity and traditional bitumen during the STOA and LTOA aging (STOA/LTOA) is similar. It implies that the rate of change of static creep modulus of asphalt concrete does not depend on the kind of bitumen.

From the analyses of test results after aging we may state that the aggregate used in its production has a significant impact on its mechanical properties. Quarzite aggregate is least suited, especially when the traditional 35/50 bitumen is applied. In this case the stability and static creep change is highest as compared to diabase and garbo aggregate.

To assess resistance to water and frost the tests were performed to determine:

- indirect tensile strength before and after curing cycles, simulating weathering on roads according to the American procedures – the AASHTO T283 method. Its detailed description can be found in [2].

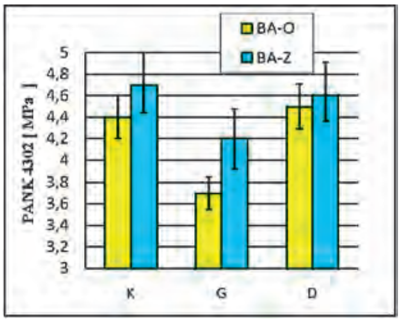
Indirect tensile strength after curing, simulating the impact of temperatures below 0°C, according to the PANK 4302 standard is described in [2] and [5].

An assessment of aging on water and frost resistance was also made. The tests were focused only on the the short – term aging due to its significant influence on mechanical properties. The results are presented in Table 4.

Table 4. The impact of aging on water and frost resistance of asphalt concrete

No.	Property of asphalt concrete	The kind of aging	The kind of asphalt concrete					
			BA-D		BA-G		BA-K	
			Z	O	Z	O	Z	O
1.	Indirect tensile strength at -2°C according to PANK 4302 [MPa]	NS	4.0	3.9	3.7	3.2	4.1	3.9
		STOA	4.5	4.3	4.0	3.5	4.5	4.2
		LTOA	4.6	4.5	4.2	3.7	4.7	4.4
2.	Indirect tensile strength ratio at 20°C according to AASHTO T283 [%]							
2a.	After curing in water and frost W_{WM}	NS	76.1	79.9	78.0	81.9	77.4	79.2
		STOA	74.1	76.2	74.9	78.6	73.8	76.1
		LTOA	70.5	75.4	71.5	76.4	67.9	75.2

There is a significant impact of the aging on water resistance and combined water and frost resistance as well as resistance to low – temperature cracking. The aging has the worst effect in case of asphalt concrete with quarzite aggregate. In this case the binder was the 35/50 bitumen with the adhesive agent. Indirect tensile strength after aging (according to PANK 4302) at 2°C was 4.7 MPa (i.e. close to the critical value of 4.8 MPa). Aging, especially short – term aging, did not cause excessive stiffening in the case of asphalt concrete with the low – viscosity bitumen. Consequently, if the road surface is made from asphalt concrete with quarzite aggregate it can experience low – temperature cracking during winter. However, this is much more likely to happen for asphalt concrete with the traditional bitumen. The aging process has also an unfavourable impact on water and frost resistance according to AASHTO T283 methododology. The indirect tensile strength ratios after aging of asphalt concrete produced from quarzite, diabase and gabbro aggregate with the 35/50 bitumen were below 75%. That is the limiting value of proper water and frost resistance. In the case of asphalt concrete produced from quarzite aggregate and the 35/50 bitumen, it lost its resistance in low temperatures as a result of aging (the ratio was below the critical value of 70%). The indirect tensile strength ratios after aging process according to AASHTO and indirect tensile strength according to PANK are presented in Figure 5.



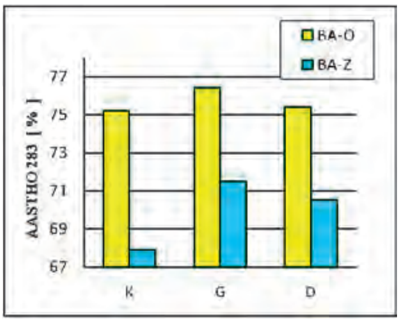


Fig. 5. Indirect tensile strength after long – term aging at 2°C and the ratios of indirect tensile strength of cured samples of asphalt concrete after long – term aging

Asphalt concrete with the low – viscosity asphalt remains elastic despite the destructive impact of aging on water and frost resistance. It may be also much more durable. In spite of aging it is still resistant to the effects of temperatures below 0°C.

The values of the indirect tensile strength ratios of asphalt concrete with low – viscosity asphalt and diabase and quarzite aggregate are similar. It can be explained by a significant void fraction content in asphalt concrete with diabase aggregate.

Based on the tests of the impact of aging on water and frost resistance of asphalt concrete with the low – viscosity bitumen, it can be concluded that this kind of bitumen limits the effects of aging due to the reduced stiffening of the mastix. Thus its significantly improving water and frost resistance of asphalt concrete.

5. Conclusions

From the analysis of the test results the following conclusions can be drawn:

1. Low-viscosity bitumen is suitable for production of asphalt concrete.
2. Low – viscosity bitumen has higher softening point and lower penetration than the traditional bitumen.
3. Asphalt concrete with the low – viscosity bitumen is characterised by better mechanical properties such as: stability, static creep and indirect tensile strength, and less considerable changes after aging.
4. The use of the low – viscosity bitumen slowed down and reduced the consequences of aging of asphalt concrete.
5. This has a significant impact on maintaining its physical and mechanical properties at the required level during the operation period.
6. Low – viscosity bitumen maintains the water and frost resistance and resistance to low temperature cracking of asphalt concrete.
7. The use of Olexobit 30 NW bitumen enables to lower the required compaction temperature of asphalt concrete of about 15-20°C.
8. Its physical and mechanical properites are at the required level; the resistance to weathering is also ensured.

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Wpływ starzenia na wodo- i mrozoodporność betonu asfaltowego z asfaltem niskotemperaturowym

1. Wprowadzenie

Jednym ze sposobów rozwiązania problemów optymalizacyjnych w zakresie technologicznym i ekologicznym produkcji betonu asfaltowego, jak również innych rodzajów mieszanek mineralno-asfaltowych wytwarzanych „na gorąco" jest zastosowanie podczas ich produkcji asfaltów niskowiskozowych. Skład ramowy tych asfaltów został wzbogacony o składniki (parafiny twardokrystaliczne) obniżające lepkość w wyższych temperaturach, którymi są węglowodory alifatyczne o długich łańcuchach. Ponadto tego rodzaju asfalty charakteryzują się znacznie wyższą temperaturą mięknienia oraz obniżoną lepkością w temperaturze 25ºC w porównaniu z tradycyjnymi asfaltami ponaftowymi [Nowości Zagranicznej Techniki Drogowej 2007].

Z uwagi na zastosowanie dużej ilości ziarn łamanych oraz normowych ograniczeń ilości plastycznej zaprawy uzyskuje się mieszanki mineralno-asfaltowe coraz trudniejsze w zagęszczaniu. Mieszanki o niskiej temperaturze zagęszczania znacznie obniżają tarcie wewnątrz mieszanki zmniejszając opór zagęszczania w temperaturach o około 20°C niższych niż w sytuacji, gdy jako lepiszcze zastosowano asfalty zwykłe. Dodatkowo uwzględniając etapy starzenia wg programu SHRP oraz redukując temperaturową intensyfikację etapu pierwszego można uzyskać mieszanki o stosunkowo dobrych wynikach odporności na działanie wody i mrozu przy niskiej wrażliwości na zmiany w procesie starzenia.

2. Badania asfaltu niskowiskozowego

W badaniach wpływu starzenia na wodo- i mrozoodporność betonu asfaltowego zastosowano asfalt Olexobit 30 NV (NV – niskowiskozowy) czyli o niskiej lepkości nazywany również asfaltem niskowiskozowym oraz w celach kontrolnych asfalt zwykły 35/50 pochodzący z petrochemii w Płocku (Polska).

Analiza wyników badań pozwala stwierdzić, że asfalt niskotemperaturowy charakteryzuje się korzystniejszymi parametrami w porównaniu z asfaltem 35/50. Posiada on mniejszą o połowę penetrację przy jednocześnie większej o 10ºC temperaturze mięknienia w porównaniu z asfaltem 35/50. Dodatkową jego zaletą jest duży nawrót sprężysty, przy prawie braku tej właściwości asfaltu tradycyjnego.

Należy również zaznaczyć, że podczas wykonywanych badań asfaltu Olexobit 30NW nie odczuwano prawie wcale emisji lotnych związków asfaltu, natomiast podczas prac z asfaltem 35/50 emisja lotnych związków asfaltu była bardzo duża [Iwański, Mazurek 2008].

3. Projekt betonu asfaltowego

W celu oceny odporności betonu asfaltowego na działanie wody i mrozu w aspekcie zastosowanego asfaltu badania wykonano na betonie asfaltowym o uziarnieniu 0/11 mm przeznaczonym na warstwę ścieralną nawierzchni obciążonej ruchem. Istotnym elementem badań była również ocena wpływu rodzaju mineralogicznego kruszywa na właściwości betonu asfaltowego ze stosowanymi w badaniach asfaltami. Zaprojektowano beton asfaltowy z kruszywem głównym diabazowym (BA-D), kwarcytowym (BA-K) oraz z kruszywem gabro (BA-G). Jako kruszywo doziarniające zastosowano mieszankę dolomitową 0/4 oraz piasek łamany granitowy.

W celu zapewnienia wymaganej adhezji pomiędzy asfaltem a ziarnami kruszywa mieszanki mineralnej zastosowano dodatek środka adhezyjnego Teramin 14 w stosunku do asfaltu w ilości 0,2% dla badanych betonów asfaltowych z grysem gabro oraz diabazowym. Natomiast dla betonów asfaltowych z grysem kwarcytowym ilość środka adhezyjnego ustalono na poziomie 0,4%. Wymaganą ilość asfaltu w zaprojektowanych betonach asfaltowych określono na podstawie badań wytrzymałościowych Marshalla. Należy dodać, iż beton asfaltowy z asfaltem zwykłym zagęszczano w temperaturze 145°C, natomiast beton asfaltowy z asfaltem niskowiskozowym w temperaturze 125°C [Iwański, Mazurek 2008].

Mieszanki mineralne betonu asfaltowego z kruszywem gabro, kwarcytowym, diabazowym zaprojektowano tak, aby zawartości wolnych przestrzeni w badanych betonach asfaltowych z różnymi rodzajami asfaltów i tym samym rodzajem grysu były zbliżone do siebie. Umożliwi to dokonanie prawidłowej oceny i porównywanie wyników badań wykonanych betonów asfaltowych. W tym celu poddano krótkiej analizie statystycznej wyniki zawartości wolnych przestrzeni próbek z asfaltem zwykłym i niskowiskozowym. Sprawdzono hipotezę o równości średnich zawartości wolnych przestrzeni.

Stwierdzono, że wartość statystyki mieści się w obszarze dopuszczalnym, zatem uzyskane wartości nie przeczą hipotezie, że zawartości wolnych przestrzeni są istotnie równe.

Aby doprowadzić zawartość wolnych przestrzeni w próbkach betonu asfaltowego z asfaltem niskowiskozowym wymagane było obniżenie ilości asfaltu w stosunku do próbek z asfaltem zwykłym o maksymalnie 0,2% dla mieszanek z grysem kwarcytowym (z poziomu 5,5% do 5,3%) i diabazowym (z poziomu 5,4% do 5,2%). Natomiast w mieszankach z grysem gabro pozostawiono wartość asfaltu na poziomie 5,2%.

4. Metodyka oraz analiza rezultatów badań

Beton asfaltowy z asfaltem niskowiskozowym charakteryzuje się tym, że proces starzenia, szczególnie krótkoterminowego STOA, nie wywołuje nadmiernego jego usztywnienia tak jak w przypadku gdy jako lepiszcze zastosowano zwykły asfalt drogowy. Również bardzo niekorzystnie proces starzenia wpływa na odporność betonu asfaltowego na oddziaływanie wody i mrozu ocenianą zgodnie z AASHTO T283. Wskaźnik wytrzymałości na pośrednie rozciąganie po procesie starzenia betonów asfaltowych wykonanych z kruszyw kwarcytowych, diabazowych i gabro, mającymi w składzie asfalt 35/50 osiągnęły wartości mniejsze niż 75% która odpowiada dobrej odporności na działanie wody i mrozu. W przypadku betonu asfaltowego z kruszywem kwarcytowym i asfaltem drogowym 35/50 należy zauważyć, iż utracił w wyniku starzenia odporność na oddziaływanie niskich temperatur z uwagi na wartość wskaźnika poniżej krytycznego poziomu 70%. Natomiast w przypadku betonów asfaltowych w skład których wchodził asfalt niskowiskozowy pomimo destrukcyjnego wpływu starzenia na wodo- i mrozoodporność nadal zachowują one rezerwę elastyczności i będą znacznie trwalsze. Pomimo procesu starzenia są one w dalszym ciągu odporne na oddziaływanie ujemnych temperatur. Należy zwrócić uwagę iż wartości wskaźnika wytrzymałości na rozciąganie pośrednie w betonach asfaltowych z asfaltem niskowiskozowym z kruszywem diabazu i kwarcytu są zbliżone. Na fakt ten może mieć wpływ stosunkowo duża zawartość wolnych przestrzeni w betonie asfaltowym z kruszywem diabazowym.

Podsumowując wykonane badania wpływu procesu starzenia betonu asfaltowego na oddziaływanie wody oraz mrozu z asfaltem niskowiskozowym można stwierdzić, że tego rodzaju asfalt ogranicza skutki starzenia, poprzez zmniejszenie usztywnienia mastyksu, poprawiając przy tym znacznie wodo- i mrozoodporność betonu asfaltowego.

5. Wnioski

Dokonując analizy wyników wykonanych badań można stwierdzić, że zastosowanie asfaltu niskotemperaturowego w betonie asfaltowym wpływa korzystnie na zmiany jego parametrów mechanicznych w porównaniu ze stosowaniem asfaltu zwykłego. Asfalt niskotemperaturowy powoduje zwolnienie tempem starzenia temperaturowego (LTOA i STOA) betonu asfaltowego. Dynamika procesu starzenia jest znacznie mniejsza z tym rodzajem asfaltu, niż gdy stosowano asfalt zwykły 35/50. Beton asfaltowy z asfaltem niskotemperaturowym charakteryzuje się również większą odpornością na oddziaływanie wody i mrozu zarówno przed, jak i po okresie starzenia, niż w przypadku, gdy jako lepiszcze zastosowano asfalt drogowy 35/50.

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ROAD SUBGRADE EMBANKMENT DEFORMATION

Abstract

The impact of snow melting on slope's stability on the roads in cold regions is presented. Examples from Russia are given and the analysis of the results of investigation is presented. The authors point out to lack of modern tools and the lack of adequate preventive technologies.

Keywords: asphalt concrete, low viscosity bitumen, asphalt weather resistance, LTOA, STOA, AASHTO T283, PANK 4303

1. Introduction

The practice of construction and reconstruction of roads showed that the basic types of deformation of the earth embankments (roadbed), made from granular materials (sands, sand and gravel ground etc.) are suffered erosion and local shear deformations in the form of landslides, earthflows, caused by the impact of water on the ground. Such a kind of deformation one may see in the regions with quite a cold climate, in the regions with snow falls, snowstorms and cold winter. This is the Northern and Central parts of the European territory of the Russian Federation, the whole territory of Siberia and Far East of the Russian Federation, Alaska (USA), high mountain areas of China (Tibet). It is confirmed by the observations of numerous authors (Fig. 1) [1, 2, 3, 4].

