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Teoretične in eksperimentalne osnove za izdelavo mehanskih izolacijskih pen

Theoretical and Experimental Foundations for the Manufacturing of Mechanical Insulation Foams

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V tem prispevku obravnavamo teoretične pogoje, ki so potrebni za izdelavo stabilne mehanske izolacijske pene. Poleg tega navajamo tudi stvarne predloge za izvedbo izdelave mehanske pene in nanosa na gradbene površine. Mehanska pena se oblikuje razmeroma preprosto, zagotovljeni morajo biti samo ustrezni pogoji. Izolacijske lastnosti dajo drobno porazdeljeni zračni mehurčki v izolacijski plasti. Podobne lastnosti imajo tudi različni izdelki iz penjenega betona in penjenega polistirena, ki pa se ne izdelujejo neposredno na gradbišču, temveč v proizvodnih obratih. Glavna zamisel pri tem je nastanek porozne mehanske pene na gradbišču in nanašanje le te na gradbene površine. Pena mora biti dovolj stabilna, da se lahko nanaša na gradbene površine in se tam tudi utrdi.

(Ključne besede: pene izolacijske, pene mehanske, stabilnost, lastnosti reološke)

This paper deals with the theoretical conditions necessary for the formation of stable mechanical insulation foam. In addition to this it gives concrete proposals for the formation of mechanical foam and its application to surfaces in the field of civil engineering. Mechanical foam is formed relatively easily, provided suitable conditions are present. The insulating character is provided by finely distributed air bubbles in the insulation layer. Similar characteristics can be found in various products made of foamed concrete as well as foamed polystyrene, which are not manufactured on site but in manufacturing plants. The main objective is the formation of a porous mechanical foam on the construction site and its application onto construction elements. The foam must be stable enough to be applied to the construction surface and then solidify.

(Keywords: insulating foams, mechanical foams, stability, rheological characteristics)

0 UVOD

Na tržišču je veliko število različnih izolacijskih gradbenih gradiv, ki se v glavnem izdelujejo v proizvodnih obratih v obliki plošč ali zidakov. S pripravljenimi izolacijskimi gradivi se oblagajo gradbene površine, v nekaterih primerih pa se lahko uporabljajo tovrstna gradiva namesto zidakov. V tem prispevku obravnavamo mehanizem nastajanja mehanske izolacijske pene ter postopek nanašanja na gradbene površine. Izhajamo z vidika, da ima gradivo z velikim številom majhnih zračnih mehurčkov zelo dobre izolacijske lastnosti. Podobne lastnosti imajo tudi različni izdelki iz penjenega betona, ki pa se ne izdelujejo neposredno na gradbišču, temveč v proizvodnih obratih, kjer se

0 INTRODUCTION

A large number of insulating construction materials exist on the market. These materials are mostly manufactured in production plants in the form of plates and bricks/blocks. Confectional insulating materials are used for the cladding of construction surfaces and in some cases as a substitute for brick. This paper deals with the mechanism of forming mechanical insulating foam and the procedure of its application onto construction elements. We start from the basis that a material with a large number of small air bubbles has very good insulating characteristics. Various products made of foamed concrete posses similar characteristics. These are not manufactured on site but in production plants pripravijo v obliki različnih zidakov in izolacijskih plošč. Tako kakor izdelki iz penjenega betona, se proizvajajo v industrijskih obratih tudi izolacijski materiali iz steklenih vlaken, penjenega polistirena, penjenega poliuretana itn. Ta izolacijska gradiva se vgradijo v obliki različnih pripravljenih kosov na fasade, stropove, tla in druge gradbene površine, kjer želimo povečati toplotno in zvočno izolacijo. Na takšne in podobne izolacijske materiale je treba nato nanesti ali pritrditi še pročelna gradiva za lepši videz in ustrezno mehansko trdnost (omet, pročelne obloge itn.).

where they are confectionalized in the form of bricks and insulation plates. Likewise, insulation materials made of glass fibres, foamed polystyrene, foamed polyurethane, etc. are produced in production plants. These insulating materials are fitted in the form of standardised pieces on facades, ceilings, floors and other surfaces where we wish to increase the heat and sound insulation. After the application of these and similar insulating materials it is only necessary to apply or fasten the facade material for an improved appearance and adequate mechanical strength (mortar, facade cladding etc).

