Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 613-624
UDK - UDC 678:677
Strokovni članek - Speciality paper (1.04)

Izdelava politetrafluoretilenskih membran in njihovo laminiranje na tekstilne podloge

Producing Polytetrafluorethylene Membranes and Laminating Them on Textile Backings

Darko Drev
(Fakulteta za gradbeništvo in geodezijo, Ljubljana)

V prispevku so prikazani preizkusi izdelave politetrafluoretilenskih membran (PTFE) in njihovega laminiranja na tekstilno podlogo. Ker je osnovni postopek izdelave PTFE membran patentno zaščiten in je tehnologija izdelave težko dostopna ([6] in [7]), smo sami razvili ustrezne tehnološke postopke za izvedbo pilotnih preizkusov izdelave PTFE membran. Izdelani vzorci PTFE membran so bili primerljivi s tržnimi izdelki. Pri laminiranju smo naredili še korak naprej in razvili izdelke z enakimi prepustnostmi, kakršne so imele membrane pred laminiranjem. Naš inovativni postopek smo tudi patentirali [5].

(Ključne besede: membrane PTFE, izdelava membran, laminiranje, metode eksperimentalne)

This paper discusses a variety of experiments related to the manufacturing of polytetrafluorethylene (PTFE) membranes and laminating them on textile backings. Due to the fact that the PTFE membrane production process is protected by international patent law, making the PTFE technology somewhat inaccessible ([6] and [7]), the author of this paper used innovative production processes and techniques to conduct the pilot PTFE membrane production experiments. In the field of PTFE membrane lamination, another step forward was made by patenting an innovative production process [5].

(Keywords: PTFE membranes, production processes, laminating, experimental methods)

0 UVOD

Politetrafluoretilenske (PTFE) membrane so se pojavile na tržišču po letu 1970. Tehnologija izdelave PTFE membran, ki so na trgu poznane kot membrane GORE - TEX, izvira iz patenta družbe W.L. Gore and Associates, Inc., Newark, iz leta 1971 [6].

Politetrafluoretilenske membrane se že vrsto let masovno uporabljajo za izdelke široke porabe in industrijo. Pri izdelkih široke porabe so vgrajene v vodo-neprepustna oblačila in obutev. V industriji pa se uporabljajo za različne vrste filtrov za industrijsko odpraševanje ter tekočinsko filtracijo. Poleg tega so PTFE membrane zelo pogosto pomembna sestavina različnih naprav v medicini, farmaciji, zaznavalni tehniki, itn. PTFE membrane so zelo prepustne, saj je njihova struktura bistveno bolj odprta kakor pri drugih membranah. Odprtost strukture se spreminja

0 INTRODUCTION

Polytetrafluorethylene (PTFE) membranes first appeared in the international market in the 1970s. PTFE membrane production technology dates back to the 1971 patent of the Newark-based company W.L. Gore and Associates Inc [6].

As a consequence, PTFE membranes are usually referred to as GORE-TEX membranes. PTFE membranes have been used on a large scale for making a myriad of products for a number of years. In the case of consumer products, they have been used as the basic input materials in waterproof apparel and clothing production, and in the case of company-to-company products, they have mostly been used in the production of dust filtration systems, liquid filtration systems and sensors. The openness of the PTFE membrane structure makes it

Preglednica 1. *Različne vrste PTFE membran, ki nastanejo zaradi različne stopnje raztezanja*
Table 1. *Dependence of PTFE membranes characteristics on the level of biaxial stretching*

Velikost por Pore size μ	Debelina Thickness mm	Poroznost Permeability %	Pretok zraka * Air flow * ml/min cm^2	Prestop vode ** Water entry ** bar
0,02	0,08	50	2,3	24
0,2	0,06	78	72	2,75
0,45	0,08	84	190	1,35
1,0	0,08	91	370	0,48
3	0,025	95	930	0,13
5	0,025	95	3870	0,07
10 - 15	0,013	98	11300	0,03

* prepustnost zraka pri ΔP 0,01/air flow at ΔP 0.01
** najmanjša prepustnost vode/minimal water entry

od stopnje dvoosnega raztezanja v fazi izdelave. V preglednici 1 so podane glavne značilnosti PTFE membran [8].

Poleg velike odprtosti strukture imajo PTFE membrane veliko prednost pred večino drugih membran v kemijskih in fizikalnih lastnostih osnovnega polimernega materiala. PTFE je izredno kemijsko stabilen. Zelo odporen je tudi za povišano temperaturo, saj je obstojen še pri 350 °C do 400 °C. Poleg tega ima PTFE tudi hidrofobne in oleofobne lastnosti. Zaradi te lastnosti se na površini filtrirnega sredstva pogača ne nabira, temveč hitro odpade.

Postopek izdelave membran, ki je opisan v tem prispevku, ni potekal v optimalnih razmerah, ki so navedene v patentu, temveč v laboratorijskih in pilotnih razmerah na različnih krajih. Za laminiranje pa smo uporabljali različne vrste lepil ter tekstilne podloge, ki se najpogosteje uporabljajo za izdelavo filtrov za odpraševanje.