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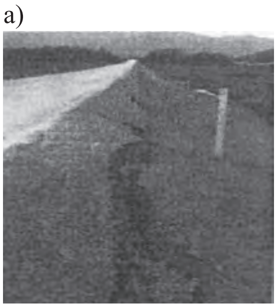

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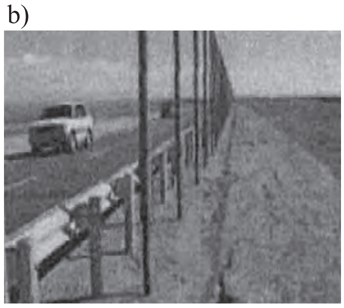

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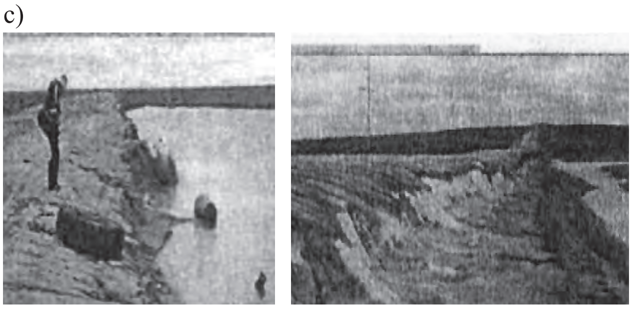

d)

Fig. 1. Local deformations of subgrade embankment: a) road in Alaska [4]; b) Qinghai - Tibet railroads [3]; c) Russia – road «Yamal» [1]; d) Russia – road «Don» 104 km [1]

2. Forms of local deformation of the slope

Deformations of grade level, caused by water erosion, are developed in the period, when the surface of formation is still not hardened and caused by considerable overspeeding of the water flowing from the ground surface (usually during the rains) of the standard (not eroding) speeds for the ground. The ways of prevention of such kind of deformations are well-known – it is timely embedment of the traffic way, waysides and slopes of grade level with the materials, which are highly resistant to the washaway.

The situation is more difficult with the deformations of the second type – shifts on the slopes. Local deformations of this type can be observed on the embankment slope of all types of ground. What is particularly interesting is the fact of appearance of shear deformations on the fill slopes from the cohesionless soil. Besides such deformations develop on the slopes of even high fills (up to 8 and more m), with asphalt and cement-concrete pavements at the carriageway and shoulders, with good grassy turfs at the slopes. Particularly often these deformations occur in the first 1-3 years of grade level service.

The possible schemes of local deformation developments are presented at the Figure 2. In all cases there are slip lines of the definite coat massif of soil in the coating surface of the slope:

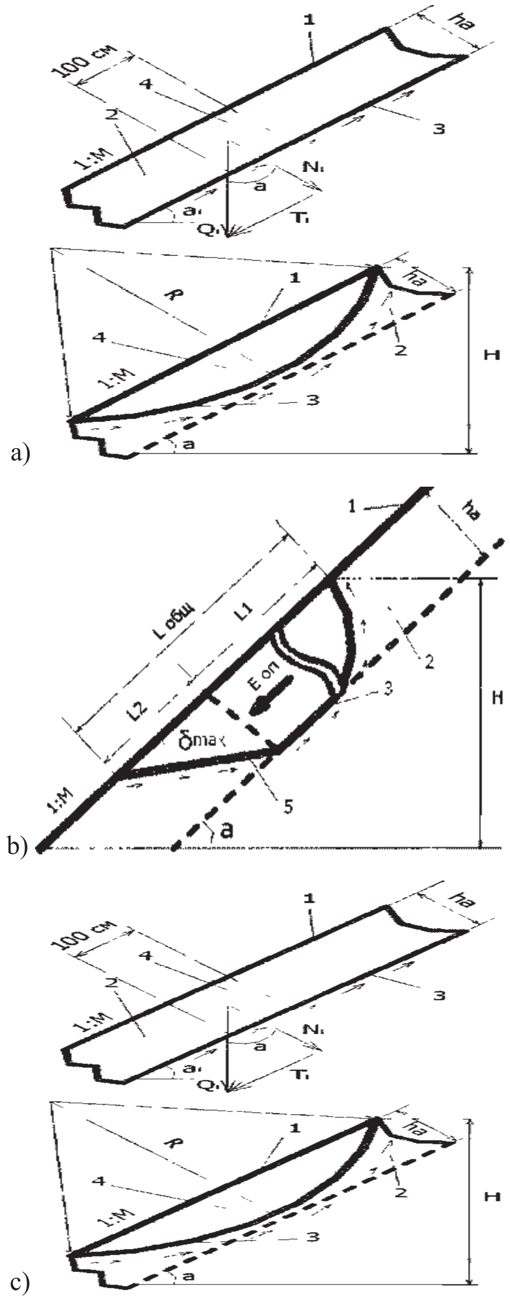

Fig. 2. Development scheme of shear deformations on the fill slopes [6]: a) due to identity element; b) inplane slip with uplift; c) destruction of the whole slope in the belt of weathering on the circular cylindrical surface; 1 – face of slope; 2 – capacity of the active zone ha; 3 – shift surface; 4 – assumed blocks; 5 – retaining prism in uplift zone

The condition of the slope stability is the balance or excess of restraining forces over the shear forces. Stability coefficient is:

$$R_{zap} = \frac{\gamma_{Zi} tg\varphi_n + C_n}{\gamma_{Zi} tg\alpha} = \frac{tg\psi_{Zi}}{tg\varepsilon}, \qquad (1)$$

$$tg\psi_{Zi} = tg\varphi_n + \frac{C_n}{\gamma_{Zi}}, \qquad (2)$$

where: γ – soil density; Zi – running coordinate of the active zone capacity of the slope perpendicularly its surface; $tg\psi_{Zi}$ – coefficient of soil shift of the active zone h at depth Zi; $tg\varphi_n$, C_n – correspondingly calculated values of angle of repose and soil cohesion at depth Zi; α – rate of slope.

2.1. The water and it role in losing stability of the slope

The analysis of the complex of restraining force showed that, the main role in the loss of local soil stability on the slopes is played by water, which causes decreasing of angle of repose and cohesion between the particulates and dynamically effects the soil grains.

Structural cohesion C_n in graded materials takes place only in case of high density and soil compactness and predominantly in case of low homogeneity on grain-size classification and is predetermined, mainly, by interlocking grain arrangement [9].

Table 1. Dependence of cohesion and angle of internal friction of soil from its porosity [9]

Type of refuse stone	Cohesion C (MPa) and angle of internal friction φ (grade) with the porosity factor ε			
	0.45	0.55	0.65	0.75
Gravel and coarse sand	0.02	0.01	–	–
	43	40	38	–
Sands of average coarseness	0.03	0.02	0.01	–
	40	38	35	–
Fine sand	0.06	0.04	0.02	–
	38	36	32	28
Dust sand	0.08	0.06	0.04	0.02
	36	34	30	26

Note: Upper line – cohesion, lower – angle of repose.

The water gets into the soil on the slopes as a result of percolation in case of storm event and snow melting.

In winter the soil of grade level freezes (after the temperature fall below -5°C). Isothermal curve of zero temperature falls lower and lower from the surface of grade level. Temperature distribution in depth gives evidence of the character of the soil straight-freezing: maximal under the roadway paving and lesser on the slopes of fills (Fig. 3 [8]).

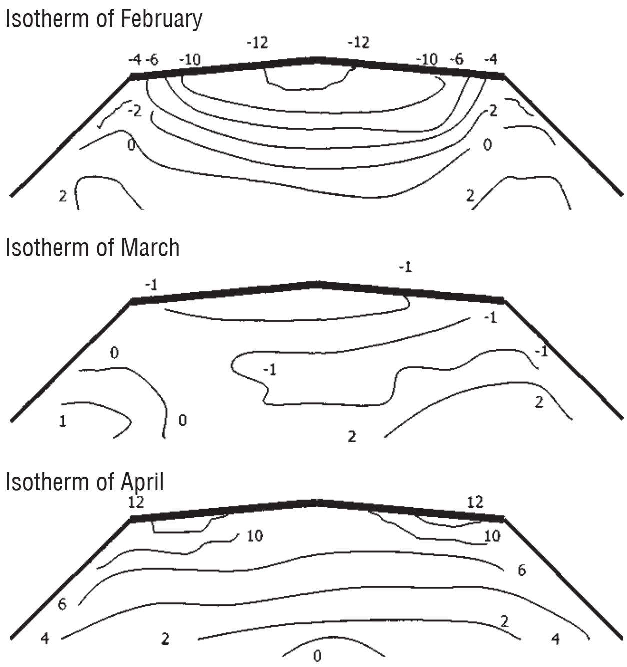

Fig. 3. Isotherms (°C) of the coat of grade level during the winter-spring months (Moscow and Moscow region)

In spring there is started a constant soil temperature rise in the upper part of the grade level. Heat current changes its direction, moreover before the start of melting. Soil frost retreat starts from two sides: from above, from the surface of grade level, and from below, from the side of thawed ground (in the mess or the ground of the grade level). The speed of frost retreat from above is more or less identical on all the areas and averages (for Moscow region) to 4 cm/day. Frost retreat from within averages to 0.6-0.7 cm/day. On the whole the thickness of layer, melted from within, amounts – in relation to the whole thickness of frost-bound layer – to 7 up to 34%.

After the start of snow melting the water from the upper coating of the snow cover, subject to the forces of gravitation, passes through the snow to the soil slope. Under the influence of melt-water there is started gradual coat frost retreat. The part of melt-water gets into the pores of the unfrozen soil, the remaining part flows through the slope – through the face of slope, under the snow cover. As the snow melts and the soil thaws the major part melt-water gets into the soil pores and the smallest part of it flows down the slope surface. At last there comes a moment, when the depth of the melted soil-work at the slope surface reaches the value, wherein the all amount of melt-water which enters the soil goes to the soil pores. The flow down the surface of the slope stops. Melt-water through the soil pores under the gravity forces reaches the surface of the soil still not melted. In case of quite a large openness there appears the water flow in the soil. Gradually takes place the formation of seepage, which flows in the soil above the border of the section «thawed ground – frozen ground» (Fig. 4).

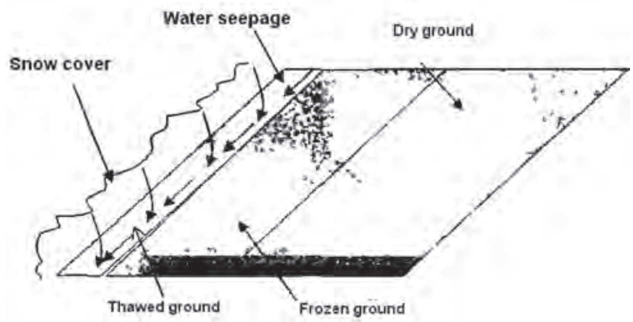

Fig. 4. Formation of the seepage on the slopes of the grade level during the snow melting

As a result there happens a considerable soil overwetting, followed by the decrease of forces, which secure the soil grains from the shift. In the zone of water filtration on soil grains operates the hydrodynamic head h_B, which appears as the result of penetration of elementary rate of water flow q, and the following formation of seepage with the rate $Q = \Sigma q_i$. Elementary rate of flow qi is formed by water, which penetrates into the soil during the snow melting on the slopes, and, in case of storm event, rainwater. The water flows through the surface of aquifuge – the surface of still frozen soil-work (in spring) or the surface of a more solid soil-work which lies lower (in summer and in autumn).

The melting surface is not plain. That is why in some places, because of the outflow obstacle, the local additional body of water may occur, which increases weighing water impact and therefore decreases restraining forces.

The water of rains which fall during the snow melting period accelerates and increases the process of snow melting, therefore leveling up the water flow in the coat. The rainwater itself also penetrates into the soil pores (because of the infiltration) increasing more the filtration flow and soil dampness. Because of the accelerated snow melting and soil frost retreat in the zone of the shelf of grade level there is possible a situation, when the water from the overdamping zone under the roadway paving through the unfrozen coat under the wayside and the upper part of fill slope comes into the filtration flow, which flows in the surficial belt of the slope.

At some time the soil overdamping reaches the level when, the shearing force exceed restraining forces. So there happens a shift – local deformation in the form of slope gutter.

As regards sand the possibility of shift deformation is worsened by its tendency to attenuation in aqueous state. Attenuation often happens [5] under the influence of filtration flow on the sand structure, in particular in case of dynamic character of filtration forces. Recently settled refuse stone of earthworks is very sensitive to the dynamic forces. Dynamic effects usually cause small shift of sand-grains, which cause sand fluidization.

In case of sand fluidization on the slopes, instead of vertical displacement of sand-grains in the process of sand settlement, there occurs considerable relative flat and vertical displacement of values as a consequence of running ground dispersion. In case of sufficient surface slope the burdens rush in the form flows to the lower areas, forming the covers, filling the cavities and hollows.

Deformation ratio depends on the rate of dynamic effects. Earthquakes can cause passing of sand into dilute state on the large area. The effects of explosions and vibration are caused only by local fractures of area structure, quite close to the whence of dynamic effects. Very often the fluidization event happens in comparatively small scales, for example, in the event of people walking or vehicle passing over the surface of loose water- saturated sands [5].

Fluidization is native to all quite loose granular soils of any grain size. However due to a larger permeability to water the retention time of coarse-grained soils in dilute state is less, than that of compact-grained and that is why the fluidization practically never occurs there.

The danger of fluidization for the resistibility and structural competence is defined not by the fact of fluidization, but by the character of its flow. The dwelling time of sand in dilute condition and toughness of burdens influences the possible construction displacement.

The rightfulness of theoretical considerations concerning the reasons for formation of local deformations on the slopes of grade level of roads was confirmed by the results of full-scale measurements of water content and soil (sand) density on the fill slopes of roads «Don» (km 103-104), built from fine sand of the borrow pit «Martemianovo» of Tula region (filtration coefficient 1-3 m/day, gradation factor -1,67). Embankment height – from 1.5 to 8 m. The research was carried out in the years 2001-2005. Water content and soil density on the slopes were defined at depth 0, 20, 40 and 60 cm during different times of the year. The depth was counted from the lower surface of top soil.

The research was carried out in field and laboratory conditions with the use of certified appliances. The character of coat moisture gradient of the slope part during the spring months is shown on Figure 5.