1 MATERIALI IN METODE

1 MATERIALS AND METHODS

V kašasto snov, ki je sestavljena iz veziva, polnil, vode in drugih dodatkov, želimo vmešati čim večjo količino zraka. Mehanska pena je lahko stabilna le takrat, ko so mehurčki čim manjši, saj je pri tem vzgon najmanjši. Velikost mehurčka je odvisna od gostote razpršnine, površinske napetosti, specifične teže razpršnine, njene homogenosti (vrste gradiv) ter parametrov, ki so odvisni od nastavitve strojne opreme (tlak, vrtenje mešalne glave itn.). Zunanji tlak razpršnine na stene mehurčka in notranji tlak v mehurču morata biti v stabilnem ravnovesju:

Our objective is to mix in an as much air as possible into a pasty material composed of binder, filler, water and other admixtures. The mechanical foam is stable only when the bubbles are as small as possible, since the corresponding buoyancy is then minimized. The size of the bubble depends on the density of the dispersion, its homogeneity and other parameters that vary with the settings of the mechanical equipment (pressure, rotation of the mixer etc.) The outer pressure of the dispersion on the wall of the bubble and the inner pressure in the bubble itself must be in stable equilibrium:

$$P_R = P_\infty - \frac{2\gamma . P_\infty . M}{R\,\rho_d . \mathrm{Re} . T} \qquad (1),$$

pri tem morata biti vzgon in površinska napetost v ravnovesju:

the buoyancy and surface tension must be in equilibrium:

$$v.g.\rho = 2\pi.\gamma.r \qquad (2)$$

$$\rho = \rho_d - \rho_z \qquad (3).$$

Na sliki 1 je prikazan nastanek mehurčka v razpršnini in sile, ki delujejo nanj pri stabilnih pogojih.

Pri stabilni mehanski peni je specifična teža razpršnine enaka:

Figure 1 presents the formation of a bubble in the dispersion and the forces that act on it under stable conditions.

In a stable mechanical foam the specific weight of the dispersion equals:

$$\frac{P_\infty M}{\mathrm{Re}.T} = \rho_d \qquad (4),$$

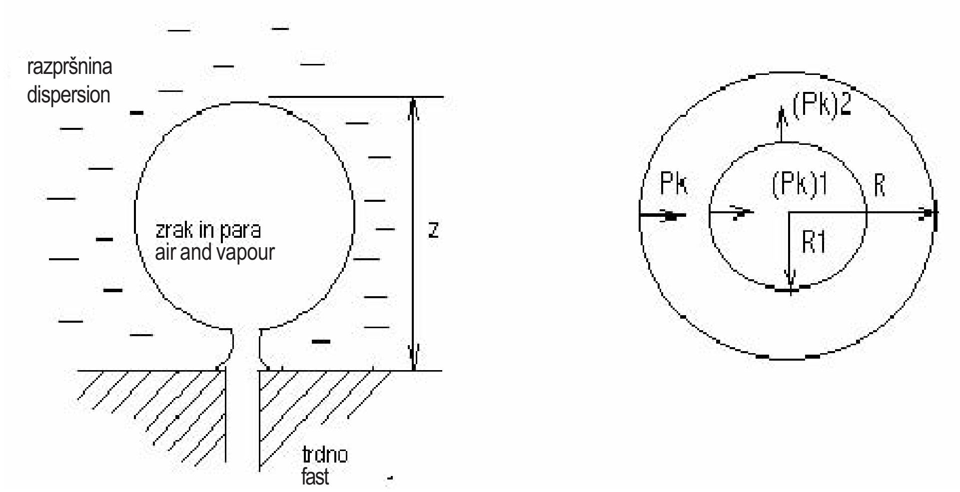
prostornina mehurčka je pri tem:

the volume of the bubble is:

$$V = \frac{4}{3}\Pi r^3 \qquad (5),$$

tlak v mehurčku mora biti v ravnovesju z vsoto atmosferskega tlaka in kritičnih tlakov na notranji in

the pressure inside the bubble must be in equilibrium with the sum of the atmospheric pressure and critical



Sl. 1. *Shematski prikaz oblikovanja mehurčka mehanske pene*
Fig. 1. *A schematic representation of the formation of a bubble of mechanical foam*

zunanji steni mehurčka:

pressures on the inner and outer sides of the bubble wall:

$$P_i = P_A + P_K + (P_K)_1 \quad (6),$$

kritični tlak na notranji steni mehurčka je odvisen od površinske napetosti in velikosti mehurčka:

the critical pressure on the inner wall of the bubble depends on the surface tension and the bubble size:

$$(P_k)_2 = -\frac{2\gamma}{r} \quad (7),$$

tlak v mehurčku je v ravnovesju z vsoto atmosferskega tlaka in pritiskov na zunanji in notranji steni:

the pressure inside the bubble is in equilibrium with the sum of the atmospheric pressure and the pressures on the outer and inner walls:

$$P_i = P_A + \frac{2.\gamma}{r} + \frac{2.\gamma}{r_1} = P_A + 2.\gamma.\left[\frac{1}{r} + \frac{1}{r_1}\right] \quad (8),$$

za zelo tanke stene mehurčkov velja:

for very thin walls:

$$r \approx r_1 \quad (9),$$

pri čemer je:

where:

$$P_i = P_A + \frac{4.\gamma}{r} \quad (10)$$

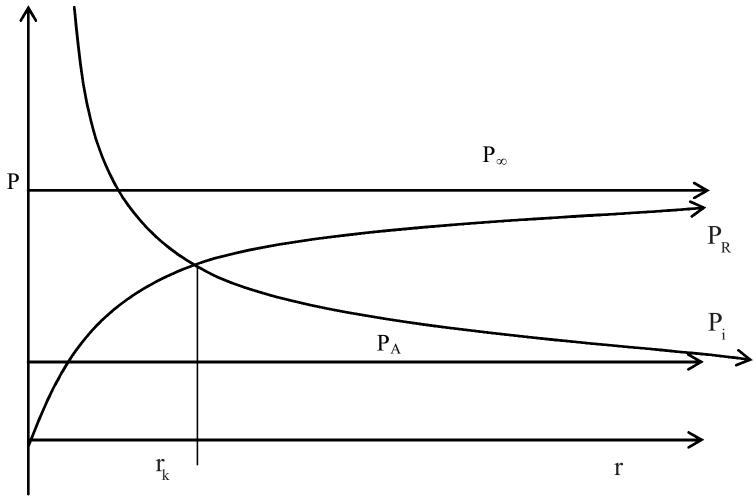
in velikost mehurčka je odvisna od površinske napetosti in razlike notranjega in atmosferskega tlaka:

and the size of the bubble depends on the surface tension and the difference in the internal and atmospheric pressures:

$$r = \frac{4.\gamma}{P_i - P_A} \quad (11).$$

Na sliki 2 so prikazani kritični pogoji, ki veljajo za stabilno mehansko peno. V razpršnino je mogoče pri danih pogojih vmešati samo določeno količino

Figure 2 presents the critical conditions that apply for a stable mechanical foam. Under given circumstances only a specific amount of air can be



Sl. 2. *Kritični pogoji pri oblikovanju polimerne mehanske pene*
Fig. 2. *Critical conditions in the formation of polymer mechanical foam*

zraka. Če dovedemo na stroj za oblikovanje mehanske pene večjo količino zraka od teoretično dovoljene, dobimo neenakomerno strukturo z velikimi mehurčki. Premajhna količina zraka pa povzroči nastanek debelih sten, večjo gostoto in slabše izolacijske značilnosti nanosa.

Kritični pogoji: $R = R_\infty$

applied to a dispersion. In the event that a larger quantity of air, with regards to the theoretically permitted limit, is applied to the mechanical foam-forming machine, we get a non-homogenous structure with large bubbles. On the other hand, an insufficient quantity of air causes the formation of thick walls, a larger density and poorer insulation characteristics of the coating.

Critical conditions $R = R_\infty$

$$\left(P_i\right)_k = \left(P_R\right)_k \tag{12}$$

$$\ln\frac{P_\infty}{\left(P_R\right)_k} = \frac{M.\left(\left(P_R\right)_k - P_A\right)}{\mathrm{Re}.T.\rho_d} = \frac{M}{\mathrm{Re}.T.\rho_d}.\frac{2.\gamma}{P_k} \tag{13}$$

Pri dviganju mehurčka mora biti vzgon večji od sil, ki držijo mehurček v razpršitvi:

In the event of the rising of the bubble the buoyancy must be greater than the forces that hold the bubble in the suspension:

$$v = \frac{2.g.r^2}{9.\eta_d}.\left(\rho_d - \rho_z\right)\frac{3.\eta_z + 3.\eta_d}{3.\eta_z + 2.\eta_d} \tag{14}$$

pri tem sta gostota in površinska napetost razpršnine mnogo večji kakor pri zraku:

where the density and surface tension of the dispersion are greater than with the air:

$\rho_d >> \rho_z$ in / and $\eta_d >> \eta_z$

pri takšnih pogojih je hitrost dviganja mehurčka:

under these conditions the velocity of the rising bubbles is:

$$v = \frac{2.g.r^2.\rho_d}{9.\eta_d} \tag{15}$$

kjer pomenijo:
Indeksi:
1 = zrak + para
2 = tekočina (razpršnina)

where the indexes and symbols mean:
Indexes:
1 = air + steam
2 = fluid (dispersion)

3 = trdno
r = na krivulji
Simboli:
ρ_d = gostota polimerne razpršnine
ρ_z = gostota zraka u mehurčku
V = prostornina
r_1, r_2 = polmer mehurčka
$P\infty$ = tlak pare pri ravni površini ($r\infty$)
P_1 = notranji tlak
P_R = tlak na konkavno ali konveksno površino
P_A = atmosferski tlak
ρ_D = gostota pare
Re = Reynoldsovo število
v = hitrost dviganja mehurčka
η_d = viskoznost polimerne razpršnine
η_z = viskoznost zraka v mehurčku
γ = površinska napetost
g = težnostni pospešek (9,81 m/s^2)
m = masa polimerne razpršnine

3 = solids
r = on graph
Symbols:
ρ_d = density of the polymer dispersion
ρ_z = density of the air in the bubble
V = volume
r_1, r_2 = radius of the bubble
$P\infty$ = steam pressure in the event of a flat surface ($r\infty$)
P_1 = internal pressure
P_R = pressure on a concave or convex surface
P_A = atmospheric pressure
ρ_D = steam density
Re = Reynolds number
v = velocity of rising bubble
η_d = viscosity of the polymer dispersion
η_z = viscosity of the air inside the bubble
γ = surface tension
g = ground acceleration (9.81 m/s^2)
m = mass of the polymer dispersion