Pri postopku izdelave PTFE membrane so tudi mehčala, ki jih je treba na koncu odstraniti. Odstranijo se lahko toplotno z odparevanjem ali z ekstrakcijo. Toplotni postopek lahko kombiniramo z delnim toplotnim utrjevanjem. Toplotno utrjena membrana je zato mehansko stabilnejša od tiste, ki je brez toplotne stabilizacije. Pri toplotnem utrjevanju se sprostijo in uredijo napetosti med polimernimi verigami. Naši preizkusi so bili omejeni le na toplotno odstranjevanje molekul mehčala in delno tudi toplotno utrjevanje. Prepustnost membranske filtrirne snovi je odvisna tudi od debeline membrane in od tekstilnega materiala. Debeline membran se gibljejo med 0,1 in 0,01 mm. Lepila, ki se do takrat uporabljala, so po naših meritvah in ocenah zmanjševala prepustnost membran. Razlog za to je bila delna zamašitev membranske strukture z lepilom.

extremely permeable to air and other specific substances, and this openness of the structure depends on the level of biaxial stretching in production. Table 1 shows the main characteristics of PTFE membranes [8].

Aside from the structural openness effects, the chemical and physical characteristics of the PTFE polymer itself make PTFE membranes superior to other similar products. PTFE polymer has great chemical stability. It is also resistant to temperatures as high as 350 to 400^{0}C. Also, PTFE is hydrophobic and oleophobic, which enhances the cake release properties on the PTFE membrane filter, thus making PTFE membranes very suitable for use in filtration.

The PTFE-membrane production-process experiment that is described in this paper was not operated under the optimal conditions stated in the original 1971 patent, but rather under sub-optimal laboratory conditions. For the lamination process several types of glue and textile backing materials, mainly found in the production of filtration systems, were used.

Solvents are used in the PTFE membrane production process. However, they have to be removed at the end of the process either by thermic solvent removal techniques or by plain chemical extraction. The former can be conducted in combination with thermic membrane strengthening. In the thermic membrane strengthening process some inter-polymer-chain tensions are loosened or transformed. This enables such membranes to exhibit a superior mechanical stability. For the purpose of this paper, we limited our experiments to using thermic solvent removal techniques and some thermic strengthening techniques. The permeability of PTFE membrane filter media depends heavily on the

Z našim postopkom laminiranja smo ta problem odpravili. Izdelani laminati so imeli enake prepustnosti kakor PTFE membrane. Pri tem so morale biti prepustnosti tekstilnih nosilcev za filtrirne snovi bistveno večje kakor pri membranah. To pa ne velja za laminate v oblačilni in obutveni industriji, kjer gre pogosto za gosto tkane in zato slabo prepustne materiale.

1 EKSPERIMENTALNI DEL

1.1 Materiali in metode

Na tržišču je več proizvajalcev PTFE v obliki prahu, ki je primeren za izdelavo membran. Pri laboratorijskih in pilotnih preizkusih smo uporabili politetrafluoretilen podjetja Hoechst AG ter drsno sredstvo podjetja SHELL Industrial Chemicals [12]

Pri laminiranju smo preizkusili večje število različnih materialov, od katerih so bili nekateri opredeljeni kot lepila. Najboljše rezultate smo dobili z uporabo specialnih veziv na podlagi silikonov in fluorkarbonov. Pri tem posebej izdvajamo silikonsko vezivo proizvajalca DOW CORNING z oznako Q2-7406. V preglednici 3 so navedeni glavni tekstilni materiali, ki se uporabljajo pri izdelavi laminatov PTFE za industrijsko odpraševanje ter njihova obstojnost.

Pilotni preizkus laminiranja dvoosno raztegnjene PTFE membrane izdelovalca Tetratex Co smo izvedli na laboratorijski progi Werner Mathis, AG in industrijski pilotni progi ISOTEX, Inc. Laboratorijska pilotna naprava je omogočala delovno širino okoli 30 cm, pilotna proga ISOTEX pa delovno širino 160 cm. V obeh primerih smo imeli več možnosti nanosa lepila (z nanašalno glavo s podlogo in brez podloge, s sitom, z brizganjem, z nanašalnim valjem). Temperaturo sušenja je bilo mogoče uravnavati v temperaturnem območju od sobne temperature do 280 °C. Kot dodatni način segrevanja smo imeli še infra peč. V obeh primerih smo imeli na voljo tudi hladilne valje in kalander z nastavljivim pritiskom. Pri

membrane thickness, the type of textile backing material and the type of glue used in the lamination process. Membrane thickness is normally found to be in the range 0.01–0.1mm. The glue types, primarily found in the lamination process, usually deteriorate the membrane filter media's permeability. The innovative lamination process described here removes this problem.

1 EXPERIMENTAL PART

1.1. Input materials and methods

Hoechst AG polytetrafluorethylene and Shell Industrial Chemicals solvent were used in the laboratory and pilot experiments. PTFE films of our own production and Tetratex PTFE membrane were used in the lamination experiments [12].

For gluing, a variety of materials was used, of which only a few are officially marketed as glue products. The most favorable results were obtained by using a special silicone-based and fluorocarbon-based glue. In this experiment, the DOW CORNING Q2-7406 silicone-based glue provided by far the best results. Textile backing materials, mainly used in the production of filtration systems, were used. They are described in more detail in Table 3.