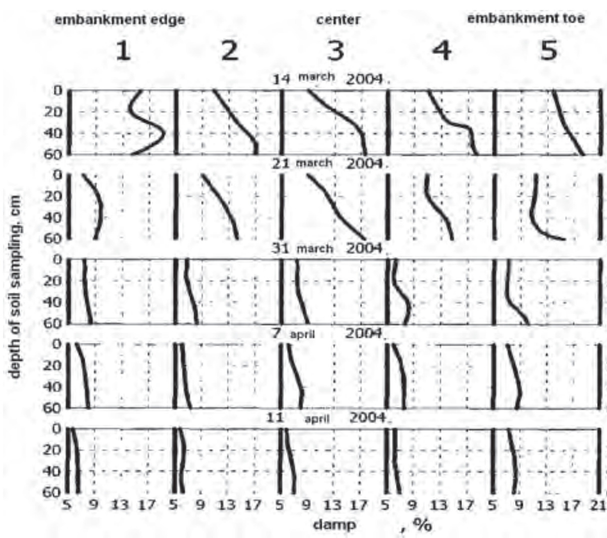

Fig. 5. Coat moisture gradient of the slope part of grade level in spring 2004 year. km 104 a/r «Don». 1-5 – point on slope contour: 1 – on the edge, 5 – embankment foot, 2-3 – passing points

Table 2. The character of placement of thawed and frozen layers on the slope of the fill in the first half of the day March, 2004, km. 104 a/r «Don», depth of fill 8 m, slope ratio 1:1.75. Slope orientation - south, air temperature at night -10°C, day +5°C

№ layer	Soil state in the layer	Layer height, m
1	Frozen ground	0.03 – 0.05
2	Hydromorphic soil	0.05 – 0.10
3	Fluidity soil	0.05 – 0.10
4	Frozen soil	0.15 – 0.20
5	Non frozen soil	–

The fact of water flow in the soil (filtration flow) was photographed (Fig. 6).

Fig. 6. Water filtration on the border of frozen and unfrozen soil (km 104 a/r «Don», 14.03.2004)

Density measurements, carried out simultaneously with the humidity estimation showed that the soil on the slopes is in quite friable state (Table 3).

Table 3. Soil density and humidity of the fill slope on 104 km road «Don» (average rates). Slope orientation – south. 14.03.2004

№ measurement point	Depth of measurement point, cm	Coat density g/cm^3	Coat humidity %
1	0 -20 -40 -60	1.83 1.80 1.76 1.87	14.5 13.8 17.3 15.7
2	0 -20 -40 -60	1.85 1.85 1.83 1.87	10.0 12.5 15.1 15.7
3	0 -20 -40 -60	1.83 1.80 1.76 1.87	9.1 12.5 16.0 17.5
4	0 -20 -40 -60	1.83 1.80 1.76 1.87	10.9 12.2 15.6 15.0
5	0 -20 -40 -60	1.76 1.83 1.83 1.85	13.0 14.0 16.2 17.5

Note: Optimum density for this sand is 1.89 g/cm^3, optimum humidity – 10.9%.

Actual values of compacting factors (0.93-0.95-0.97) during the first 2.5 years of slope work (0.93-0.95 - 0.97) turned out to be lower than regulatory value (min 0.99), which certifies soil high porosity on the fill slopes.

The research of dynamic effects of automobile transport on the soil of the slope fill parts was carried out at 104 km a/r «Don» (depth of sand fill – 6-8 m) and 94 km MKAR (depth of sand fill 2 m). On the a/r «Don» convulsion in coat generated by passage of single-unit truck of the mass 22 t with the speed of 50, 60 and 80 km/h, at Moscow Ring Motorway there was moving a real traffic flow with the intensity (in one direction) 6480 veh/h (km 9) and 7200 veh/h (km 14). The carriageway of the road «Don» has 4 lanes (two lanes in each direction), at Moscow Ring Motorway - 4 lanes in each direction. Shoulders at 1.0 m from the upper edge of embankment are hardened by plant formation. In both cases the the road pavement made of asphaltic concrete, the roadbase – of low cement content concrete, base – of sand.

Vibrational impact of automobiles on the soil of grade level was studied in dry weather, in July under the temperature of +23°C and in November under the temperature of +4°C. There were registered mean square and peak heights (X, Y, Z) of vibration acceleration. Axle X is directed perpendicularly to the road axle. The measurement time amounted to 5 to 10 minutes and included the automobile drive to the measurement point and automobile removal.

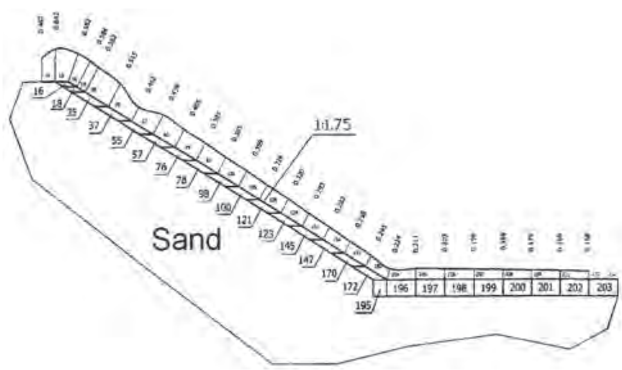

Fig. 7. Curve of the soil particles flow (mm) as a result of operation of single load. Summary constituent, disturbing frequency 10 Hz

There were made measurements (the values of vidroaccelerations), processing of the results received according to the finite element method enabled to define, that the vibration impact on the slopes for the conditions discussed in case of problem solving on normal stress amounted, average, from 0.1 up to 0.044 kg/cm^2, tangentially – from 0.04 to 0.001 kg/cm^2. Value peaks fall within the upper and lower slope part, which suggests the increased load in these zones. The movement of soil parts amounts to 0.6 up to 0.2 mm and on the whole uniformly decreases in proportion to the standing off pumping source (from the cover of the road) (Fig. 7).

3. Conclusions

The results of the research carried out enables to make a conclusion that local soil deformation on the embankment slopes are determined by the combination of the range of factors: low soil density in the slope surficial belt, high soil moistening in spring period, the presence of filtration stream of melted (and rain – in case of rain fall) water in the slope part of the roadbed. Vibrations generated in the soil of the roadbed by the cars passing by contribute to the disturbance of equilibrium of restraining and shearing forces.

Only one from the abovementioned factors is subject to control by the roads constructors – soil density of slope parts of embankment. However at the present time the embankment construction method implies that the slope soil is not compacted. The technology of soil compacting of slope of embankments still is not worked out. The recommendations concerning the following overcutting of the unconsolidated slope soil, which one may find in references, cannot be considered as rational due to many reasons. As a consequence, the tools for the works execution on slope soil stabilization are not available (one cannot view a small road roller, which rolls down the slope as a major compaction tool).

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Deformacje skarp nasypów drogowych

Praktyka konstruowania i modernizacji budowli ziemnych pokazuje, że podstawowe typy deformacji nasypów ziemnych, wykonanych z granulowanych materiałów, spowodowane są zjawiskiem erozji powierzchniowej poddanej lokalnym deformacjom spowodowanym ścinaniem. Sytuacja ta pojawia się na osuwiskach, gdzie występuje oddziaływanie wody w gruncie. Przeprowadzone wyniki badań umożliwiły sformułowanie wniosków, że lokalne deformacje gruntów na skarpach nasypów są spowodowane poprzez oddziaływanie następujących czynników: mała gęstość objętościowa pasów nasypów, wysoka wilgotność gruntu w okresie wiosennym, lokalne przenikanie wody w okresie topnienia lodu w korycie drogi. Drgania generowane w korycie drogi poprzez oddziaływanie ruchu pojazdów przyczynia się do zakłóceń w równowadze pomiędzy naprężeniami ścinającymi a hamowaniem. Aktualna wiedza dotycząca konstruowania skarp nasypów obecnie nie jest jeszcze usystematyzowana.


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POSSIBILITY OF THE APPLICATION OF MICROSTRUCTURES IN HEATING AND VENTILATION SYSTEMS

Abstract

Microstructural coatings may by successfully applied in phase – change heat exchangers to enhance heat transfer. They can be used in heating and ventilation systems as presented in the literature review. The test results of boiling heat transfer prove that it is possible to significantly increase heat flux comparing to the smooth surface if porous microstructures are applied. The measurements were conducted on the non – isothermal surface of the fin. Distilled water was used as the working fluid.

Keywords: heat exchangers, microstructures

1. Introduction

Currently, much scientific effort is directed towards the production of more efficient heat exchangers. Particularly interesting are phase – change exchangers, since they offer the dissipation of significant heat fluxes at small temperature differences. They are commonly used in refrigeration, air conditioning and other areas. The need to dissipate even higher heat fluxes led to the discovery of enhanced structures. They cover the heating/cooling surfaces and enable to improve heat transfer conditions. Consequently, eleveted heat fluxes might be expected. Such enhanced microstructures might be produced on surfaces through sintering metal powders, meshes, fibers on them or as regular microfins or microgrooves. They can be used either in condensation or in boiling, which is described further in the paper.

2. Microstructures in heating and ventilation

The pioneer work focused on boiling heat transfer enhancement was conducted by Jakob and Fritz in 1931. They found that increased roughness of the heating surface leads to the increase in dissipated heat flux. However, this effect disappears with time. This phenomenon did not cause much interest. Later, in the years 1955 – 1965, significant progress was made in exploring the mechanisms of phase change processes. That resulted in developing heat transfer enhancing structures. The first one was patented in 1968 [1]. There are many types of coatings available on the market. And many ways of manufacturing them. Figure 1 presents examples of some microstructures.

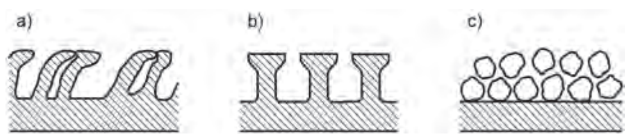

Fig. 1. Commercial microstructures: a) Hitachi Thermoexcel, b) Gewa, c) High Flux [2]

Microstructural coatings may have many applications. Gottzmann et al. [3] investigated the use of High Flux metallic covering of 50-65% porosity. Based on the experimental results of air conditioning evaporators with ammonia as the working fluid, it was concluded that it might be possible to increase heat flux twice. And, at the same time to reduce the temperature difference by about 1 K. The designed absorption ammonia chiller with the High Flux microstructure enabled to decrease the length of cooling pipes 6-7.5 times as compared to conventional systems.

The enhanced heat exchangers reduce the mass of the devices. And, consequently, the transportation and installation costs. Moreover, the amount of working fluids is limited. For refrigeration and air conditioning applications channels with internal microfins are used.

Such a surface modification results in a small increase in pressure loss as compared to smooth pipes [4].

Porous microstructures are used as the internal coating of heat pipes. They are part of efficient heat exchangers [5, 6]. In one end of a heat pipe (Fig. 2) vaporisation occurs. The heat is dissipated from the cooled element. On the other end heat is reliesed to the surroundings and condensation takes place inside. Such a heat exchanger is very reliable since there are no moving parts. The temperature difference along the heat pipe is small. This is the additional advantage. Consequently, it might be widely used in the broad temperature range (from criogenics to temperatures reaching 1600°C).

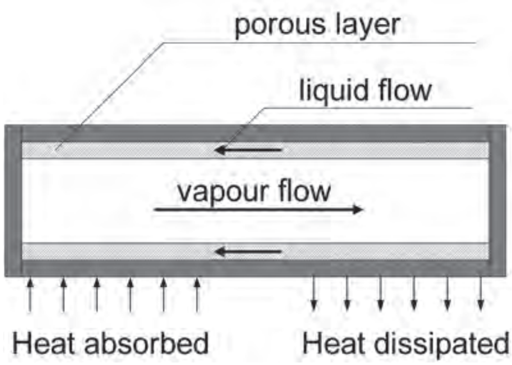

Fig. 2. Heat pipe

If, for example, a waste heat source is available heat can be efficiently transported to different rooms using the heat pipe. This concept is presented in Figure 3.

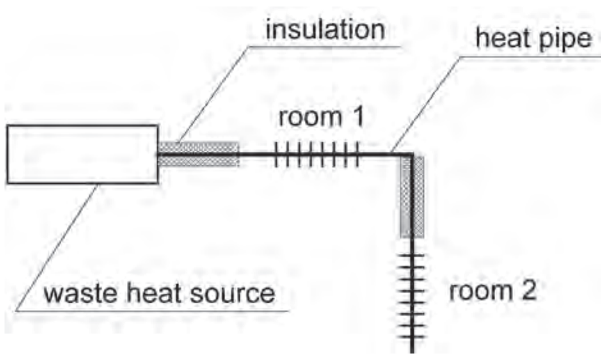

Fig. 3. Heating system constructed with heat pipes [5]

Abd El – Baky et al. [7] investigated a heat exchanger consisting of heat pipes, used to recuparate heat in air conditioning systems. The two ducts are present – one which transports fresh air from the outside of temperature 32-40°C and the other with the cooled air of constant temperature 26°C. The ducts are parallel to each other and joined with the heat pipe heat exchanger. Ratios of mass flow rate between the return and the fresh air were 1, 1.5 and 2.3. The results proved that efficiency and heat transfer for evaporator and condenser sections are increased to about 48%, when the fresh air temperature is increased to 40°C. The rise in the ratio of the return to fresh air mass flow rate by about two times results in an increase in the temperature change of fresh air by ca. 20%. And the effectiveness of the heat exchanger by ca. 26%. Figure 4 presents the scheme of the studied heat pipe heat exchanger in the ventilation ducts.

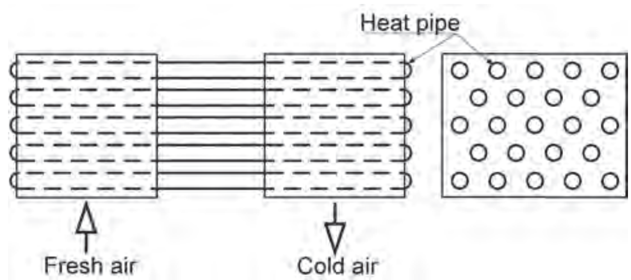

Fig. 4. Scheme of the heat pipe heat exchanger [7]

3. Boiling on surfaces with porous layers

The impact of microstructural porous coatings is investigated on the example of the non – isothermal surface of the copper fin. To this surface the metallic layers are attached and sintered in the furnace without oxygen. That is done in order to prevent oxidation. The fin is part of the vessel. Its connected with the liquid on the side with the microstructure. The other side of the fin is examined with the infrared camera. The main heater is attached to the fin at one end. It warms it up to temperatures over the saturation temperature. Because heat is supplied to one end of the fin, the temperature gradient is created. The temperature distribution is then measured with a long – wave (8-14 mm) thermovision camera. The camera is equipped with a detector of 384 x 288 pixels. Its thermal resolution is 0.08 K. The obtained temperature distribution is used to draw boiling curves. That is done according to the method presented by Orzechowski [8]. In this method the heat transfer coefficient depends exponentially on superheat (which is the difference between the wall temperature and the saturation temperature):

$$\alpha = a\theta^{n} \tag{1}$$

The experimental determination of constants: a, and n leads to the equation for the boiling curve. According to the methodology [8] the formula for superheat gradient along the fin in logarithmic coordinates can be expressed as:

$$\ln\left(\frac{d\theta}{dx}\right)^2 = \ln\left(\frac{2m^2}{n+2}\right) + (n+2)\ln\theta \qquad (2)$$

while $n \neq 2$ and m^2 is defined as the ratio:

$$m^2 = \frac{aP}{\lambda F} \qquad (3)$$

Here P and F are the circumference and surface area of the copper fin, respectively. The l is the thermal conductivity of the material.