2 PREIZKUSNI DEL

Mehansko izolacijsko peno bi lahko izdelovali neposredno na gradbišču z ustrezno strojno opremo. Za izdelavo mehanske pene bi lahko v načelu uporabili strojno opremo, ki se uporablja za oplemenitenje tekstila, ali pa posebej za to izdelane stroje. Ker gre za novost, še ni izdelane namenske strojne opreme za oblikovanje mehanske izolacijske pene v gradbeništvu. Pri praktičnih preizkusih se je zato uporabljala laboratorijska strojna oprema za oplemenitenje tekstila ter kuhinjski mešalnik za smetano. Strojno opremo razdelimo na dva dela:

- strojno opremo za oblikovanje mehanske pene,
- strojno opremo za nanos na gradbene površine.

Nekaj mogočih sestav mehanske pene:

- cement, voda, anorganski prah, stabilizator mehanske pene, pigmenti, drugi dodatki,
- mavec, voda, stabilizator mehanske pene, pigmenti, drugi dodatki,
- gašeno apno, voda, anorganski prah, stabilizator mehanske pene, pigmenti, drugi dodatki,
- polimerno vezivo, voda, anorganski prah, stabilizator mehanske pene, pigmenti, drugi dodatki,
- polimerno vezivo, voda, organski prah, stabilizator mehanske pene, pigmenti, drugi dodatki,
- polimerno vezivo, voda, lesni prah, stabilizator mehanske pene, pigmenti, drugi dodatki, itn.

2 EXPERIMENTAL SECTION

The mechanical foam could be produced on site with the appropriate mechanical equipment. In principle we could use the equipment employed in the upgrading of textiles or specially developed machinery. However, because this is an innovation, special, purposely constructed machines for the formation of mechanical foam in civil engineering do not exist. Therefore, in practise, mechanical laboratory equipment, such as that for the upgrading of textiles and kitchen food-mixers, is used. The mechanical equipment can be divided into two parts:

- mechanical equipment for the formation of mechanical foam,
- mechanical equipment for its placement on construction surfaces.

Some of the possible compositions of the mechanical foam are as follows:

- cement, water, inorganic dust, mechanical foam stabilisers, pigments, other additives,
- gypsum, water, mechanical foam stabilisers, pigments, other additives,
- lime, water, inorganic dust, mechanical foam stabilisers, pigments, other additives,
- polymer binders, water, inorganic dust, mechanical foam stabilisers, pigments, other additives,
- polymer binders, water, organic dust, mechanical foam stabilisers, pigments, other additives,
- polymer binders, saw dust, mechanical foam stabilisers, pigments, other additives.

Preglednica 1. Nekaj podatkov o snoveh, ki se uporabljajo v gradbeništvu (Pravilnik o toplotni zaščiti in učinkoviti rabi energije v stavbah (Ur.l. RS, št. 42/02))
Table 1. A few characteristics of the materials frequently used in civil engineering (Regulation regarding the efficient use of energy in buildings (Ur.l. RS, št. 42/02))

gradivo material	ρ kg/m^3	C J/kgK	λ W/mK	μ	α_i 10^{-6} K^{-1}
apnena malta lime mortar	1600	1050	0,81	10	0,8
cementna malta cement mortar	2100	1050	1,4	30	1,1 do/to 1,2
cementna malta + lateks cement mortar + latex	1900	1050	0,7	30	1,2
porolit porolit – clay blocks	1200	920	0,52	4	0,5
steklena pena glass foam	145	840	0,056	100000	0,8
PS plošče (v kladah) PS plates (in blocks)	15	1260	0,041	25	6
penjeno steklo foamed glass	140	1100	0,06	?	
klada iz celičnega betona, porobetona blocks of cell concrete, porous concrete	450 500	860 860	0,14 0,15	3,5 4	

Pravilnik o toplotni zaščiti in učinkoviti rabi energije v stavbah (Ur.l. RS, št. 42/02) ima v prilogi navedene snovne podatke o velikem število izolacijskih materialov, med katere bi lahko uvrstili tudi mehanske izolacijske pene, ki bi bile narejene po našem postopku. V preglednici 1 zato navajamo neaj skupin materialov, kamor bi lahko uvrstili izolacijske mehanske pene.

2.1 Mogoče tehnične rešitve oblikovanja in nanašanja mehanske pene na gradbene površine

Tehnološki postopek lahko razdelimo na naslednje faze:
- priprava razpršitve,
- oblikovanje mehanske pene,
- nanašanje mehanske pene na gradbeno površino.

Priprava razpršitve

Pri opisu se bomo omejili le na vodne razpršnine, čeprav so mogoče tudi druge razpršitve. Priprava razpršnine poteka:

V vodo doziramo med mešanjem ustrezne deleže posameznih komponent (vezivo, polnilo, pigment, stabilizator mehanske pene, drugi dodatki).

The regulations regarding the efficient use of energy in buildings (Ur.l. RS, št. 42/02) specify the material characteristics for a large quantity of insulation materials, among which we could include mechanical insulation foams produced according to our procedure. Table 1 lists a few groups of materials where we could list insulation mechanical foams.