The former enabled a 30-cm work width and the latter a 160-cm work width. Both made possible various glue-adding techniques (coating head with base and without base, sieve cylinder, jetting, coating cylinder). The equipment was functional in the room-temperature to 280^{0}C drying-temperature interval. As an additional heating source an infra oven was used. Both production lines were equipped with cooling rolls and adjustable-pressure calenders. However, the ISOTEX industrial pilot production line was equipped with an automatic calender pressure control system, whereas the Werner Mathis laboratory production line allowed only manual pressure control. The latter also failed to provide a

Preglednica 2. *Nekatere surovine, ki so primerne za izdelavo PTFE membran*
Table 2. *Input materials used in the PTFE membrane-production experiment*

Izdelovalec Manufacturer	Surovine Material	Opomba Type
DU POINT Fluoropolymer Division	Teflon 669 N, 62 N, 636 N	PTFE
ICI Plastics Division	Fluon, CD1	PTFE
HOECHST AG Werk Gendorf	Hostaflon TF 2028, TF 2027, TF 2025	PTFE
SHELL Industrial Chemicals	Shellsol T, Shellsol K, Shell Sinarol II	drsno sredstvo solvent

Preglednica 3. *Tekstilni nosilniki za membranske filtrirane snovi in njihove lastnosti*
Table 3. *Filter-media production textile backing materials and their characteristics*

Nosilni material Fiber type	Delovna temp. Operating temp. °C	Odporen proti kislinam Resistency to mineral acids	Odporen proti alkalijam Resistency to alkalis	Odporen proti solem Resistency to salts	Odporen proti oksidantom Resistency to oxidizing agents	Odporen proti org. topilom Resistency to organic solvents	Odporen proti vodni pari Resistency to water vapor
polst (PES) poliester Polyester Felt	130	xxx	xx	xxx	xxx	xxxx	x
polst (PP) polipropilen Polypropilen Felt	90	xxxx	xxxx	xxxx	x	xx	
poliamid Nomex Nomex Felt	200	xx	xxx	xx	xx	xxx	xx
polivinilsulfid Ryton Ryton Felt	200	xxxx	xxxx	xxxx	xx	xxxx	xx
steklena tkanina glass fabric	260	xxx	xx	xx	xxxx	xxxx	xxxx
polst poliakrilnitril Polyacrylnytril Felt	130	xxx	xx	xxx	xxx	xxxx	xxx

x - neobstojen/unstable   xxx - dobro obstojen/stable
xx - delno obstojen/partially stable   xxxx - zelo obstojen/extremely stable

pilotni progi je bilo mogoče pritisk na kalandru krmiliti avtomatsko, pri laboratorijski progi pa le ročno. Na laboratorijski progi ni bil zagotovljen neprekinjen pretok materiala čez različne tehnološke faze, temveč je šlo za prekinjan postopek.

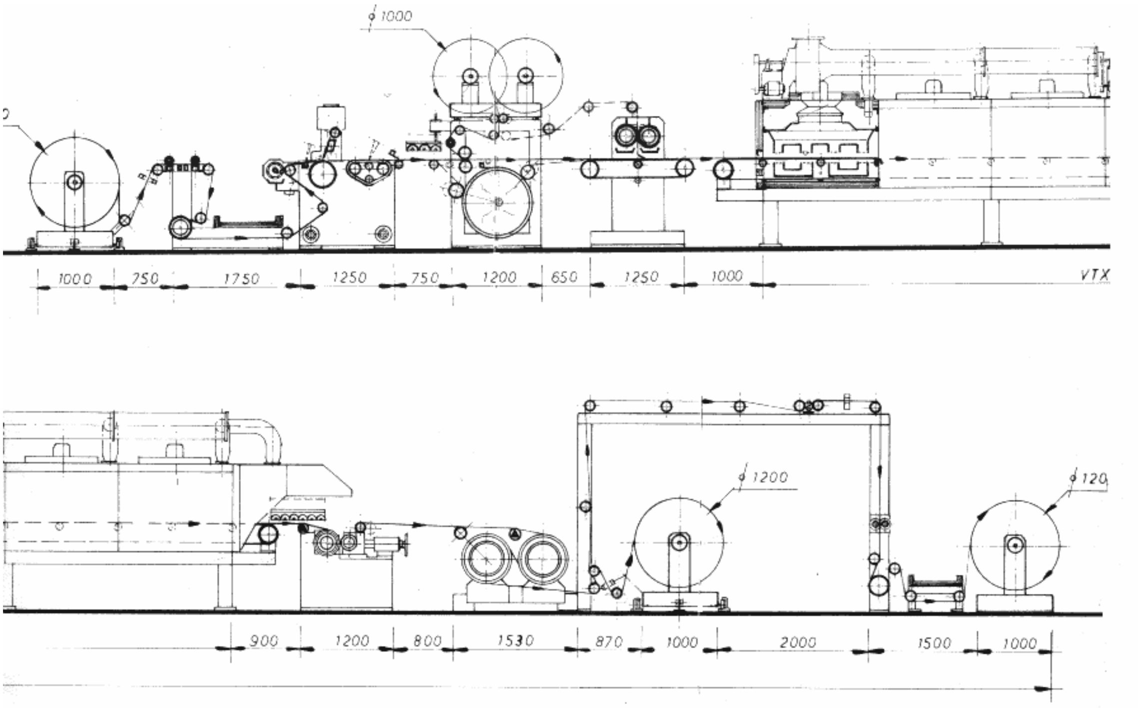
Pri industrijski pilotni progi ISOTEX je bil zagotovljen neprekinjen pretok materiala od faze odvijanja do navijanja z možnostjo natančne nastavitve hitrosti in strižnih sil na posameznih tehnoloških fazah. Pomemben del preizkusov so bili tudi postopki za testiranje. Del teh preizkusov smo izvedli sami (meritev prepustnosti zraka, učinkovitost laminiranja itn.), velik del pa pri zunanjih ustanovah. Fotografije z elektronskim mikroskopom so bile narejene na FNT Ljubljana, Oddelek za tekstil, nekateri preizkusi pa na IHTM ITR v Beogradu in pri BIA ustanovi v Bonnu.