The knowledge about the temperature distribution along the fin (after numerical differentiation) enables the constants a and n to be determined from the data fitting. Thus, the boiling curve can be drawn as a function of local values of heat transfer coefficient (or heat flux) and wall superheat using the equation (1).

The measurements were carried out for the porous microstructure. Its height was 0.6 mm and porosity ca. 0.6. The test began with recording the temperature distribution along the fin. It was done with the thermovision camera for three different levels of electric power. The power was supplied to the main heater (Fig. 5). Numerical differentiation produced the first derivative. This is presented in Figure 6. The constants a and n could be determined according to equation (2) through the linear least square fitting. Based on the above mentioned the boiling curve could then be drawn (Fig. 7). For comparison the smooth surface test results [9] are given. The test was limited to nucleate boiling heat transfer – with superheat not exceeding 18 K. It was conducted under ambient pressure. Distilled water was the working fluid.

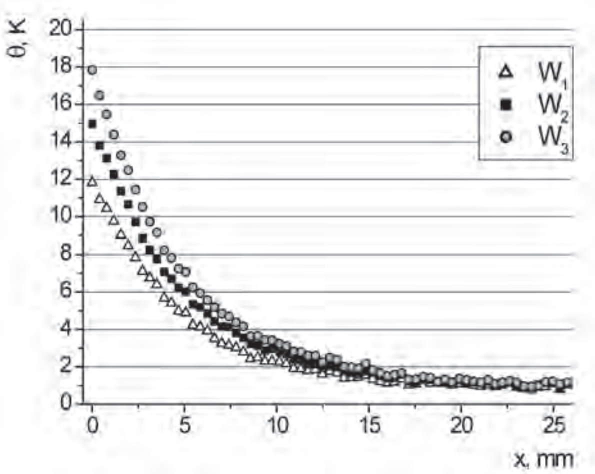

Fig. 5. Temperature distribution along the fin for three levels of electric power (W) supplied to the main heater

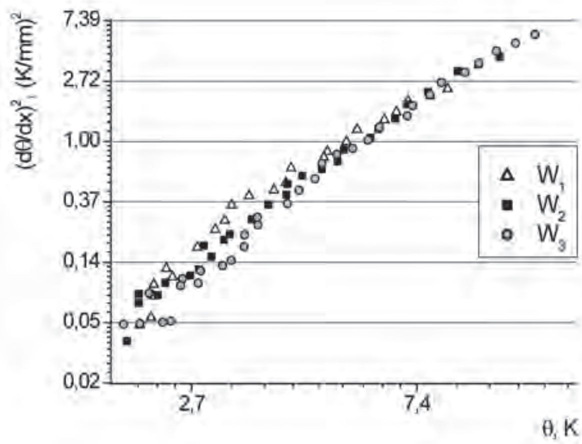

Fig. 6. Superheat gradient vs. superheat for three levels of electric power (W) supplied to the main heater ($\theta > 2K$)

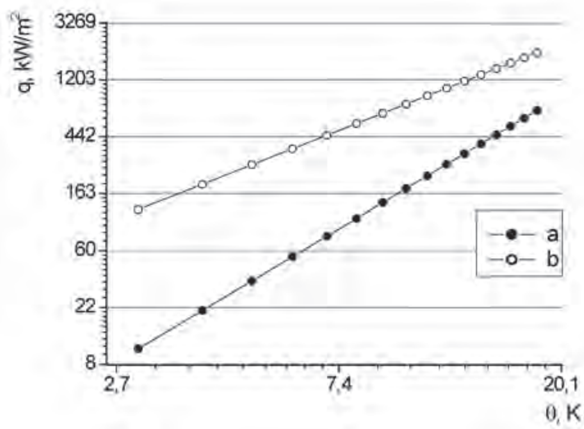

Fig. 7. Boiling curves for distilled water: a – smooth surface [9], b – microstructural coating

As can be seen in Figure 7 the application of the microstructural coating resulted in elevated heat flux in comparison to the smooth surface for the same superheat. This enhancement is especially apparent in the low superheat region. As the temperature increases more vapour is produced on the surface. Its transport through the porous layer becomes difficult due to flow resistance. Consequently, for higher superheats the curve representing the microstructure approaches the one for the smooth surface.

4. Conclusions

The microstructural coatings are part of phase – change heat exchangers. Their application might lead to the significant enhancement of heat flux at the same temparature difference. Based on the test results presented above it can be concluded that it is possible to dissipate over 10 times more heat – for lowest superheats – if porous layers are used, as compared to smooth reference surface. Heat exchangers produced with microstructures could be working with different fluids. More tests are needed to determine optimal geometrical and material properties of different kinds of porous layers. They will ensure the maximal heat flux to be dissipated. Thus, the design guidelines could be proposed for the production of such heat exchangers.

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Łukasz J. Orman

Możliwości zastosowania mikropowierzchni strukturalnych w ogrzewnictwie i wentylacji

1. Wstęp

Obecnie szerokie zainteresowanie wzbudzają wysoce efektywne wymienniki ciepła. Szczególnie interesujące są te, które pracują przy zmianie fazy czynnika, ponieważ umożliwiają odbieranie znacznych gęstości strumienia ciepła. Są one powszechnie stosowane m.in. w chłodnictwie czy klimatyzacji. Potrzeba odbierania coraz większych strumieni ciepła doprowadziła do odkrycia pokryć intensyfikujących wymianę ciepła, które nakłada się na powierzchnie wymienników. Takie mikrostruktury wytwarza się ze spieczonych proszków metalicznych, siatek czy włókien lub jako mikrożebra lub mikrowgłębienia. Mogą być one stosowane w przypadku zarówno kondensacji jak i wrzenia.

2. Mikropowierzchnie strukturalne w ogrzewnictwie i wentylacji

Pierwszą pracą dotyczącą intensyfikacji wymiany ciepła przy wrzeniu były badania Jakoba i Fritza w 1931 r., w których wykazali, że zwiększenie chropowatości powierzchni grzejnej prowadzi do zwiększenia ilości odbieranego ciepła. Zjawisko to nie było jednak obiektem większego zainteresowania. Dopiero lata 1955-1965 zaowocowały opracowaniem struktur intensyfikujących wymianę ciepła przy wrzeniu. Pierwszą taką strukturę opatentowano w 1968 r. [1].

Mikropowierzchnie strukturalne mogą być stosowane w wielu gałęziach przemysłu. Gottzmann i in. [3] opisali zastosowanie powierzchni High Flux w parownikach klimatyzatorów wykorzystujących cykl absorbcyjny amoniaku. Przeprowadzone doświadczenia przy wrzeniu roztworu 16-17% amoniaku dowodzą, że możliwe jest dwukrotne zwiększenie gęstości strumienia ciepła przy jednoczesnej redukcji różnicy temperatury o około 1 K.

Wymienniki rurowe intensyfikujące wymianę ciepła są powszechnie stosowane w chłodnictwie i klimatyzacji. Powodują zmniejszenie wymiarów urządzeń i wymaganej ilości płynów chłodniczych w wymienniku. W przypadku zastosowań chłodniczych i klimatyzacyjnych stosuje się obecnie rury z wewnętrznymi mikrożebrami [4].

Powierzchnie porowate stosowane są jako wypełnienie rur ciepła, stanowiących element efektywnych wymienników ciepła [5, 6]. W rurze ciepła można wyróżnić część, w której następuje parowanie (odbieranie ciepła) i skraplanie, gdzie następuje oddawanie ciepła. Brak części ruchomych oznacza wysoką niezawodność takich urządzeń. Dodatkową korzyścią jest prawie stała temperatura na ich długości.

Abd El – Baky i in. [7] przedstawili wyniki badań wymiennika złożonego z rur ciepła przeznaczonego do rekuperacji ciepła w układach klimatyzacyjnych. Układ pomiarowy obejmował dwa kanały – jeden ze świeżym powietrzem zewnętrznym o temperaturze 32-40^{o}C i drugi z powietrzem o stałej temperaturze 26^{o}C. Kanały zlokalizowano równolegle i połączono wymiennikiem z rurami ciepła. Około dwukrotny wzrost ilorazu strumienia powietrza chłodnego do świeżego powoduje zwiększenie spadku temperatury powietrza świeżego między wejściem a wyjściem z wymiennika o ok. 20% i zwiększenie efektywności wymiennika o ok. 26%.

3. Wrzenie na powierzchni z pokryciem porowatym

Badania wykonano na stanowisku, którego głównym elementem jest miedziane żebro z mikrostrukturą porowatą o grubości 0,6 mm i porowatości ok. 0,6. Do badań wykorzystano kamerę termowizyjną o rozdzielczości 0,08 K, w celu określania rozkładu temperatury na długości. W wyniku zastosowania procedury opisanej przez T. Orzechowskiego [8] uzyskano krzywą wrzenia, którą porównano z wynikami dla powierzchni gładkiej. Wykazano znaczne możliwości intensyfikacji wymiany ciepła w porównaniu do powierzchni odniesienia, jeśli zastosuje się dodatkowe pokrycie mikrostrukturalne.

Największą intensyfikację wrzenia obserwowano dla obszaru małych przegrzań – rys. 7 (przegrzanie oznacza różnicę temperatury powierzchni grzejnej i temperatury wrzenia). Wzrost temperatury powodował zwiększoną produkcję pary, a utrudniony jej transport z powierzchni grzejnej przez warstwę porowatą powodował, że krzywa wrzenia dla analizowanego pokrycia zbliżała się do wyników dla powierzchni gładkiej.

4. Wnioski

Struktury porowate mogą stanowić element efektywnych wymienników ciepła, wykorzystujących zjawisko przemiany fazowej. Zastosowanie mikropowierzchni strukturalnej spowodowało ponad 10-krotny wzrost gęstości strumienia ciepła dla najmniejszych przegrzań przy wrzeniu wody pod ciśnieniem atmosferycznym. Rozszerzenie badań na inne czynniki i struktury może umożliwić określenie optymalnych parametrów geometrycznych i materiałowych, celem maksymalizacji gęstości strumienia ciepła. W związku z czym możliwe byłoby wówczas zaproponowanie wytycznych projektowych dla takich wymienników.

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MICROCLIMATE IN A FLAT WITH ADDITIONAL AIR INTAKES

Abstract

The relation between the gravitational ventilation and distribution of intake openings are presented here. The possibility of installing additional openings to provide sufficient quantity of indispensable air is presented here. These are essential to gas combustion in heating devices. Two different ways of localization of such openings are discussed. The first one is based on making openings supplying the air to external barriers. This results in the limitation of backward duct in ventilating ducts. Simultaneously, the decrease of comfort zone in flats is noticeable. Placing the opening directly in the external barrier causes rapid cooling of flats. This results in feeling of draught. The second solution dealt with placing identical opening in an internal barrier, bordering with the staircase. The effect of such solution was similar to the first one. It was also based on limiting the occurrence of backward ducts inside ventilating ducts. However, in the latter case, we did not notice the deterioration of microclimatic conditions in examined flats.

Keywords: Building's microclimate conditions, ventilating air, ventilating ducts, carbon dioxide concentration

1. Introduction

In Poland in the past 20 years or so, there has been a growth of interest in energy saving construction. They were mainly: constructors, developers and investors planning modernization of existing buildings. They used energy saving technologies essential to heating of the buildings. They were focused on hermetic woodwork and warming of external walls. The hermetic woodwork was accomplished through the exchange of door's and window's woodwork. The warming of external walls was done with foamed polystyrene. The measurable benefits of these solutions were: less costs in heating of the building and in renovation of the facade Due to such solutions, they qualified for so called "thermo modernizational bonus" from nation's budget. Unfortunately, they did not pay enough attention to the air exchange. As they considered it to be too expensive, not profitable enough and of little importance. In these buildings constructors planned the necessary minimum (following only the national norm guidelines). In case of thermo modernization they totally ignored this problems. It resulted in good building lagging without the inflow of the right quantity of ventilating air. But that (i.e. the right quantity of ventilating air) is essential to sanitary conditions, conditions of living and to gas combustion in gas-fired boilers. Sufficient quantity of air intake flow is necessary for combustion process. It is supplied through air intakes and untightness in external lining. Lack of that flow causes the phenomenon of backward duct in ventilating ducts. Its occurrence causes deterioration of microclimatic conditions in the flats.

2. Requirements of national norms

All requirements pertinent to gravitational ventilation are to be found in three legal acts. In the decree (Dz.U. Nr 75, poz. 690) the outline of the general requirements which buildings, their technical conditions, their location, and ventilation, is presented. Detailed requirements pertinent to individual solutions regulates norm (PN-83/B-03430), together with its supplement (PN-83/B-03430:Az3:2000). This norm says, that windows with infiltration coefficient smaller than 0.3 $m^3/(mhdaPa^{2/3})$ mounted in habitable buildings of public usefulness should be equipped in air intakes. They should provide the right quantity of an air necessary for ventilation. In case of the lack of air intakes, mechanical supply ventilation has to be installed. In other cases, the coefficient of infiltration of woodwork has to be within 0.5 – 1.0 m^3 $(mhdaPa^{2/3})$. However the definition of the range of coefficient of air penetration through the window and the differential pressure, for which the values are given rises some concern. According to valid regulations the value $\Delta p = 10$ Pa, is set regardless of the shape or size of the building. The specifications of requirements in selected countries are presented in Table 1.