2.1 Possible technical solutions for the formation and application of mechanical foam onto surfaces in civil engineering

The technological procedure can be broken down into the following phases:
- the preparation of the dispersion,
- the formation of the mechanical foam,
- the application of mechanical foam onto surfaces in civil engineering.

The preparation of the dispersion

Although other dispersions are possible we will limit the description of the procedure to water dispersions. The preparation of the dispersion includes:

While stirring we mix in the required quantities of individual components (binder, filler, pigment, mechanical foam stabiliser, other admixtures).

Priprava razpršnine lahko poteka prekinjano ali zvezno. Pomembno je, da je zagotovljena ustrezna sestava razpršnine (deleži ustreznih komponent, homogenizacija).

Če je v razpršitvi takšno vezivo, ki se zelo hitro utrdi (mavec, cement itn.), je treba zagotoviti takojšnjo obdelavo na stroju za nastanek mehanske pene in uporabo produkta na gradbeni površini, ki jo želimo izolirati ali dekorativno obdelati. Stabilizatorji mehanske pene in drugi dodatki za izboljšanje reoloških lastnosti se dodajajo glede na stvarne potrebe (nastanek pene, barva, utrjevanje itn.).

Nastanek mehanske pene

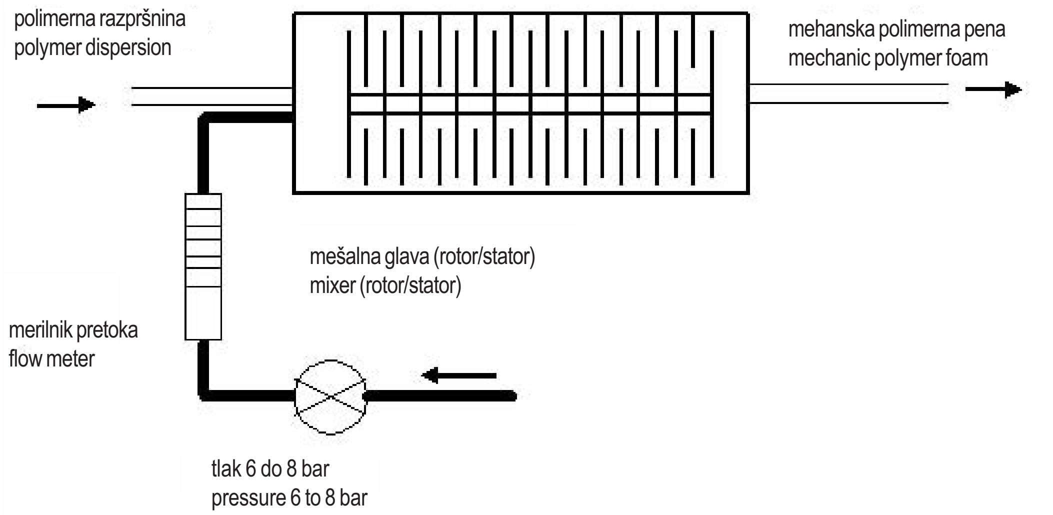
Iz pripravljene razpršnine, ki mora vsebovati predpisano sestavo in biti ustrezno homogenizirana, se lahko izdela mehanska pena. Za to pa morajo biti izpolnjeni pogoji, ki so navedeni v teoretičnem delu. Na sliki 3 je prikazana shema strojne opreme, ki se uporablja za nastanek mehanske polimerne pene za oplemenitenje tekstila. Ta shema vsebuje vse značilne sestavine, ki bi jih moral imeti namenski stroj za nastanek mehanske pene v gradbeništvu. Na dotoku v mešalno glavo priteka razpršnina, v katero želimo vmešati čim večjo količino zraka. Vmešavanje zraka poteka na mešalni glavi, kjer se mešata razpršnina in zrak. Količino razpršnine in zraka se lahko uravnava. Pri zraku je treba poleg količine uravnavati tudi tlak. Na iztoku iz stroja izstopa stabilna mehanska pena, ki se mora čimprej nanesti na ustrezno gradbeno površino.

The preparation of the dispersion can be continuous or discontinuous. It is important that an adequate composition of the dispersion is guaranteed (parts of the individual components, homogeneity).

If the dispersion contains fast-setting binders (gypsum, cement etc.) it is necessary to ensure immediate treatment in the machine for the formation of mechanical foam and use of the product on the surface we wish to insulate or decorate. Stabilisers of the mechanical foam and other additives for the improvement of its rheological characteristics are added according to specific needs. (formation of the foam, colour, hardening etc.).