Membranske filtrirne snovi iz PTFE imajo zmožnost zadrževanja veliko drobnejših delcev od običajnih filtrirnih snovi. To pomeni, da dosegajo višji filtracijski razred. Filtracijski razred označuje količino zadrževanega standardnega prahu. Za testiranje se uporablja kremenčev prah koncentracije

continuous material flow through the production phases. The former not only allowed for continuous material flow, but also for precise adjustments of the various production-environment parameters.

The testing of the produced materials was the core part of the experiments. The testing was partially conducted by the author (air-permeability measurements, lamination effectiveness measurements, etc) and partially by well-equipped research institutions. Specific measurements were conducted at the IHTM ITR Research Institute in Belgrade and at the BIA Institute in Bonn. The electron microscope photographs were produced at the Textiles Department of the University of Ljubljana’s Faculty of Natural Sciences and Engineering.

The PTFE-membrane filter-media particle-retention capability is far superior to that of other filter media. Formally, this means that they achieve a higher “filtration class”. This term is used to describe the amount of standard dust retained by the filter media. For testing purposes, flintstone dust with a concentration of 200 ± 50 mg/m^2 was used. Ninety



Sl. 1. *Industrijska pilotna proga ISOTEX*
Fig. 1. *ISOTEX Inc. industrial pilot-production line*

200 ± 50 mg/m^2. 90 odstotkov delcev ima velikost med 0,2 in 2 μm po Stokesu. Pri testiranju se filtrirna snov obremeni 60 min s testnim prahom pri določeni hitrosti zraka. Prenosni faktor se izračuna po naslednjem obrazcu:

percent of the dust particles had a Stokes value between 0.2 and 2 μm. The test involves the filter media being exposed to test dust at a specific wind velocity for 60 minutes. The transmission factor is then calculated according to the following formula:

$$D = \frac{(C_H - C_0)\, dt}{T(C_V - C_0)}.100\% \quad (1),$$

kjer so:
D = prenosni faktor (stopnja prepustnosti),
C_H = signal sipane svetlobe za filtrom,
C_v = signal sipane svetlobe pred filtrom.

Prenosni faktorji pri meritvah zaradi meje zanesljivosti niso doseženi, zato jih preračunavamo s statističnimi faktorji. Mejna vrednost prenosnega faktorja je:

where are:
D = transmission factor (permeability level),
C_H = light signal behind filter,
C_v = light signal before filter.

Due to the sub-optimality of its measurements, the transmission-factor values are adjusted using statistical parameters. The marginal value of the transmission factor is calculated as follows:

$$D_g = D + t \cdot s \quad (2),$$

kjer sta:
t = statistični faktor (95% statistične verjetnosti),
s = število stopnje prostosti.

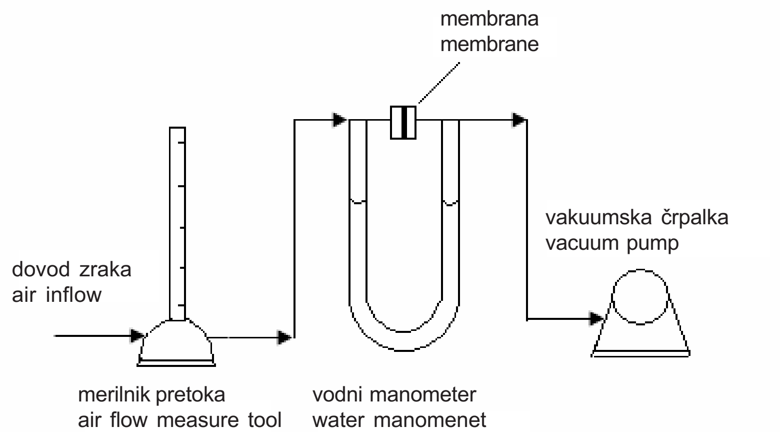
Za preizkušanje filtrov v navedenih razmerah smo uporabili pilotni testni kanal, ki je zgrajen tako, da ustreza predpisanim pogojem za določitev filtracijskih razredov ([12] do [14]). Pri tem smo

where are:
t = statistical parameter (95% probability interval)
s = degrees of freedom

A pilot test channel was used for the testing. The test channel was built according to the filtration-class determination standards ([12] to [14]). A standard flintstone dust with a standard

Preglednica 4. *Filtracijski razredi [16]*
Table 4. *Filtration classes [16]*

Filtracijski razred Filtration class	Opis razreda Class description	Mejne vrednosti za prenosni faktor D Transmission factor D marginal value
U	delci z MAK > 1 mg/m particles with MAK > 1 mg/m	5%
S	delci z MASK > 0,1 mg/m particles with MASK > 0.1 mg/m	1%
G	delci z MAK particles with MAK	0,5%
C	delci s KAK ali delci, ki povzročajo raka particles with KAK or carcinogen particles	0,1%
K	zdravju škodljivi delci health-hazard particles	filter razred S po DIN 24184 class S filters by DIN 24184



Sl. 2. *Shematski prikaz naprave za določevanje prepustnosti membrane za zrak*
Fig. 2. *The air-permeability measurement equipment*

uporabili standardni kremenčev prah s predpisano porazdelitvijo delcev.