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Table 1. The comparison of window tightness (Miśniakiewicz, 2002; Nowakowski, 2002) – part one

No.	The country and the name of the norm	The description of the building	Required coefficient of air penetration	Single quantity of air for $\Delta p = 1$ Pa
1.	Belgium STS 52.0	H = 0 – 18 m H > 18 m	3.0 m^3/mh for 100 Pa 2.0 m^3/mh for 100 Pa	0.040 dm^3/ms 0.027 dm^3/ms
2.	Denmark DS. – 417	For all buildings	0.50 dm^3/ms for 30 Pa	0.053 dm^3/ms
3.	Finland SFS 3304	Class 1 (max) Class 2 (min) Class 2 (max) Class 3 (min)	0.50 m^3/m^2h for 50 Pa 0.5 m^3/mh for 50 Pa 2.50 m^3/mh for 50 Pa < 7.0 m^3/mh for 50 Pa	0.011 dm^3/m^2s 0.011 dm^3/m^2s 0.053 dm^3/m^2s 0.093 dm^3/m^2s
4.	France NF P20 302	Class A1 Class A2 Class A3 (tight buildings)	20 – 60 m^3/m^2h for 100 Pa 7 – 20 m^3/m^2h for 100 Pa < 7 m^3/m^2h for 100 Pa	0.266 – 0.789 dm^3/m^2s 0.093 – 0.266 dm^3/m^2s < 0.093 dm^3/m^2s
5.	Holland NEN – 3661	The „normal" terrain: H ≤ 15 m H = 15 – 40 m H = 40 – 100 Terrain close to the sea: H ≤ 15 m H = 15 – 40 m H = 40 – 100 m	 2.50 dm^3/ms for 75 Pa 2.50 dm^3/ms for 150 Pa 2.50 dm^3/ms for 300 Pa 2.50 dm^3/ms for 300 Pa 2.50 dm^3/ms for 300 Pa 2,50 dm^3/ms for 450 Pa	 0.145 dm^3/ms 0.092 dm^3/ms 0.058 dm^3/ms 0.058 dm^3/ms 0.058 dm^3/ms 0.044 dm^3/ms
6.	Canada 3–A440–M84	Small buildings A1 Medium buildings A2 Tall buildings A3	2.79 m^3/mh for 75 Pa 1.65 m^3/mh for 75 Pa 0.25 m^3/mh for 75 Pa	0.045 dm^3/ms 0.027 dm^3/ms 0.004 dm^3/ms
7.	Germany DIN-18055	A – H = 0 – 8 m B – D – H > 8 m	6.00 m^3/mh for 50 Pa 3.00 m^3/mh for 50 Pa	0.126 dm^3/ms 0.063 dm^3/ms
8.	New Zeland NZS N42211:87	Tight buildings Buildings of medium tightness Buildings of low tightness	0.60 – 2.00 dm^3/ms for 150 Pa 2.00 – 8.00 dm^3/ms for 150 Pa 8.00 – 17.00 dm^3/ms for 150 Pa	0.022 – 0.073 dm^3/ms 0.073 – 0.147 dm^3/ms 0.147 – 0.623 dm^3/ms
9.	Poland PN-EN ISO 6946:1998	All buildings	0.5 – 1.0 m^3/mh for 10 Pa	0.03 – 0,06 dm^3/ms
10.	Switzerland SIA 331	H ≤ 8 m H = 8 – 20 m H = 20 – 100 m	5.65 m^3/mh for 150 Pa 8.95 m^3/mh for 300 Pa 14.25 m^3/mh for 600 Pa	0.056 dm^3/ms
11.	Sweden	Tight buildings Untight buildings Buildings of H > 8 m	1.7 m^3/m^2h for 50 Pa 5.6 m^3/m^2h for 300 Pa 7.9 m^3/m^2h for 500 Pa	0.036 dm^3/ms
12.	Great Britain BS 6375	Open area, External pressure. < 1600 Pa As before, but^3 1600 Pa Building site Internal pressure < 1600 Pa As before, but^3 1600 Pa High tightness Open area As before, but building site	 6.34 m^3/mh for 50 Pa 4.84 m^3/mh for 50 Pa 1.00 m^3/mh for 200 Pa 1.00 m^3/mh for 300 Pa 1.00 m^3/mh for 600 Pa 6.60 m^3/mh for 600 Pa	 0.133 dm^3/ms 0.102 dm^3/ms 0.008 dm^3/ms 0.006 dm^3/ms 0.004 dm^3/ms 0.02 dm^3/ms
13.	USA/ASHRA E 90 – 80	All buildings	0.77 dm^3/ms for 75 Pa	0.045 dm^3/ms

Apart from the difference of pressure, in the majority of countries listed above other factors such as: the height of the building, its tightness or location in the area are also considered. One may notice (Table 1) that Polish requirements are one of the strictest.

3. Carbon dioxide as the indicator of an air quality

The relation between the quantity of ventilating air and the concentration of carbon dioxide is the recognized criterion of an air quality evaluation. The frequent occurrence of carbon dioxide in typical conditions is not dangerous. This gas causees the feeling of air stuffiness. The growth in carbon dioxide concentration comes from external and internal sources. The level of carbon dioxide concentration in the atmosphere steadily grows (as the consequence of industrialization). At present, its value oscillates between 400 – 600 ppm. Living organisms and gas devices are the source of carbon dioxide inside the rooms. Its concentration depends on organism's activities. For individuals (people) it varies. It depends (among others) on their diet, the mass of their body and their physical condition. Naturally, the concentration of carbon's dioxide inside the room depends on other factors as well. These are (among others): the number of people inside the room, not sufficient air exchange (i.e. the fall of the content of oxygen in the air) and intensification of combustion processes in the room (e.g.: smoking tobacco, or preparing the meals). That is why carbon dioxide was chosen as an indicator of the microclimate quality inside considered flats.

According to Hodgson (Liddament, 1996) the upper limit of carbon dioxide concentration which is not harmful to the man is in the range of about 8500 ppm. The present standards for the internal air, assume the admissible level of carbon dioxide concentration on the level of 1000 ppm. This coefficient was proposed already in the nineteenth century by Max von Pettenkofer (Nantka, 2004).

Table 2. Emission of carbon dioxide for different levels of activity (Fanger, 1980)

A type of activity	Emission of carbon dioxide [dm^3/h]
Dream (motionless recumbent position)	10 – 12
Sitting position (without doing any work)	12 – 15
Sitting posture – easy office works	18 – 25
Doing work of average difficulty	32 – 44
Doing hard work	> 55

Table 3. The influence of carbon dioxide on human organisms (Sowa, 1995)

No.	Concentration of carbon dioxide in the air [ppm]	The symptoms
1.	300 – 450	Dry external air
2.	1000	Basis for the qualification of most standards concerning the quantity of ventilating air for a single person
3.	1550 – 500	The growing feeling of stuffiness
4.	5000	Limitations concerning working posts
5.	7000 – 10000	The growth of breathing capacity
6.	15000	The appearance of metabolical stress
7.	20000	The increased frequency of breathing and headaches
8.	40000 – 52000	Carbon dioxide concentration in the air breathing out from the lungs
10.	60000 – 80000	The possibility of partial paralysis
11.	> 80000	Losing of consciousness in a few minutes

4. Object of researches

The object of researches were typical parameters of the internal microclimate: the temperature, the humidity of the air, the number of exchanges and carbon dioxide concentration. The research was conducted in habitable buildings. They were three and four – storied, semi – detached buildings, built in years 2000 – 2003. These buildings were equipped with the channel system of natural ventilation. In flats there were installed gas cookers and two – functional stoves with open chamber of combustion, powered by the earth gas. Buildings had external walls. The walls were warmed with foamed polystyrene covered with a thin – layer mineral plaster. The windows' woodwork with infiltration coefficients smaller than 0.3 $m^3/mhdaPa^{2/3}$ (according to producer's data) was equipped with an air intakes.

5. Results of investigation

During the first year, all the occupants felt inconveniences of proposed solutions. In case of gas cooker, the system of gravitational ventilation worked very well. However in case of gas stove, in the majority of these flats certain inconveniences occurred. They mostly relied on the appearance of backward ducts in air grates. Also, condensing water steam on window panels were seen. Moreover, the occupants complained of headaches and the lack of fresh air in the rooms. The above mentioned phenomena were intensified in the winter. After the first year, the focus of mould was noticed in the flats. They were mostly in the kitchens and bathrooms. In some cases they were also noticeable in habitable rooms. While performing the measurements, large discrepancies in data were noticed in considered flats. There were problems with gravitational ventilation, especially in flats situated in the last two storeys. The backward ducts in air grates was noticed. The speed of ventilation near the outlet from the air grate fell down to 1.15 m/s. While the air temperatures outside were about – 10°C, the temperatures near the grate outlet were approximately +16°C in rooms with air grates and air ventilation. And the interior temperatures near heating (while turned on) equaled about +17 – +19°C (Fig. 1). During the usage of gas range and gas heating devices, the very quick growth of carbon dioxide concentration was observed (Fig. 1 and 2). These values were several times higher than the accepted standards [about 2200 – 3500 ppm (Sowa, 1995)]. None of gas devices was turned on in periods when the level of carbon dioxide concentration fell to

500 – 1150 ppm. The very interesting phenomenon occurred in all investigated flats. It was the alternating character of the stream of ventilating air in air grates. That implied, that ventilation and removing the air took place through kitchen or bathroom air gates.

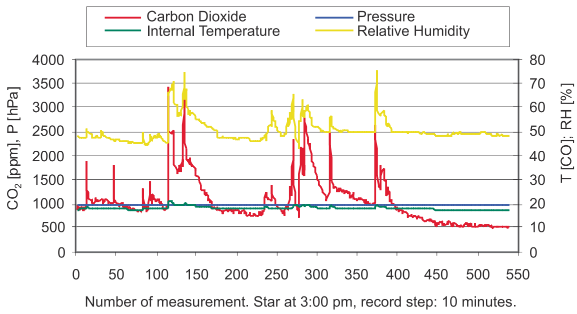

Fig. 1. The diagram of the parameters of the microclimate in selected flat with the air inflow through the ventilating duct

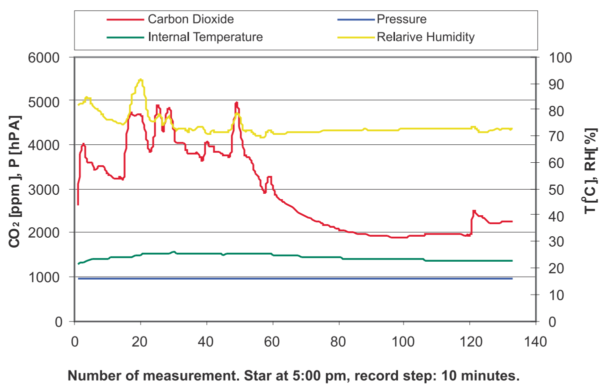

Fig. 2. The hourly diagram of microclimate's parameters in selected flat, in which users stuck some air grates

However, the air inflow occurred mostly through ventilating duct in the bathroom. That was the result of installing there two – functional stoves. They provided enough quantity of the air, necessary for gas combustion. This inflow was so large that it made impossible using the bathroom and the occupants stuck the inlets of ventilating ducts with foil. An hourly diagram of parameters of the internal microclimate for such flat is presented in Figure 2. These conditions led to a large growth of carbon dioxide concentration [up to the level of approx. 5000 ppm]. Even during the night these values didn't drop below the 2000 ppm. The relative air humidity grew up quickly. It ranged from 70% to 90%.

To solve this problem in the investigated flats and to – simultaneously – improve the microclimate conditions, making additional openings was proposed. Their diameter was that of f 120 mm was proposed for the improvement of the microclimate in considered flats. The openings had to be made in the external walls to supply the external air. Also an aspiromatic type devices on the outlets of ventilating ducts were installed. After the work was completed, the correct direction of the air flow in all ventilating ducts occurred again. Unfortunately, when the temperature fell below 0°C, the occupants noticed both: cooling of the flats and too large speed of air inflow (the feeling of draught). Considering the inhabitants safety and comfort of their living condition, the previous state was restored. The additional openings in internal walls facing the staircase and situated in the direct proximity of gas stoves were made. This resulted in better ventilation. In that way, the air was initially warmed instead of flowing directly from outside. The diagram of the parameters of microclimate in one of the selected flats where the above solutions were tested is shown in Figure 3. The analysis of this diagram shows, that there was the constant internal temperature of +20 – +22°C. The relative humidity did not exceed 65% which complied with corresponding standards. Simultaneously, the carbon dioxide concentration comprised on the level 700 – 1500 ppm. At some points it goes beyond 2500 ppm. These are however temporary values, which do not influence the health or the mood of occupants.

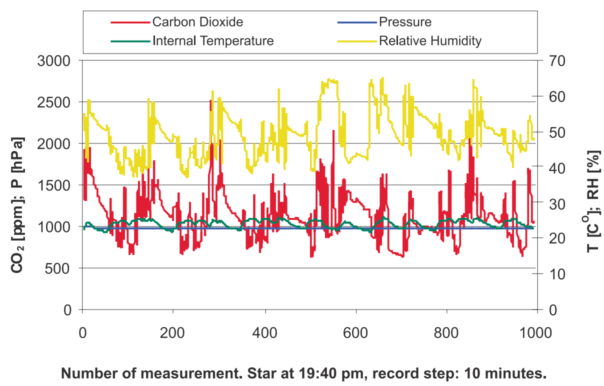

Fig. 3. Weekly diagram of microclimate's parameters in selected flat, after installing additional inflow ducts between the flat and the staircase

6. Analysis of the results

Observed irregularities are the result of the limited inflow of the external air to flats. The air inflow is indispensable for appropriate functioning of the ventilation system. And, also for the proper gas combustion in heating devices and stoves. This

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limited inflow is the consequence of unsuitable balance of the air flows. Additionally, gas heating devices disturb the proper functioning of ventilation system in the building. The sudden growth of carbon dioxide concentration is caused by an installment of the two – functional stoves with the open combustion chamber. After installment of this device, the sudden growth in carbon dioxide concentration appears, and turning back of duct in ventilating duct is observed. Window untightness influences air exchange up to the certain degree, too. The increase in the air inflow this way is inadequate. The occupants, especially the ones reluctant to their usage, should use it wisely. When it comes to untightness of the windows, one should accept the lack of control over the inflowing air stream. The quantity of inflowing air does not depend on the internal air parameters. Additionally, quick cooling of the rooms occurs in winter. It was was particularly burdensome after installing additional opening for air supply, directly from outside. The usage of openings through staircase for gas combustion in two – functional stoves, decidedly improved the parameters of internal microclimate. Yet, the microbiological analysis of the air is still required.

7. Conclusions

Based on the results of this research, the following conclusions may be drawn:

1. The quantity of ventilating air depends on external climate; and in particular: the air temperature, direction and speed of the wind.
2. Disorders of microclimatic conditions in flats with tight casing and installed intakes appear on upper storeys. They result in backward ducts and air exchange.
3. Working gas stoves with open combustion chamber make the proper work of ventilation's system difficult.
4. The appearance of heating device should depend on additional separate duct. It should either supply the air to this device or closed combustion chamber should be used.
5. The size and the placement of intake openings is important. Before making any decisions, the following factors should be considered:
   – placement of the flat,
   – constructional possibilities,
   – the demand for the air (balance).

Preliminary warming of ventilating air narrows down the possibility of disturbance of internal microclimate conditions.

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Marek Telejko

Warunki mikroklimatyczne w mieszkaniach z dodatkowymi nawiewnikami powietrza wentylacyjnego

1. Wstęp

W ostatnim okresie projektanci i deweloperzy zaczęli powszechnie stosować technologie dające duże oszczędności energii potrzebnej do ogrzania budynków, m.in. szczelną stolarkę oraz ocieplenie ścian zewnętrznych styropianem. Uzyskano w ten sposób dobrze izolowane cieplnie budynki bez zapewnienia napływu niezbędnej ilości powietrza wentylacyjnego, potrzebnego nie tylko ze względów higienicznych i bytowych, ale również do spalania gazu w piecach. Niewystarczająca ilość powietrza niezbędna dla procesów spalania, które dostarczane jest poprzez nawiewniki powietrza, oraz nieszczelności w obudowie zewnętrznej, uzupełniona zostaje w takim przypadku poprzez zjawisko wstecznego ciągu w kanałach wentylacyjnych.

2. Wymagania norm krajowych

W Polsce wymagania dotyczące wentylacji grawitacyjnej zawarte są w trzech krajowych aktach prawnych. W rozporządzeniu w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie przedstawiono ogólne wymagania dotyczące wentylacji. Natomiast szczegółowe wymagania dotyczące poszczególnych rozwiązań systemów wentylacji reguluje obowiązująca już od ponad dwudziestu lat norma PN-83/B-03430 oraz jej uzupełnienie PN-83/B-03430:Az3:2000. Powszechne wątpliwości budzi tutaj sposób określenia zakresu współczynnika przenikania powietrza przez okna oraz różnicy ciśnień, dla której podane są jego wartości. Według obowiązujących przepisów przyjmowana jest wartość $\Delta p = 10$ Pa, bez względu na warunki obliczeniowe oraz kształt czy wielkość budynku. Porównując wymagania polskie z wymogami innych krajów należy stwierdzić, że są jednymi z ostrzej postawionych przy jednoczesnym braku powiązania ich z rzeczywiście istniejącymi różnicami ciśnień.