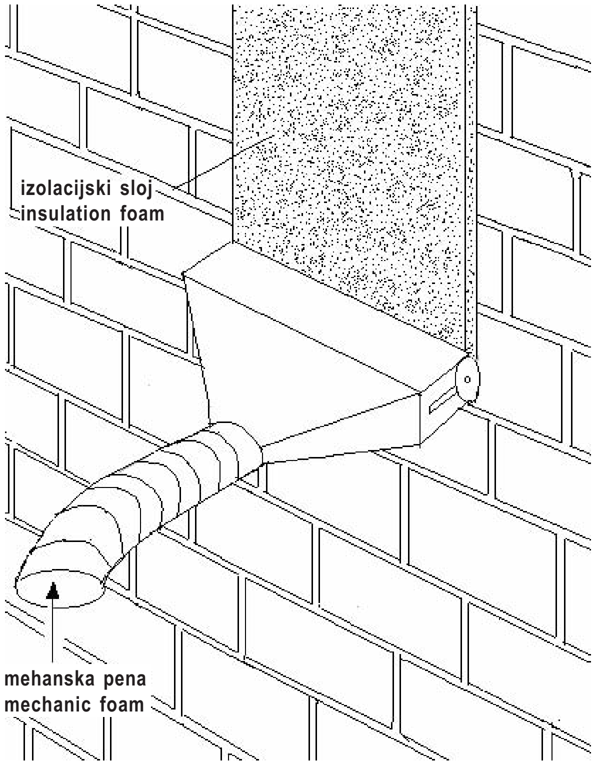
The formation of the mechanical foam

Mechanical foam can be made from a prepared dispersion composed of the required ingredients, adequately homogenised. In this case all the conditions listed in the theoretical part must be fulfilled. Figure 3 presents a scheme of the mechanical equipment needed for the preparation of mechanical polymer foam used for the upgrading of textiles. This scheme includes all the characteristic components necessary for a purpose-built machine for the production of mechanical foam in the field of civil engineering. The dispersion into which we wish to mix a large as possible quantity of air flows into the mixing head. The admixing of the air takes place in the mixing head, where the dispersion and air are mixed. The quantity of dispersion and air can be regulated. When regulating the quantity of air its pressure is also regulated. On its outflow from the machine we obtain a stable mechanical foam, which has to be applied to the construction surface.



Sl. 3. *Shematski prikaz stroja za oblikovanje mehanske pene*

Fig. 3. *A schematic drawing of the machine for the production of mechanical foam*



Sl. 4. *Prikaz nanosa mehanske izolacijske pene na ravno steno*
Fig. 4. *The application of mechanical insulation foam on a flat wall*

Nanašanje mehanske pene na gradbeno podlago

Nastala mehanska pena se mora obnašati kot tekočina pri prenosu in nanašanju, nato pa kot trdna snov. Te značilne reološke lastnosti je treba upoštevati pri prenosnem sistemu (dovodni cevi) mehanske pene na mesto nanosa ter pri obliki nanašalne glave. Mogočih načinov nanašanja mehanske pene na gradbeno podlago je lahko več. Podajamo le eno izmed mogočih rešitev, ki je prikazana na sliki 4.

Pri nanašalni glavi mora biti ustrezen distančnik, ki določa debelino nanosa. V stvarnem primeru je prikazan ta distančnik v obliki koleščka ob robu nanašalne glave. Z nastavitvijo stranskih koleščkov se lahko uravnava želen odmik od stene. S tem je določena tudi debelina nanosa mehanske izolacijske pene.

2.2 Primer oblikovanja mehanske pene iz vodne razpršnine polimernega veziva (poliakrilat), anorganskega polnila in dodatkov

Pogoji oblikovanja mehanske pene pri preizkusu so:

The application of mechanical foam onto surfaces

The produced mechanical foam must behave as a fluid during both transport and placement, while its latter behaviour must be as a solid material. These typical rheological characteristics must be considered in the transport system (feeding hoses) of the mechanical foam to the placement surfaces as well as in the construction of the applicator. There are several ways of placing mechanical foam on surfaces in civil engineering. We present one of the possibilities in Figure 4.

An appropriate spacer must be located on the applicator. Its purpose is to control the thickness of the placed layer. In this case the spacer is in the form of a guide wheel located at the edge of the applicator. By adjusting the wheels the distance from the wall can be regulated. This procedure determines the thickness of the layer of the mechanical insulation foam.

2.2 An example of the formation of mechanical foam from a water dispersion of polymer binder (polyacrilat), inorganic filler and admixtures

The conditions of mechanical foam formation in the experiment are:

Polimerna razpršnina:
ρ_d = 1200 kg/m^3
η_d = 300 m Pa s

Nastavitve na stroju za oblikovanje mehanske pene za oplemenitenje tekstila Mondomix:
- zračni tlak: 4 bar
- dotok polimerne razpršnine: 500 do 600 ml/min
- dotok zraka: 0,5 l/min
- vrtilna frekvenca mešalne glave: 1200 vrt./min
- gostota mehanske pene: 180 do 220 g/l

Izračun teoretične hitrosti gibanja mehurčka za določen preizkus:

Polymer dispersion:
ρ_d = 1200 kg/m^3
η_d = 300 m Pa s

Settings on the machine for the production of mechanical foam for the upgrading of textiles Mondomix:
- air pressure: 4 bar
- intake of polymer dispersion: 500 to 600 ml/min
- intake of air: 0.5 l/min
- mixing head velocity: 1200 rpm
- density of mechanical foam: 180 to 220 g/l