Prepustnost zraka in vode smo testirali na napravah, ki sta shematsko prikazani na slikah 2 in 3.

1.2 Eksperimentalni del

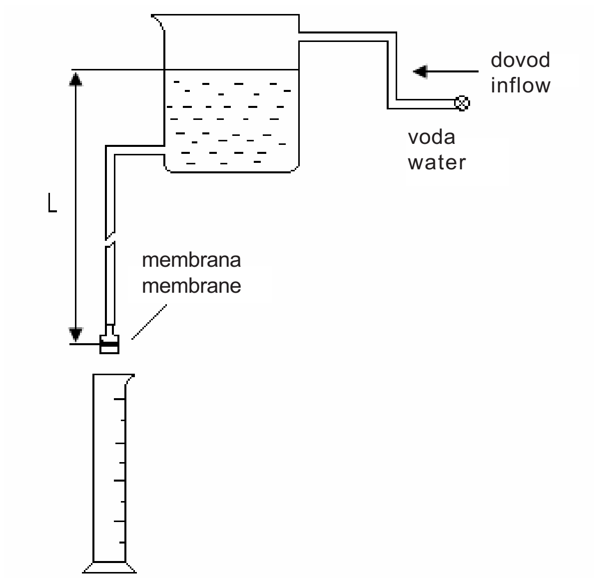
Postopek izdelave PTFE membran, ki je prikazan na sliki 4, je obsegal naslednje tehnološke faze:
- tehtanje komponent (75 do 77% prahu PTFE, 23 do 25% drsnega sredstva),
- ovlaženje prahu PTFE z ustreznim drsnim sredstvom,
- homogenizacijo navlaženega materiala (24 ur pri sobni temperaturi),
- oblikovanje predoblikovanca ustreznega prereza z iztiskanjem,
- oblikovanje folije s kalandriranjem (0,1 do 0,5 mm),
- dvoosno raztezanje folije,
- odstranjevanje drsnega sredstva s folije,
- utrditev folije.

concentration was used.

Air- and water permeability was tested with the use of the equipment shown schematically in Figures 2 and 3.

1.2 Experimental part

PTFE membrane production process, shown in Figure 4, involved the following phases:
- material weighing (75 to 77% PTFE dust, 23 to 25% solvent),
- combining PTFE dust with solvent,
- homogenizing the combined material (24 hours at room temperature),
- designing a preform with a suitable profile by extrusion,
- designing the film by calendering (0.1 to 0.5 mm)
- biaxially stretching the film,
- removing the solvent from the PTFE membrane,
- strengthening of the PTFE membrane.



Sl. 3. *Shematski prikaz naprave za določevanje prepustnosti membrane za vodo*
Fig. 3. *The water-permeability measurement equipment*

Postopek laminiranja PTFE membran na tekstilno podlogo (sl. 5) pa je obsegal naslednje tehnološke faze:
- odvijanje tekstilne podloge,
- nanos lepila na tekstilno podlogo,
- odvijanje PTFE membrane,
- kaširanje (laminiranje) PTFE membrane na tekstilno podlogo,
- sušenje,
- kalandriranje,
- navijanje laminata.

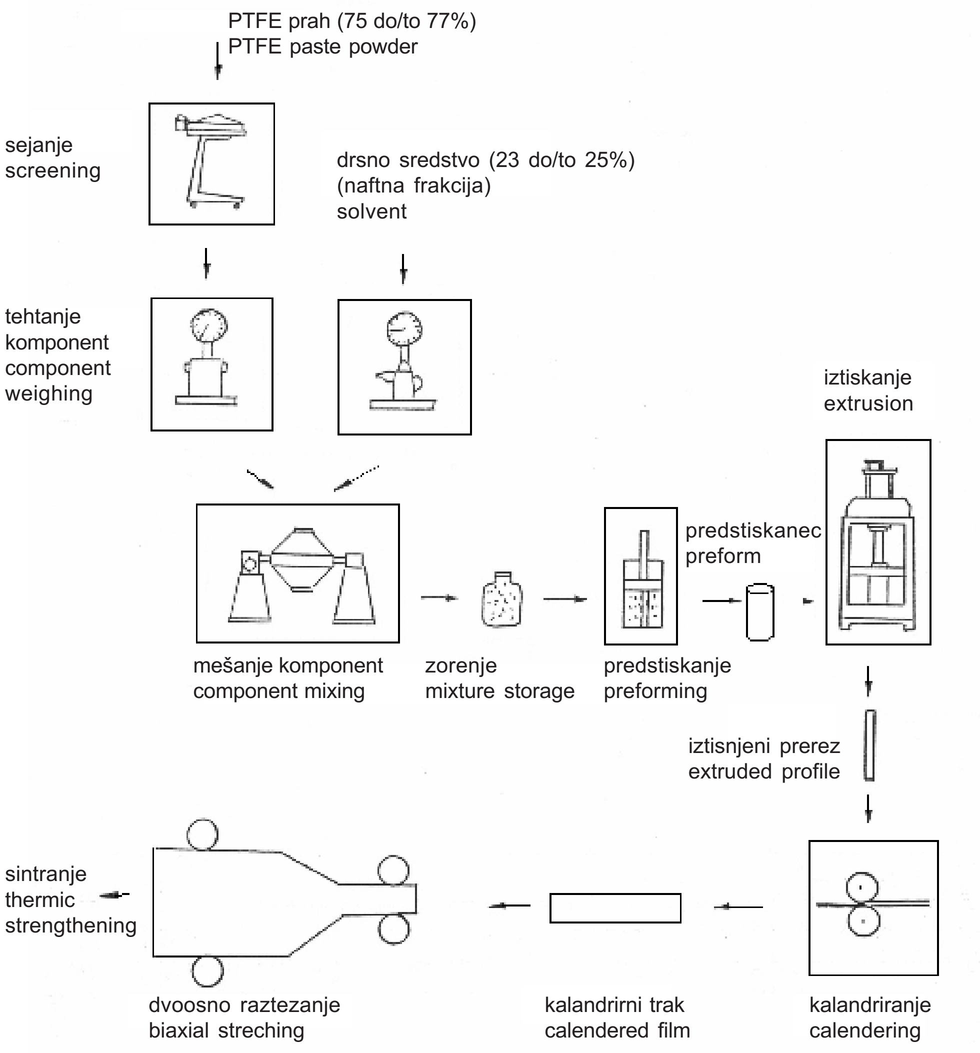
Pri pilotnih preizkusih smo nastale folije le ročno raztezali in toplotno utrjevali. Za izvedbo pilotnih preizkusov laminiranja membran na tekstilne podloge pa smo uporabljali PTFE membrano izdelovalca Tetratec Co. Filtracijske zmožnosti te membrane in laminata na podlagi poliestrske polsti so podane na slikah 8 in 9. Pri tem nismo dosegali popolnih razmer za oblikovanje PTFE membrane, ki so navedeni v patentu [6].