3. Dwutlenek węgla wskaźnikiem jakości powietrza

Związek pomiędzy ilością powietrza wentylacyjnego a stężeniem dwutlenku węgla wewnątrz pomieszczeń jest od lat uznawanym i powszechnie stosowanym kryterium oceny jakości powietrza. Obecnie jego wartość waha się w granicach 400 – 600 ppm. Obecne standardy dla powietrza wewnętrznego zakładają dopuszczalny poziom stężenia CO_2 na poziomie 1000 ppm.

4. Przedmiot badań

Przedmiotem badań były typowe parametry mikroklimatu wewnętrznego, tj. temperatura i wilgotność powietrza, krotność wymian oraz stężenie dwutlenku węgla. Badania prowadzono w budynkach mieszkalnych, 3- i 4-kondygnacyjnych, wielorodzinnych wykonanych w technologii tradycyjnej, wybudowanych w latach 2000 – 2003. Budynki wyposażone były w kanałowy system wentylacji naturalnej. W mieszkaniach zainstalowane były kuchenki gazowe oraz piece dwufunkcyjne z otwartą komorą spalania, zasilane gazem ziemnym z sieci. Budynki posiadały ściany zewnętrzne ocieplone styropianem pokrytym cienkowarstwowym tynkiem mineralnym. Stolarkę okienną o współczynnikach infiltracji mniejszych niż 0,3 $m^3/mhdaPa^{2/3}$ (wg danych producenta) wyposażono w nawiewniki powietrza.

5. Wyniki pomiarów

W rozpatrywanych mieszkaniach w trakcie pomiarów zanotowano bardzo duże zaburzenia w działaniu wentylacji grawitacyjnej zwłaszcza w mieszkaniach zlokalizowanych na dwóch ostatnich kondygnacjach. W kratkach wentylacyjnych zanotowano wsteczne ciągi, a prędkość nawiewu przy wylocie z kratki wentylacyjnej wynosiła nawet 1,15 m/s. Sytuacja była o tyle niekorzystna, iż przy temperaturze zewnętrznej osiągającej –10°C temperatura przy wylocie kratki wynosiła około +16°C. W trakcie korzystania z kuchni gazowych oraz gazowych urządzeń grzewczych odnotowano bardzo szybki wzrost stężenia CO_2 do ok. 2200 – 3500 ppm.

Charakterystycznym zjawiskiem niemal we wszystkich badanych lokalach był przemienny charakter przepływu strumienia powietrza wentylacyjnego w kratkach, tzn. nawiew i usuwanie powietrza odbywało się naprzemiennie kratką w kuchni i łazience. Napływ ten był tak duży, że uniemożliwiał swobodne korzystanie z łazienki i użytkownicy mieszkań zaklejali wloty kanałów wentylacyjnych folią. Działania te doprowadziły do bardzo dużego wzrostu stężenia CO_2 do poziomu ok. 5000 ppm, który nawet w okresie nocnym nie spadał poniżej wartości 2000 ppm. Podobnie szybko wzrosła wilgotność względna, która wahała się pomiędzy 70% a 90%.

Dla poprawy mikroklimatu w rozpatrywanych mieszkaniach zaproponowano wykonanie dodatkowych otworów o średnicy ϕ120 mm w ścianach zewnętrznych, które doprowadzałyby dodatkowe ilości powietrza zewnętrznego, a na wylotach kanałów wentylacyjnych zainstalowano urządzenia typu aspiromatic. Po wykonaniu prac, we wszystkich kanałach wentylacyjnych odnotowano prawidłowy kierunek przepływu powietrza. Niestety, w dniach, kiedy temperatura zewnętrza spadała poniżej 0°C mieszkańcy zauważyli nadmierne wychładzanie mieszkań oraz zbyt duże prędkości przepływu powietrza (odczucie przeciągu). Mając na uwadze komfort użytkowników oraz ich bezpieczeństwo, przywrócono stan poprzedni. Jednocześnie wykonano dodatkowe otwory doprowadzające powietrze wentylacyjne w ścianach wewnętrznych wychodzących na klatkę schodową i zlokalizowanych w bezpośrednim sąsiedztwie pieców gazowych. W ten sposób do mieszkań, dla potrzeb spalania gazu w piecach, doprowadzono powietrze nie bezpośrednio z zewnątrz lecz wstępnie ogrzane. Z analizy danych wynika, iż bez trudu utrzymywano temperaturę wewnętrzną na poziomie +20 – +22°C. Poziom wilgotności względnej nie przekraczał 65% co odpowiada wymogom normowym. Jednocześnie stężenie CO_2 mieściło się w przedziale 700-1500 ppm. Jedynie w kilku punktach przekracza wartości 2500 ppm, jednak są to wartości chwilowe, niemające wpływu na zdrowie i samopoczucie mieszkańców.

6. Analiza wyników

Zaobserwowane nieprawidłowości są wynikiem ograniczonego napływu powietrza zewnętrznego do mieszkań niezbędnego do prawidłowego działania systemu wentylacji oraz do właściwego przebiegu procesu spalania gazu w urządzeniach grzewczych i kuchniach. Ograniczenie to jest konsekwencją nieodpowiedniego zbilansowania przepływów powietrza. Zbyt małe ilości powietrza doprowadzanego poprzez nawiewniki uzupełnione zostały powietrzem czerpanym poprzez jeden z kanałów wentylacyjnych.

7. Wnioski

1. Zaburzenia warunków mikroklimatycznych w mieszkaniach ze szczelną obudową i zamontowanymi nawiewnikami występują szczególnie na górnych kondygnacjach i przejawiają się występowaniem wstecznych ciągów oraz zmniejszeniem wymiany powietrza.
2. Zastosowanie pieców grzewczych z otwartą komorą spalania dodatkowo utrudnia działanie systemu wentylacji.
3. Pojawienie się urządzenia grzewczego w mieszkaniu powinno być uzależnione od wykonania osobnego kanału, odpowiednio obudowanego, doprowadzającego powietrze do urządzenia lub zastosowania zamkniętej komory spalania.
4. Wielkość otworów nawiewnych i ich rozmieszczenie ma decydujące znaczenie dla prawidłowego działania wentylacji grawitacyjnej oraz zapewnienia właściwych parametrów mikroklimatu wewnętrznego. Decyzja o wielkości oraz rozmieszczeniu otworów nawiewnych powinna być poprzedzona analizą:
   - warunków lokalizacyjnych mieszkania,
   - możliwości konstrukcyjnych,
   - zapotrzebowaniem powietrza (bilans).
5. Wstępne ogrzanie powietrza wentylacyjnego ogranicza zaburzenia warunków mikroklimatu wewnętrznego.

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THE ASPECT OF WASTE MANAGEMENT IN MAN STAR TRUCKS&BUSES STARACHOWICE WITH IMPLEMENTED ENVIRONMENTAL MANAGEMENT SYSTEM

Abstract

The paper presents the industry waste management in Man Star Trucks&Buses Starachowice. Man Star Trucks&Buses produces public transport buses. Since the turn of 2006/2007 the industry waste management has been implemented in accordance with the Environmental Management System (EMS). The introduction of the EMS has contributed to positive changes in waste management, both: in terms of environmental protection and the finances.

Keywords: Environmental Management System (EMS), industrial waste management

1. Introduction

EMS is part of the complete management system. That includes: organizational structure, planning activities, procedures, processes and resources needed to develop, implement, review and maintain environmental policy and the management of environmental aspects.

The basic task of EMS is business in the field of environmental protection [1]. It helps to prevent the environmental problems by considering environmental aspects in planning, design, production and maintenance. In addition, the EMS forces to introduce organizational improvements. That allows the maximize corrective actions. And, as the consequence, to continuously reduce the negative environmental impacts.

Entrepreneurs accomplishing the EMS use tools associated with systemic approach to environmental management, such as standards ISO 14001 and EMAS.

1.1. Standard ISO 14001

Environmental Management System certification according to ISO 14001 in many cases is used to evaluate potential business partner. The main task of ISO 14001 is to support environmental protection and pollution prevention in a way, which considers the socio-economic needs. ISO 14001 contains requirements, which can be objectively audited, but do not include requirements of environmental activity. ISO 14001 is intended for all organizations, regardless of the type and size, and for use in different geographical, cultural and social conditions [1].

1.2. Eco Management and Audit Scheme (EMAS)

The essence of the Eco-Management and Audit System (EMAS), the EU's environmental management system, is looking for the possibilities of minimizing the impact on the environment and improving the efficiency of these activities [2].

EMAS registration [1] means that the organization has an efficient environmental management system, which significantly contributes to reduce operating costs, e.q. waste disposal. In addition, EMAS registration makes this organization competitive on the market. Eco-Management and Audit Scheme [1] is a tool addressed to all companies and institutions, that systematically identify the environmental aspects. It helps to develop and implement action plans which allow progressively reduce their environmental impact.

The most important is the international standard ISO 14001, because it specifies a system by which companies are implementing an environmental management system [4].

The implementation of EMS based on the requirements of ISO 14001 is regarded as a step towards EMAS registration. Comparison of key features and requirements of ISO 14001 and EMAS are shown in Table 1.

Table 1. Similarites and differences between ISO 14001 and EMAS [1, 4]

Requirements, characteristics	ISO 14001	EMAS
Scope	Worldwide	EU
The first environmental report	Voluntary	Obligatory
Environmental Policy	The organization should establish and implement a procedure for identifying legal and other requirements	Compliance with applicable regulations of environmental protection; must be published in a ecological statement
Aims & Objectives	Must be associated with the environmental policy	Should be defined by number and time limits
Ecological Programs	Programs must be relevant to the aims and objectives	Separate programs must be used for other tasks
EMS	With regard to the organization, the EMS and control documentation, requires continuous improvement	In relation to the company, communicating with authorities and shareholders, higher requirements for continuous improvement
Ecological control/internal audits	Internal audits of system in the voluntary control cycle	Assessment processes in order to protect the environment, every three years
Certification/ Registration	By accredited certification institution/ non-international registry	Only an accredited person or institution for the validation of ecological set up by the authorities of the Member State, the registration in the register of EMAS
Formal confirmation	A certificate issued by a certifying	Certificate of participation in EMAS
Additional requirements	Lack	Higher requirements for employees

2. Man Star Trucks&Buses Starachowice

Man Star Trucks&Buses Starachowice produces low-floor buses and articulated MAN. The company provides components and body in a raw state, ie after the coating process, sheeting process, and the initial assembly in the courts and Salzgitter in Germany [3]. Production capacity of this factory allows to produce buses at the rate of 18 buses per day. Annual production of buses in Starachowice reached 890 in 2006, and in 2007 – 956 [3].

3. Environmental Management System in Man Star Trucks&Buses Starachowice

EMS was launched to implement the Man Star Trucks&Buses at the turn of 2006/2007. In terms of waste management it introduced new rules aimed at protecting the environment. That included: segregation of waste at its origin, minimizing the effects of the waste (e.g. gradual abandonment of the use of unnecessary packaging). Fulfillment of the requirements and, as a consequence, the certification of ISO 14001 standards was achieved on 30 October 2007 [3].

3.1. Waste management in the Man Star Trucks&Buses Starachowice

The amount of waste generated in Man Star Trucks&Buses depends on the number of produced buses. The percentage of waste generated during production of one bus in 2007 is shown in Figure 1. Quantities of waste generated before the introduction of EMS and in the first year of EMS operation are shown in Table 2.

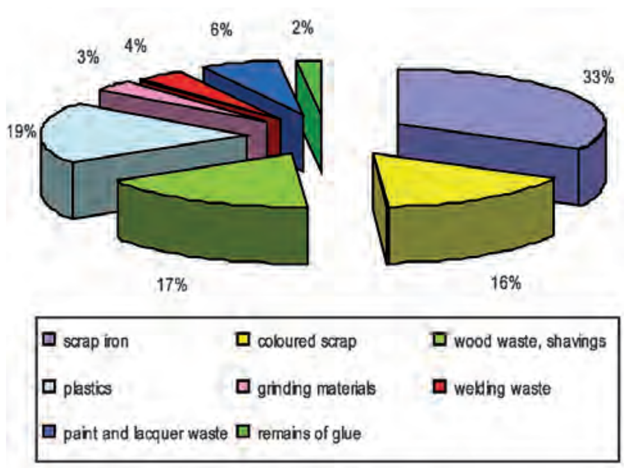

Fig. 1. The percentage of waste during production of one bus in 2007 in Man Star Trucks&Buses [3]

Table 2. Quantities of waste produced in Man Star Trucks&Buses [3]

Wastes	Quantity [Mg]		
	2005 y.	2006 y.	2007 y.*
stored waste e.g. remains oils, cooling fluids	144.1	66.8	82.62
waste for reused e.g. coloured strap	141.34	247.45	342.18
waste for reused e.g. waste paper, foil	411.63	445.1	434.86
wood waste: sawdust, shavings	314.8	263.16	335.10
Scrap	2500.9	2772.5	3357.07
Total	3512.77	3795.01	4551.83

* the first year of EMA implementation

3.1.1. Changes of waste management

Environmental Management System, introduced in Man Star Trucks&Buses contributed to changes in waste management (Table 3).

Table 3. Changes due to the introduction of the EMS [3]

Before the introduction of EMS	Following the introduction of EMS
Lack of proper waste segregation	Introduced waste segregation
Lack of sufficient quantities of waste containers, the lack of signs	Waste containers were purchased and made a sign of waste, ie waste code designation
Lack of staff awareness on environmental protection	Introduced staff training on environmental protection, leaflets are distributed among employees on the EMS
Lack of waste press	Purchased a waste press; decreased volume of waste stored
Failure to minimize the impact of waste	Separate waste at source Renounced unnecessary packaging
Poor conditions of storing waste	Introduced to improve conditions for the storage of waste (storage expansion)
The large emissions of glue during the pegulan gluing*	Change of gluing technology
A large quantity of paint consumed in the process of painting buses	Purchased a device for cathode surface coating

* waste generated during gluing inside the bus.

3.1.2. Collection and storage of waste

In the company a selective collection of municipal and industrial waste was carried out [3]. At the workstations municipal waste containers and process waste containers (tight pallet or a mesh pallet, liquid waste tanks with capacity of 1 m^3) are placed. Waste containers are marked with a code of waste in accordance with [5]. Municipal waste is collected in containers with a capacity of 5.0 m^3 located near production facilities and office space. Process wastes are segregated, compacted, weighed, and picked up by an external company. Scrap metal is collected in six containers (with a capacity of 5 cubic meters) located in the waste store. Scrap metal is collected by type: copper, brass, stainless steel [3].