Calculation of the velocity of the bubble for this concrete experiment:

$$\phi_{\text{pene/foam}} = \phi_{\text{disp.}} + \phi_{\text{zraka/air}} \quad \text{(pri/at 1 bar)}$$

$$\Phi_{zraka} = \frac{P}{P_0}\Phi = \frac{4\ \text{bar}}{1\ \text{bar}}.\frac{0,5\ \text{l}}{\text{min}} = 2\frac{\text{l}}{\text{min}}$$

$$\varphi_{pene} = 0,5\ \frac{\text{l}}{\text{min}} + 2\frac{\text{l}}{\text{min}} = 2,5\frac{\text{l}}{\text{min}}$$

teoretična gostota pene:

the theoretical density of the foam:

$$\rho_{\text{pene/foam}} = \frac{m_{\text{zraka/air}} - m_{\text{disp.}}}{V_{\text{pene/foam}}} = \frac{500\ \text{g}}{2,5\ \text{l}} = 200\ \text{g/l}$$

Dobljena gostota pene pri preizkusu: 180 do 220 g/l.

Hitrost dviganja mehurčkov:

The achieved density of foam during the experiment: 180 to 220 g/l.

The velocity of the rising bubbles:

$$v = \frac{2gr^2}{9\eta_d}\left(\rho_d - \rho_z\right)\frac{3\eta_z + 3\eta_d}{3\eta_z + 2\eta_d} \qquad \text{m/s}$$

Izmerjena velikost por (z mikroskopom): r = pribl. 10^{-5} m

The measured size of the pores (using a microscope): r = approx. 10^{-5} m

$$\rho_2 \gg \rho_1 \qquad \text{in / and} \qquad \eta_2 \gg \eta_1$$

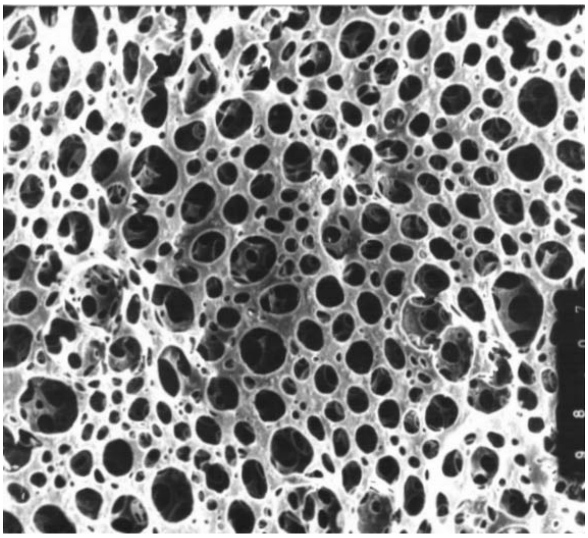
$$v = \frac{2gr^2}{9\eta_d}\cdot\rho_d = \frac{2\cdot 9,81\frac{\text{m}}{\text{s}^2}\cdot(1\cdot 10^{-5}\,\text{m})^2\cdot 1200\frac{\text{kg}}{\text{m}^3}}{9\cdot 300\ \text{m.Pa.s}} = 8,7\cdot 10^{-10}\ \text{m/s}$$

Izračunana hitrost je tako majhna, da se mehurčki praktično ne gibljejo. Mehanska pena je bila zato zelo stabilna. Takšno peno se lahko nanaša na podlago brez poškodbe njene strukture. Pri tem mora biti izbran ustrezen postopek nanašanja, pri katerem se ne poškoduje struktura pene. Na sliki 5 je prikazana fotografija toplotno utrjene obravnavane mehanske pene, posnete z elektronskim mikroskopom. S slike je razvidno, da se po utrditvi ni bistveno spremenila struktura mehanske pene.

Količina zraka v nastali mehanski peni:

The calculated velocity is so small that the bubbles are practically stationary. Therefore, the mechanical foam was very stable. Such a foam can be applied to a surface without damage to its structure. An appropriate application procedure must be chosen in order to prevent damage to the foam structure. Figure 5 presents a photograph of a hardened mechanical foam taken with an electron microscope. From the photograph it is evident that the hardening process did not have a significant influence on the mechanical foam's structure.