Na sliki 6 je prikazana membrana PTFE, ki smo jo izdelali v pilotnih razmerah. Raztegnjena je le v eni smeri v nasprotju z industrijsko izdelano na sliki 7, ki je dvoosno raztegnjena, toplotno stabilizirana in kaširana na poliestrsko polst. Obe fotografiji na elektronskem mikroskopu sta bili izdelani na FNT Ljubljana, Oddelek za tekstil. S slike 7, kjer gre za vzorec svetovnega izdelovalca podjetja GORE-TEX, je jasno razvidno, da je del membranske strukture zaprt z lepilom. Ta problem smo uspešno razrešili z našim postopkom. Nanesli smo tanek sloj lepila na

The process of applying PTFE lamination to textile backings, which is shown in Figure 5, involved the following phases:
- unrolling the textile backing,
- adding glue to the textile backing,
- unrolling the PTFE membrane,
- laminating the PTFE membrane to the textile backing,
- drying,
- calendering,
- laminate rolling.

Laboratory pilot experiments provided us with PTFE films from which membranes could be made via biaxial stretching. Such films have a relatively weak permeability. The pore size depends on the biaxial stretching level. This makes the stretching phase the most difficult and sensitive phase of PTFE membrane production. For example, to obtain 96% membrane permeability a temperature of 316°C and a stretch velocity of 1000% per second are needed [6].

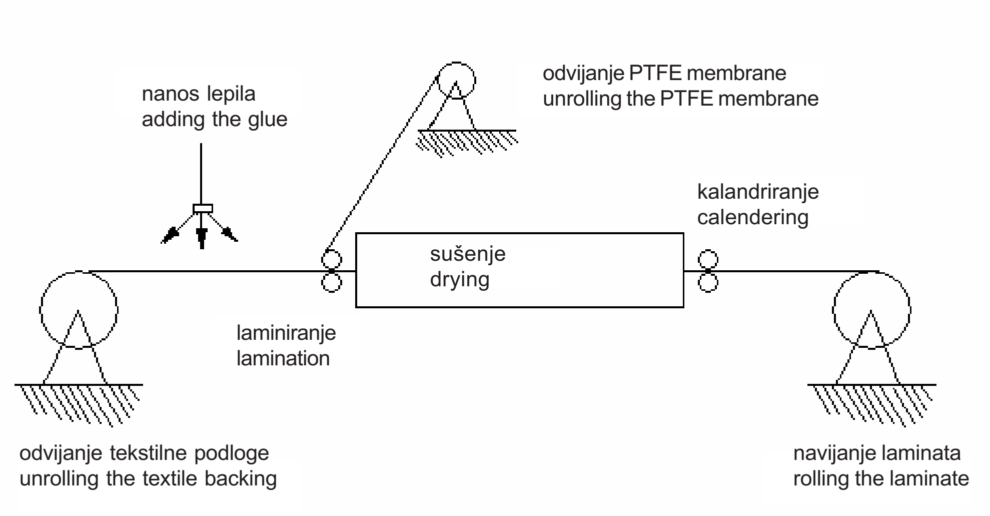
In our experiment, both the stretching and thermic strengthening were conducted manually. Figure 6 shows a PTFE membrane produced in our pilot experiment. This membrane is stretched only in one direction. One example of commercially produced membranes (a GORE-TEX sample) that are biaxially stretched, thermically strengthened and laminated to polyester felt is shown in Figure 7. Both electron microscope figures were produced at the Faculty of Natural Science and Engineering in Ljubljana. In Figure 7 we see that the commercially