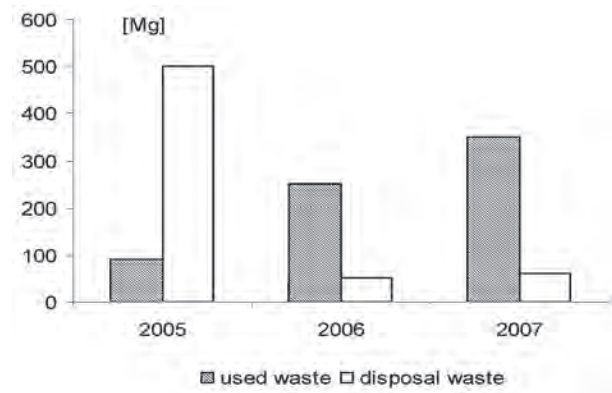

Fig. 2. Management of industrial waste in Man Star Trucks&Buses [3]

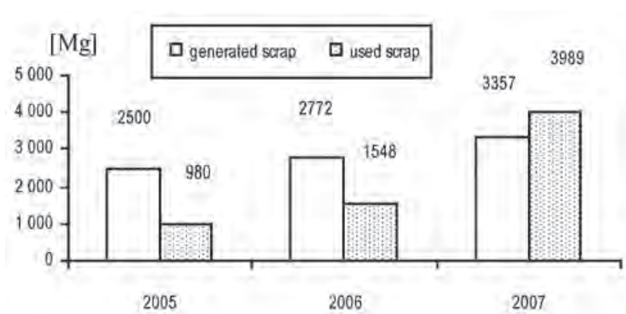

Fig. 3. Management of scrap in Man Star Trucks&Buses [3]

3.1.3. Recycling Waste

The introduction of EMS in Man Star Trucks&Buses helped to carry out the following recycling of waste [3]:

1) wood – used pallets, plywood scrap, sawdust – are sold to employees of Man Star Trucks&Buses;
2) scrap steel and color – galvanized steel, chrome, copper, aluminum, – are sold to the outside company;
3) waste paper – cartons – are sold to the outside company;
4) electronic equipment – broken electronic equipment – to be cast outside recycling company.

Man Star Trucks&Buses makes profit by recycling of electronic wastes. The outside company pays 50-70% of the value of broken electronic equipment. Wastes are transported every two months [3].

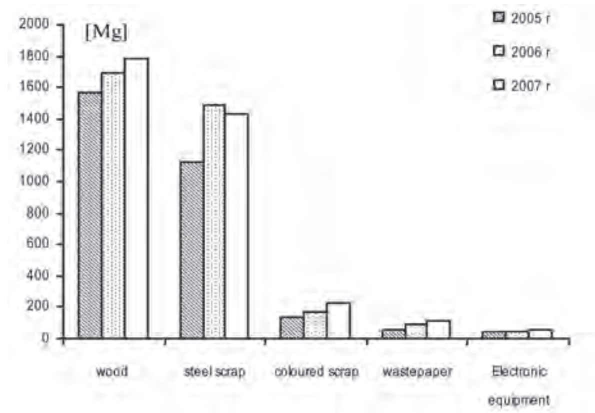

Fig. 4. The quantities of secondary raw materials used in Man Star Trucks&Buses

3.1.4. Waste Treatment

Production waste is utilized off-site. The types and quantities of recycled wastes are shown in Figures 5 – 6.

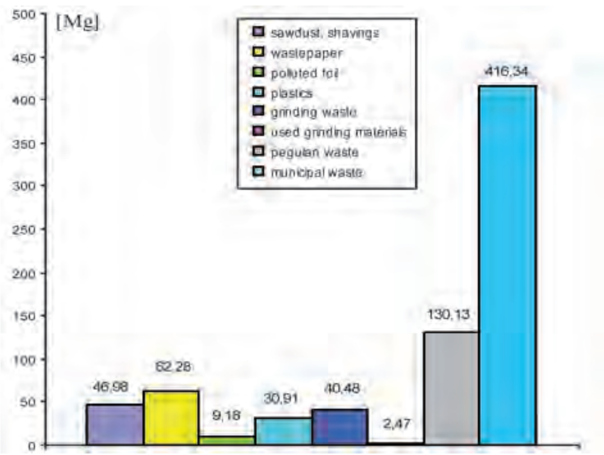

Fig. 5. Non – hazardous wastes recycled in 2007 [3]

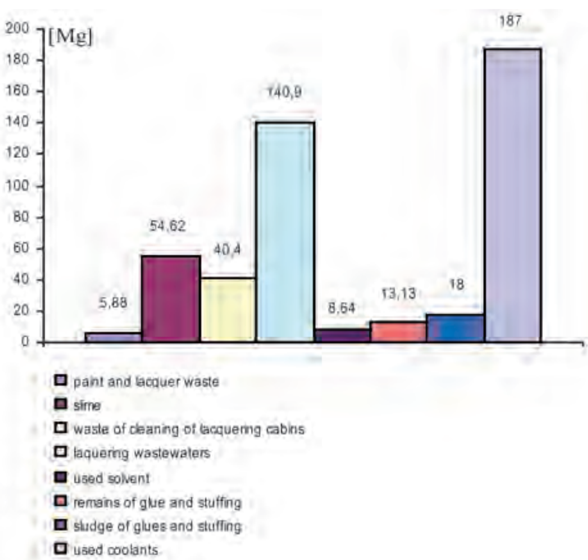

Fig. 6. Hazardous waste recycled in 2007 [3]

3.1.5. The costs of waste management

In 2007, 4551.83 Mg of waste was generated by Man Star Trucks&Buses. The company sold 3575.83 Mg of waste. The win amounted to 4582845 PLN. Directed to disposal 1496 Mg of waste, incurring the cost of 668385 PLN [3].

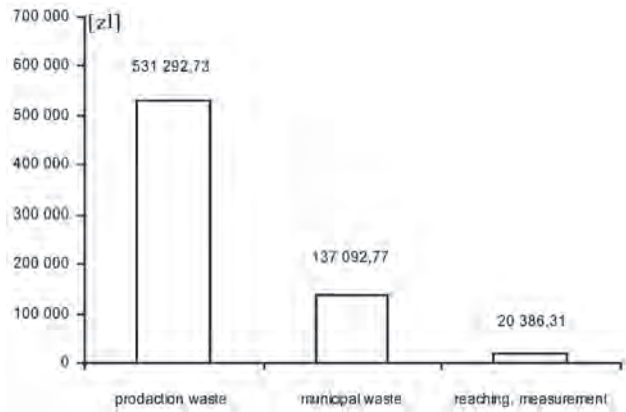

Fig. 7. Waste disposal costs in the first year of EMS [3]

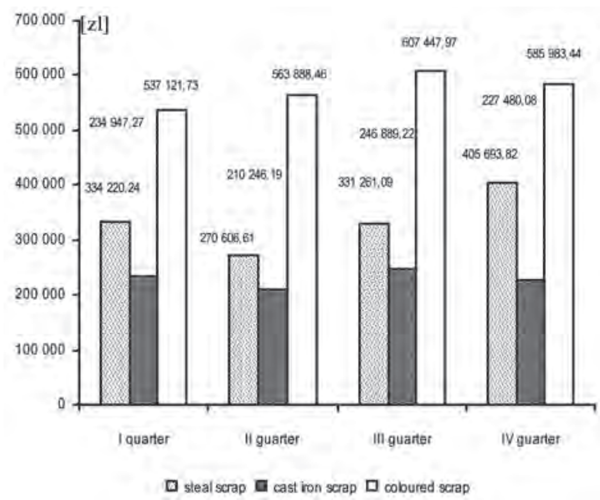

Fig. 8. Profits from the sale of scrap in 2007 [3]

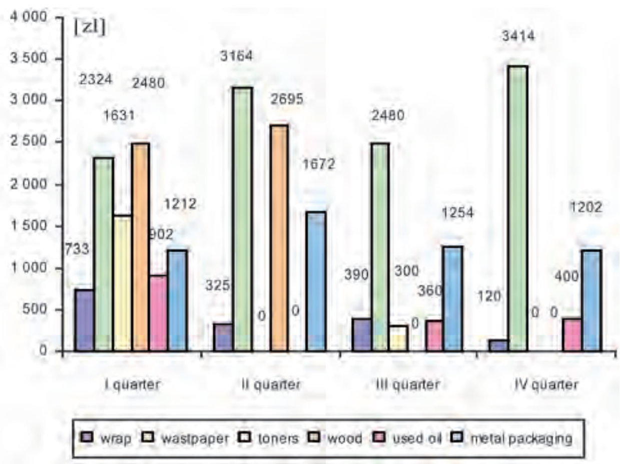

Fig. 9. Profits from the sale of recyclable materials in 2007 [3]

environment

4. Conclusions

1. The implementation of the EMS in Man Star Trucks&Buses Starachowice favorably affected the industrial waste management.
2. In the first year of operation of the Environmental Management System more than three fold increase in the amount of waste used as compared to 2005.
3. Wood wastes and steel scrap are the main raw materials used in Man Star Trucks&Buses Starachowice.
4. Expenditures during implementation of the Environmental Management System were returned in about 4%, in the year of 2007. The biggest profits were made by sale of waste paper and wood wastes.

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Jolanta Latosińska

Gospodarka odpadami w Man Star Trucks&Buses Starachowice w aspekcie wdrożonego Systemu Zarządzania Środowiskowego

1. Wstęp

System Zarządzania Środowiskowego (SZŚ) stanowi część ogólnego systemu zarządzania. Podstawowe zadania stawiane przed SZŚ to sterowanie działaniami środowiskowymi i kontrolowanie funkcjonowania przedsiębiorstwa w obszarze ochrony środowiska [1]. System Zarządzania Środowiskowego pomaga zapobiegać powstawaniu problemów środowiskowych poprzez uwzględnienie zagadnień środowiskowych w sferze planowania, projektowania, produkcji oraz w pracach serwisowych. SZŚ wymusza wprowadzenie udoskonaleń organizacyjnych, pozwalających na maksymalne ograniczenie działań korygujących na rzecz działań prewencyjnych oraz prowadzenie procesu ciągłego zmniejszania negatywnego oddziaływania na środowisko. Przedsiębiorcy realizujący SZŚ mogą korzystać z wielu narzędzi związanych z systemowym podejściem do zarządzania środowiskowego np. normy ISO 14001, system EMAS.

Podstawowym zadaniem normy ISO 14001 jest wspomaganie ochrony środowiska i zapobieganie zanieczyszczeniom w sposób uwzględniający potrzeby społeczno-ekonomiczne. Norma ISO 14001 zawiera wymagania, które mogą być w sposób obiektywny audytowane, jednak nie zawiera wymagań dotyczących efektów działalności środowiskowej. Norma ISO 14001 przeznaczona jest dla wszystkich organizacji, niezależnie od rodzaju i wielkości, oraz do stosowania w różnych warunkach geograficznych, kulturowych i społecznych [1].

Istotą Systemu Ekozarządzania i Audytu EMAS jest poszukiwanie możliwości minimalizacji oddziaływania prowadzonej działalności na środowisko oraz podnoszenia efektywności tej działalności [2].

Rejestracja w systemie EMAS [1] oznacza, że organizacja posiada sprawny system zarządzania środowiskowego, który znacząco przyczynia się do obniżenia kosztów działalności, wpływając jednocześnie na wzrost konkurencyjności takiej organizacji na rynku.

Najważniejsza jest norma międzynarodowa ISO 14001, ponieważ określa system, według którego przedsiębiorstwa wdrażają system zarządzania środowiskowego [4]. Wdrożenie SZŚ w oparciu o wymagania normy ISO 14001 traktowane jest jako krok w kierunku rejestracji w systemie EMAS.

2. Man Star Trucks&Buses w Starachowicach

Man Star Trucks&Buses w Starachowicach produkuje niskopodłogowe autobusy komunikacji miejskiej oraz przegubowe MAN. Firma dostarcza komponenty i nadwozia w stanie surowym tzn. po procesie lakierowania, oblachowania, wstępnego montażu do zakładów w Sadach i Salzgitter w Niemczech [3]. Zdolności produkcyjne starachowickiej fabryki pozwalają na wyprodukowanie 18 sztuk autobusów dziennie. Roczna produkcja autobusów MAN Star Trucks&Buses w Starachowicach w 2006 roku wynosiła 890 sztuki, w 2007 roku – 956 [3].

3. System Zarządzania Środowiskowego w Man Star Trucks&Buses w Starachowicach

System Zarządzania Środowiskowego rozpoczęto wdrażać w Man Star Trucks&Buses na przełomie roku 2006/2007. W zakresie gospodarki odpadami wprowadzone nowe zasady, mające na celu ochronę środowiska, obejmowały m.in.: segregację odpadów u źródła ich powstania, minimalizowanie skutków powstawania odpadów. Certyfikat wg Normy ISO 14001 uzyskano 30 października 2007 roku [3].

W 2005 roku wykorzystano 90 Mg odpadów przemysłowych, a unieszkodliwiono 500 Mg. W pierwszym roku funkcjonowania SZŚ (2007 r.) liczba odpadów przemysłowych wykorzystanych wyniosła 350 Mg, a unieszkodliwionych 60 Mg [3].

W przedsiębiorstwie realizowana jest selektywna zbiórka odpadów poprodukcyjnych i komunalnych [3]. Na stanowiskach pracy rozmieszczone są pojemniki na odpady komunalne oraz pojemniki na odpady poprodukcyjne. Pojemniki na odpady oznaczone są kodem odpadów zgodnie z [5]. Odpady komunalne, do czasu odbioru zbierane są w kontenerach o pojemności 5,0 m^3 rozmieszczonych na terenie zakładu. Odpady poprodukcyjne są segregowane, prasowane, ważone, a następnie odbierane przez firmę zewnętrzną. Złom zbierany jest do 6 kontenerów ustawionych w magazynie odpadów. Złom zbierany jest według rodzajów, tj.: miedź, mosiądz, stal nierdzewna [3].

Wprowadzenie SZŚ w Man Star Trucks&Buses przyczyniło się do realizowania recyklingu następujących odpadów [3]:

1) drewno – zużyte palety, ścinki sklejek, trociny; sprzedawane pracownikom Man Star Trucks&Buses;
2) złom stalowy i kolorowy – głównie blachy ocynkowane, chrom, miedź, aluminium; sprzedawane zewnętrznej firmie;
3) makulatura – opakowania tekturowe; sprzedawana firmie zewnętrznej;
4) sprzęt elektroniczny – zepsuty sprzęt elektroniczny; oddawany do recyklingu firmie zewnętrznej.

Dzięki recyklingowi przedsiębiorstwo pozyskuje fundusze, m.in. na zakup nowych części. Firma zewnętrzna odbierająca sprzęt elektroniczny płaci 50-70% ich wartości. Wywóz odpadów odbywa się co dwa miesiące [3].

Odpady poprodukcyjne powstające w Man star Trucks&Buses kierowane są do utylizacji poza zakładem.

W 2007 roku w Man Star Trucks&Buses powstało 4551,83 Mg odpadów. Sprzedano 3575,83 Mg odpadów. Uzyskano 458 2845 zł przychodu. Zysk ze sprzedaży surowców wtórnych to suma kwot: 1 568,00 zł (folia), 11 382,00 zł (makulatura), 1 631,00 zł (tonery), 5 175,00 zł (drewno), 1 662,00 zł (olej przepracowany), 5 340,00 zł (opakowania metalowe), 1 341 781,70 zł (złom stalowy), 919 562,76 zł (złom żeliwny), 2 294 441,60 zł (złom kolorowy) [3].