The quantity of air in the mechanical foam:



Sl. 5. *Fotografija mikroporozne mehanske pene na podlagi poliakrilatne razpršitve, povečava 190-krat*
Fig. 5. *A photograph of the micro-porous mechanical foam on the basis of polyacril dispersion, enlargement 190 times*

Delež polimerne razpršnine:

The percentage of the polymer dispersion:

$$(\%) = \frac{\rho_{pene} \cdot 100}{\rho_d} = \frac{0,22 \frac{\text{kg}}{\text{l}} \cdot 100}{1,2 \frac{\text{kg}}{\text{l}}} = 18\%$$

Delež zraka v mehanski peni:

The percentage of air in the mechanical foam:

$$(\%) = 100\% - 18\% = 82\%$$

3 REZULTATI IN RAZPRAVA

Izolacijske mehanske pene so lahko ena izmed mogočih tehnoloških rešitev za dodatno toplotno zaščito stavb in okrasni zgornji sloj. Nastanek mehanske izolacijske pene je teoretično razmeroma preprost. Tudi nanos na gradbeno površino ne bi smel pomeniti prevelikega problema. Večje težave lahko nastanejo v primeru, kadar je čas utrjevanja bistveno počasnejši od časa stabilnosti mehanske pene. Če bi oblikovali mehansko peno iz gašenega apna, bi verjetno nastale težave s pravočasno utrditvijo strukture. Apno se namreč utrdi z vezavo CO_2 iz zraka. Morda bi lahko oblikovali mehansko peno z dodatkom CO_2. V tem primeru bi prišlo do hitrejše utrditve. Pri uporabi različnih cementov ali cementnih malt je mogoče laže uravnavati čas utrditve strukture mehanske izolacijske pene. To je glede na omejeno stabilnost mehanske pene zelo pomembno. Tudi mavec se zelo hitro utrdi. Problem pa lahko nastane pri oblikovanju stabilne mehanske pene.

3 RESULTS AND DISCUSSION

Insulation mechanical foams can be one possible technological solution for the additional thermal protection of buildings as well as for decorative coatings. Theoretically, the formation of mechanical insulation foam is relatively simple. Its application onto surfaces in civil engineering should not pose any major problems. Larger problems could occur in the event that the hardening time is greater than the time the mechanical foam is stable. If we were to form mechanical foam from hydrated lime we would most likely have problems with timely hardening of its structure. Lime hardens by binding with CO_2 from the air. Perhaps we could form a mechanical foam with the addition of CO_2. In this case we could achieve a faster binding. With the use of various cements or cement mortars it is easier to regulate the hardening time of the mechanical insulation foam structure. Even gypsum hardens quickly. Problems can occur in the formation of a stable mechanical foam. The simplest way is the formation of mechanical foam

Najpreprostejše je oblikovanje mehanske pene pri vodni razpršnini na podlagi polimernih veziv, kar smo prikazali s praktičnim preizkusom.

Preizkusi uporabe različnih anorganskih veziv so šele v začetni fazi, zato še nimamo ustreznih rezultatov. Ne glede na to, ali je vezivo anorganskega ali organskega porekla, velja enak mehanizem oblikovanja mehanske izolacijske pene. Tudi nanos na gradbeno površino se ne more bistveno razlikovati. Mehanska pena ima v vsakem primeru približno enake reološke lastnosti, ki jih je potrebno upoštevati. Penasto gradivo nastane tudi v zmesi vodnega stekla in alkohola. Po utrditvi pa je nastalo penasto gradivo zelo trdno. V primeru, da bi bila mehanska pena hidrofobna, bi imela tudi hidroizolacijske lastnosti. Hidrofobnost bi lahko zagotovili predvsem pri mehanskih penah na podlagi polimernih veziv. Če bi bilo vezivo na podlagi polisikolsanov ali fluorogljikov, bi dosegli zelo veliko hidrofobnost, polimerni material pa bi se razmeroma hitro utrdil na zraku.

Poleg izbire ustreznih materialov je pomembna tudi strojna izvedba oblikovanja mehanske pene in sistem za nanašanje na gradbeno podlago. V tem prispevku podajamo le idejne rešitve, ki jih je treba v praksi preizkusiti in dograditi. Po nanosu na gradbeno podlago je treba utrjene materiale še testirati glede toplotno-izolacijskih zmožnosti in drugih fizikalnih in kemijskih lastnosti.

S tem prispevkom želimo odpreti novo področje na področju izolacijskih in dekorativnih materialov v gradbeništvu, ki ga je treba šele razviti in preizkusiti v praksi.

with a water dispersion made on the basis of polymer binders, as we showed in our practical test.

Usage tests of various inorganic binders are still in the developing stage, so we do not have any results available. Regardless of the binder, be it of organic or inorganic origin, the mechanism of the mechanical insulation foam remains the same. Not even its application to construction surfaces can differ significantly. In all cases the mechanical foam has approximately the same rheological characteristics, which need to be considered. Foamy material also forms in mixtures of water glass and alcohol. After it hardens the formed foamy material is very hard. In the event that the mechanical foam would be hydrophobic it would also have hydro-insulation characteristics. Hydrophobic characteristics could be obtained mainly with mechanical foams on the basis of polymer binders. If the binder was based on polysicolsan or fluorine-carbons we could achieve good hydrophobic characteristics and the polymer material would harden relatively quickly in air.

Apart from the choice of appropriate materials, the execution of the formation of mechanical foam as well as its application to surfaces in civil engineering are of great significance. This paper presents only the idea for the solution, which must be tested in practise and upgraded. After the application of the materials it is necessary to test the hardened materials with regards to their insulating capacities and other physical and chemical characteristics.

The intention of this article is to open a new segment in the field of insulation and decorative materials in civil engineering. This segment must be developed and proven in practise.

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