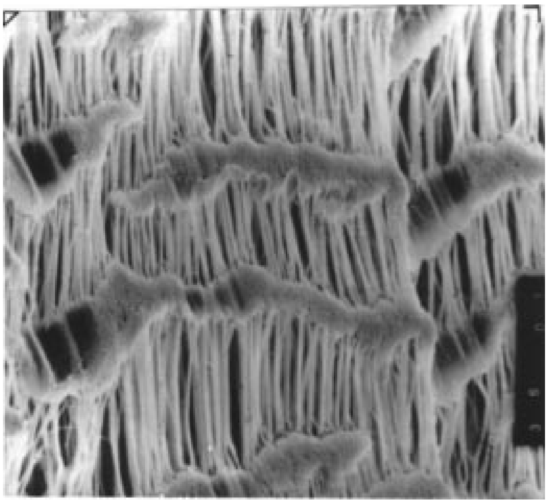
Sl. 4. *Shematski prikaz postopka izdelave PTFE membran*
Fig. 4. *The PTFE membrane-production process*

tekstilna vlakna v podlogi in na to kaširali PTFE membrano. Lepilni sloj med PTFE membrano in tekstilno podlogo je bil zato omejen le na stik membrana – vlakno. Glavni problem za uresničitev našega inovativnega postopka kaširanja PTFE membrane na tekstilno podlogo je bilo iskanje ustreznega lepila. PTFE je oleofoben in hidrofoben material, ki se zelo težko lepi. Po analiziranju vzorcev PTFE laminatov svetovnih izdelovalcev smo ugotovili, da so verjetno nanašali lepila na površine točkovno (s sitom) in po laminiranju lepila še dodatno zamrežili. Eno izmed verjetnih lepil, ki se je takrat uporabljalo, je bilo narejeno na podlagi poliuretanov. Morda so se uporabljala še kakšna druga lepila in drugi postopki. Pri vseh laminatih, ki smo jih našli na

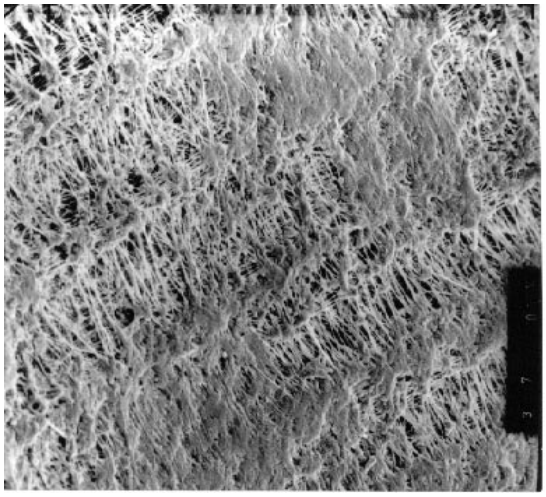
produced membrane has a part of its mechanical structure filled with glue. This problem was successfully removed using our innovative production process. We added a thin glue layer to the textile backing material fibers and then laminated the PTFE membrane on it. The glue layer between the PTFE membrane and the textile backing was, in this way, reduced to being in contact only with the membrane and the fibers. The air-flow and water-entrance measurements testing for the PTFE membrane on PES Felt 500 g/m^2 provided results that differ from those in the official manufacturer catalogues. The main concern with regard to the realization of our innovative lamination process was finding the right type of glue material. PTFE is



Sl. 5. *Shematski prikaz izvedbe preizkusov laminiranja membrane PTFE na tekstilno podlogo*
Fig. 5. *The process of applying PTFE lamination to textile backings*



Sl. 6. *PTFE membrana, ki je raztegnjena samo v eni smeri (elekt. mikroskop, povečava 1900-krat)*
Fig. 6. *PTFE membrane, stretched in only one direction (electron microscope, magnified 1900 times)*



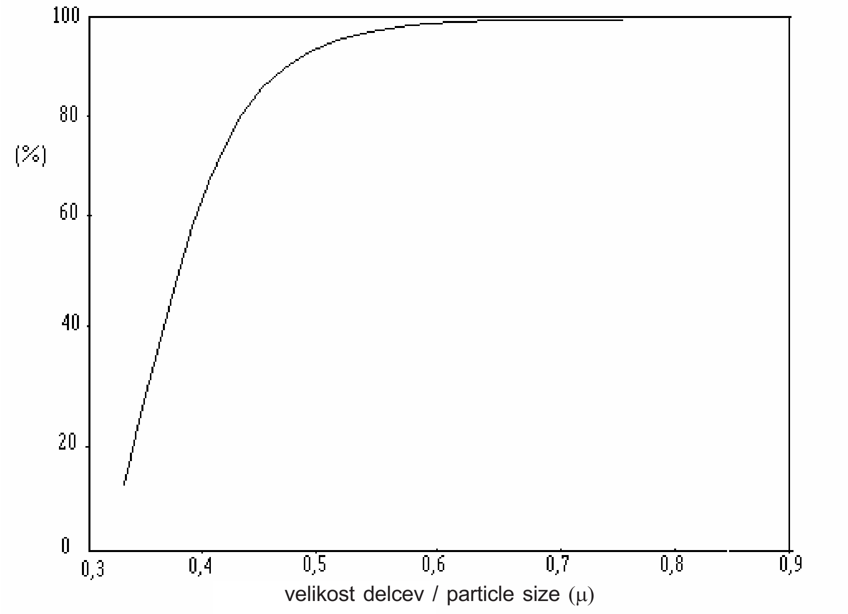
Sl. 7. PTFE *membrana na polsti PES 500 g/m^2 (elekt. mikroskop, povečava 190-krat)*
Fig. 7. *PTFE membrane on PES Felt 500 g/m^2, (electron microscope, magnified 1900 times)*

trgu, smo ugotovili delno zaprtje membranske strukture z lepilom. To kaže, da takrat niso uporabljali takšnega postopka laminiranja, ki je naveden v tem prispevku. Ker je tudi PTFE membrana vlaknaste strukture, gre v našem primeru za povezavo med PTFE vlakni in tekstilnimi vlakni iz podloge. Zaradi tega se v večini primerov prepustnost takšnih laminatov ne spremeni v primerjavi s čisto membrano. Pogoj za to pa je veliko večja prepustnost tekstilne podloge v primerjavi z PTFE membrano.