Do utylizacji przekazano 1 496 Mg odpadów ponosząc koszt 668 385,00 zł [3]. Sumę kosztów utylizacji odpadów w pierwszym roku funkcjonowania SZŚ tworzyły koszty utylizacji odpadów poprodukcyjnych (531 292,73 zł), koszty utylizacji odpadów komunalnych (137 092,77 zł) oraz koszty pomiarów i badań (20 386,31 zł).

4. Wnioski

1. Wdrożenie Systemu Zarządzania Środowiskowego w Man Star Trucks&Buses Starachowice korzystnie wpłynęło na gospodarkę odpadami poprodukcyjnymi.
2. W pierwszym roku funkcjonowania Systemu Zarządzania Środowiskowego uzyskano ponad 3-krotny wzrost ilości odpadów wykorzystanych w porównaniu do ilości wykorzystywanych w roku 2005.
3. Drewno i złom stalowy to główne surowce wtórne wykorzystane w Man Star Trucks&Buses Starachowice.
4. Nakłady poniesione na wprowadzenie Systemu Zarządzania Środowiskowego zwróciły się w około 4% w 2007 roku. Największe zyski osiągnięto ze sprzedaży makulatury oraz drewna.

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CALCULATION OF TEMPERATURE IN VENTILATING ROOF SPACE

Abstract

Condensation is a problem in the roof space. The solution to this problem is an air – hole in the roofing. We can calculate the air temperature in the roof space with equations found in literature. The modified equations are presented in this article. They take the air – hole area into consideration.

Keywords: ventilating roof space, air grates, moisture condensation

1. Introduction

In ventilating roof space the temperature is constantly changing. It depends on weather conditions and air grates size [1]. This situation has an influence on humidity in the flat – roof. One of the consequences might be the condensation of moisture.

We suggest the modified calculation method, in which an internal temperature and hipped roof temperature is considered.

2. Subject of an analysis

The analysed roof is equipped with eight air grates. Air grate size is equal to 0.15 x 0.21m. Roof inclination is 20^o. Roofing is made of galvanized steel.

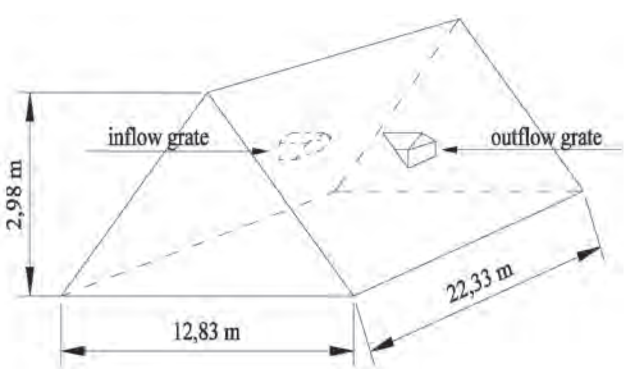

Fig. 1. Scheme of the roof space

Analyzed roof was located in Kielce. The ceiling surface is 286.5 m^2, while the roofing surface is 315.8 m^2. Heat transfer coefficient is equal to

$$0.32 \ \frac{W}{m^2 \cdot K} \quad \text{and } 5 \ \frac{W}{m^2 \cdot K}$$

During the measurement the air grates were covered and uncovered.

3. The analysis of the results of measurement and calculations

During the measurement the external air humidity was changing (Fig. 2). The average internal humidity was 56%. After uncovering the air grates it equalled 76%.

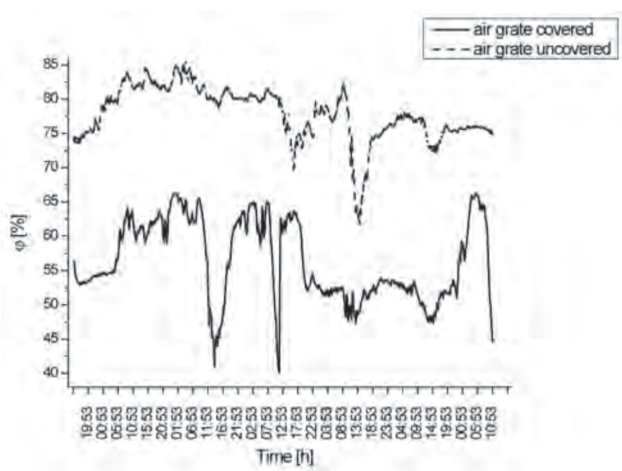

Fig. 2. External air humidity

During the analysis of internal air humidity (Fig. 3) its average value was 75%. After uncovering the air grates it equalled 76%.

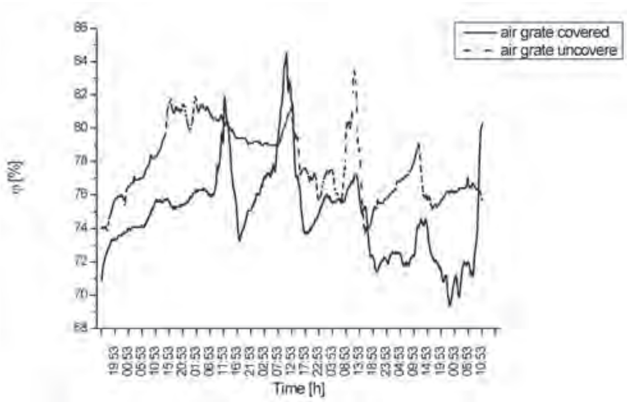

Fig. 3. The internal air humidity

In spite the low humidity of external air, the humidity of internal air was high. Its value was almost the same when the humidity of external air was high but the air grates were covered. We can conclude that when the humidity of external air is high and the air grates are uncovered, the humidity of internal air increases. As a result of this condensation can occur.

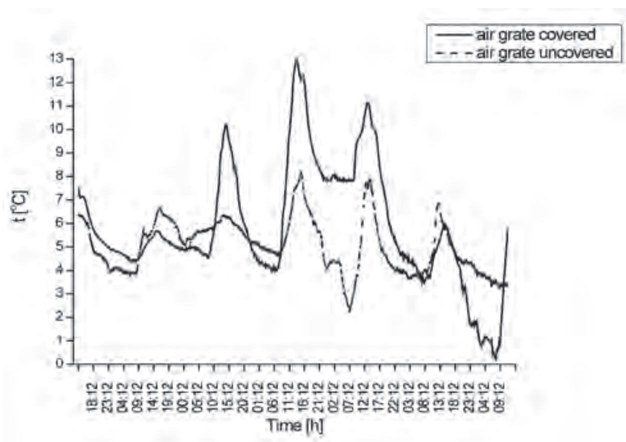

Fig. 4. Temperature of internal air

The average value of the temperature in the roof space was 3.8°C. After the air grates were uncovered the temperature increased to 5.9°C.

4. Calculation and analysis

The calculation of the temperature in the roof space was made using the formulas from the literature [2].

Steady – state temperature in some distance from inflow – grate is given by:

$$t_{st} = \frac{U_i \cdot t_i + U_e \cdot t_e}{U_i + U_e} [℃] \quad (1)$$

where: U_i – heat transfer coefficient of the ceiling, U_e – heat transfer coefficient of the roofing surface, t_i – temperature of internal air, t_e – temperature of external air.

$$t_{st} = 3.11 [℃]$$

The above formula does not take into account the surface of inflow – grate. The new formula, where this parameter is considered, is proposed.

The air velocity inside roof space is much lower than wind velocity. So we can presume that pressure of internal air is the same barometric pressure (statical). Therefore pressure loss is equal to:

$$\Delta p_N = K_1 \cdot \frac{v^2}{2} \cdot \rho_N [\mathrm{Pa}] \quad (2)$$

where: K_1 – aerodynamic coefficient, v – external air velocity, ρ_N – air density.

On the basis of above-mentioned the modified formula is proposed:

$$G_N = \mu_N \cdot F_N \cdot \sqrt{2 \cdot K_1 \cdot \frac{v^2}{2} \cdot \rho_N^2} \left[\frac{\mathrm{kg}}{\mathrm{s}}\right] \quad (3)$$

where: μ – spreading of inflow air coefficient, F_N – inflow – grate surface, K_1 – aerodynamic coefficient, v – external air velocity, ρ_N – air density.

$$G_N = 0.001 \left[\frac{\mathrm{kg}}{\mathrm{s}}\right] = 3.71 \left[\frac{\mathrm{kg}}{\mathrm{h}}\right]$$

Now the calculation of air temperature in roof space is given by:

$$t_p = \frac{U_i \cdot F_i \cdot t_i + U_e \cdot F_e \cdot t_e + c_p \cdot G_N \cdot t_e}{U_i \cdot F_i + U_e \cdot F_e + c_p \cdot G_N} [℃] \quad (4)$$

where: U_i – heat transfer coefficient of the ceiling, U_e – heat transfer coefficient of the roofing, t_i – internal air temperature, t_e – external air temperature, F_i – ceiling surface, F_e – roofing surface, C_p – specific heat of air, G_N – air stream.

$$t_p = 3.0 [℃]$$

When the temperature is calculated and the humidity is measured the dew point may be determined (Mollier graph) t_R = -0,1°C.

The next step is calculation of the roofing surface temperature:

$$t_{pow} = t_p - \frac{U_e}{\alpha_w} \cdot (t_p - t_e)\left[{}^{\circ}\mathrm{C}\right] \qquad (5)$$

where: α_w – heat transfer coefficient.

$$t_{pow} = 2.5\left[{}^{\circ}\mathrm{C}\right]$$

Because the roofing surface temperature is higher than the dew point, the moisture will not condense.

The calculated values were compared against the measured ones. The calculated and measured temperatures were similar. The average measured temperature was 3.08°C. While carrying out this experiment we didn't notice any condensation. It may confirm the correctness of the formulas used.

5. Conclusions

The proposed method of calculation makes it possible to determine the internal temperature in roof space. It includes the inflow – grates surfaces. Additionally, the temperature of roofing surface may be calculated. It enables to estimate the moisture condensation.

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Obliczanie temperatury powietrza w przestrzeni dachów wentylowanych

1. Wstęp

W przestrzeni dachów następuje ciągła zmiana temperatury powietrza uzależniona od warunków zewnętrznych oraz wielkości otworów wentylacyjnych. To bezpośrednio oddziaływuje na stan wilgotności w przestrzeni stropodachu, a w konsekwencji na możliwość wykraplania pary wodnej.

W artykule zaproponowano metodykę obliczeniową temperatury w przestrzeni dachu wentylowanego oraz temperatury połaci dachowej. Ponadto obliczenia zweryfikowano wykorzystując badania wstępne.

2. Przedmiot analizy

Dach poddany analizie wyposażony był w osiem kratek wentylacyjnych o wymiarach 0,15 x 0,21 m. Nachylenie dachu wynosiło 20°. Pokrycie wykonano ze stali ocynkowanej.

Analizowany dach zlokalizowany był w Kielcach. Powierzchnia stropu wynosiła 286,5 m^2, natomiast połaci dachowej 315,8 m^2. Współczynniki przenikania ciepła wynoszą odpowiednio:

$$0{,}32 \ \frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}} \quad \text{oraz } 5 \ \frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}} \ .$$

Podczas analizy dokonano pomiarów przy osłoniętych i odsłoniętych kratkach wentylacyjnych w celu określenia czy w warunkach rzeczywistych wentylacja przestrzeni dachowej zmniejsza wilgotność powietrza.

3. Analiza wyników pomiarów

Podczas wykonywania pomiarów wilgotność powietrza zewnętrznego uległa zmianie. Średnia wartość mierzonego parametru, gdy otwory wentylacyjne były zasłonięte wynosiła 56%. Natomiast po odsłonięciu kratek wynosiła 76%.

Średnia wartość wilgotności powietrza w przestrzeni dachu wyniosła 75%, gdy zasłonięto otwory wentylacyjne oraz 76% gdy kratki były odsłonięte.

Wilgotność powietrza w przestrzeni dachu jest niemal taka sama przy niższej wilgotności powietrza zewnętrznego i zasłoniętych otworach wentylacyjnych jak przy wyższej wilgotności zewnętrznej, ale otwartych otworach wentylacyjnych. Można wnioskować, iż w przypadku większej wilgotności powietrza zewnętrznego przy zasłoniętych kratkach wentylacyjnych wilgotność powietrza w przestrzeni dachu niebezpiecznie wzrośnie.

Średnia temperatura w przestrzeni dachu wynosiła 3,8°C. Natomiast po zasłonięciu otworów wentylacyjnych wartość parametru wzrosła do 5,9°C.

4. Obliczenia i ich analiza.

Wykonano obliczenia temperatury w przestrzeni stropodachu w oparciu o sformułowane w literaturze wzory.

Ustalona temperatura powietrza w pewnej odległości od wlotu powietrza wyniosła 3,11^{o}C

Dostępne w literaturze wzory nie uwzględniają powierzchni kratek nawiewnych w określeniu temperatury w przestrzeni dachu dlatego zaproponowano wzór, w którym wielkość ta występuje.

Uzyskano następujący wzór pozwalający obliczyć strumień powietrza dopływającego do przestrzeni dachu:

$$G_N = \mu_N \cdot F_N \cdot \sqrt{2 \cdot K_1 \cdot \frac{v^2}{2} \cdot \rho_N^2} \left[\frac{\text{kg}}{\text{s}}\right]$$

Obliczona wartość według powyższego wyniosła 3,71 kg/h.

Dla obliczonego strumienia powietrza można obliczyć temperaturę powietrza w przestrzeni dachu:

$$t_p = \frac{U_i \cdot F_i \cdot t_i + U_e \cdot F_e \cdot t_e + c_p \cdot G_N \cdot t_e}{U_i \cdot F_i + U_e \cdot F_e + c_p \cdot G_N} [^{o}\text{C}]$$

Obliczona temperatura powietrza wyniosła 3^{o}C.

Dla obliczonej wartości temperatury oraz zmierzonej wilgotności powietrza w przestrzeni dachu odczytujemy (wykorzystując wykres h – X) temperaturę punktu rosy t_R = -0,1^{o}C.

W kolejnym kroku obliczono temperaturę powierzchni dachu, która wyniosła 2,5^{o}C.

Temperatura powierzchni dachu jest wyższa od temperatury punktu rosy stąd na podstawie obliczeń można stwierdzić, iż nie będziemy mieć do czynienia z wykraplaniem wilgoci.

Porównując wartości obliczone wg wzorów z wielkościami mierzonymi w obiekcie rzeczywistym okazało się, iż temperatury obliczone obiema metodami były zbliżone do wartości wskazanej przez mierniki. Średnia wartość zmierzona temperatury wyniosła bowiem 3,08^{o}C.

Ponadto podczas wykonywania badań nie zaobserwowano wykraplania wilgoci co może potwierdzać słuszność wzorów.

5. Wnioski

Zaproponowana metoda umożliwia obliczenie temperatury powietrza w przestrzeni dachu wentylowanego z uwzględnieniem powierzchni otworów wentylacyjnych. Dodatkowo można obliczyć temperaturę powierzchni połaci dachowej co pozwala na określenie zagrożenia skraplaniem się pary wodnej.

Porównanie zaproponowanej metodyki ze stosowanymi obecnie wzorami nie rozstrzyga jednoznacznie użyteczności wzorów zatem potrzebne są dalsze badania terenowe w celu weryfikacji obliczeń.

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