Na sliki 9 je podana zmožnost zadrževanja delcev kremenčevega prahu pri membranskem filtru TETRATEX (PTFE membrana + polst PES 500 g/m^2)

oleophobic and hydrophobic, which makes it resistant to glue. All the laminates found on the market have part of their mechanical structure filled with glue. This shows that sub-optimal lamination processes were used in their production. Because the PTFE membrane has a fiber structure, both the PTFE membrane and the textile membrane are of similar structure. This leads to laminate permeability that does not differ significantly from the textile backing permeability provided the textile backing is more permeable than the PTFE membrane itself.

Figure 9 shows the particle retention capability of the PES Felt 500 g/m^2. It can be seen



Sl. 8: *Zmožnost zadrževanja standardnega prahu s preizkusno Tetratex membrano iz polsti PES 500 g/m² [8]*
Fig. 8. *Standard dust-particle retention capability in the case of PTFE membrane laminated to PES felt 500 g/m² [8]*

[8]. Pri testiranju pretoka zraka in vode skozi vzorec PTFE membrane na polsti PES 500 g/m^2 smo dobili rezultate, ki nekoliko odstopajo od podatkov iz kataloga izdelovalca PTFE membran.

2 SKLEP

Z laboratorijskimi in pilotnimi preizkusi smo dobili PTFE membrane ustreznih značilnosti, ki so primerljive s tržnimi izdelki. Z inovativnim postopkom laminiranja PTFE membrane na tekstilno podlogo pa smo obdržali prepustnost osnovne

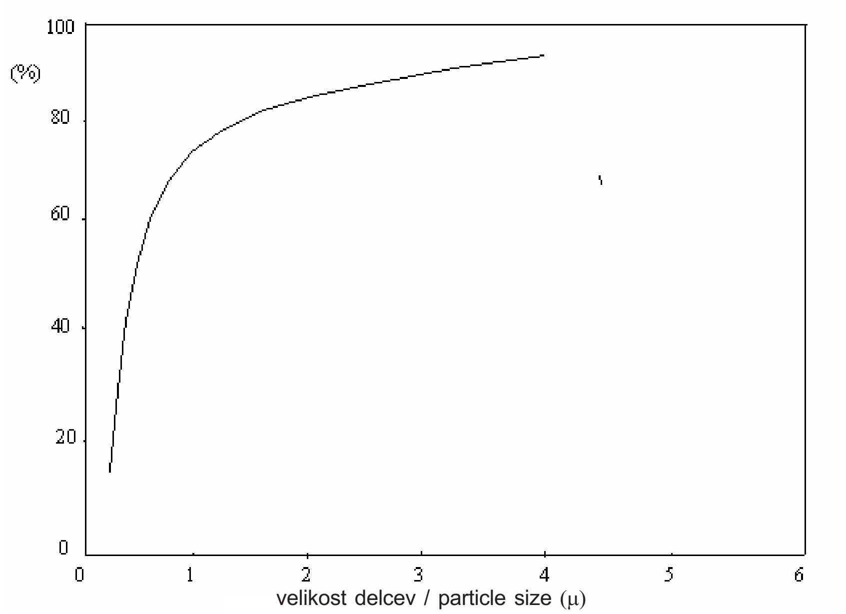
from the figures above that the test membrane filter media retains all the particles larger than 0.6 μm, while the PES Felt 500 g/m^2 laminated membrane retains all the particles in the 1–4 μm interval.

2 CONCLUSION

Our laboratory and pilot experiments have resulted in PTFE membranes that are of comparable quality to commercially marketed PTFE membrane products. The innovative PTFE membrane to textile backings lamination process succeeded in producing

Preglednica 5. *Pretok skozi filtrirne snovi*
Table 5. *Air-flow and water-entrance results*

Filtrirna snov Filter material	Pretok zraka (l/dm^2) pri 20 mm vodnega stolpca Air flow (l/dm^2) at 20 mm water level	Pretok vode (l/m^2 min) pri 0,35 bar Water inflow (l/m^2 min) at 0.35 bar
PTFE/polst PES 500 g/m^2 (iz kataloga) PTFE/PES felt 500 g/m^2 (catalogue data)	6,5 do/to 50	203 do/to 570
PTFE/polst PES 500 g/m^2 (naše meritve) PTFE/PES felt 500 g/m^2 (our measurements)	49	90 do/to 160
polst PES 500 g/m^2 PES felt 500 g/m^2	77 do/to 93	2400
PTFE (testna membrana) PTFE (test membrane)	10	280
PTFE/polst PES 500 g/m^2 (naš vzorec) PTFE/PES felt 500 g/m^2 (our sample)	10	280



Sl. 9. *Zmožnost zadrževanja standardnega prahu s polstjo PES 500 g/m² [8]*
Fig. 9. *Standard dust-particle retention capability in the case of PES filc 500 g/m² [8]*

membrane in hkrati dosegli zadovoljivo adhezijsko zmožnost med membrano in tekstilno podlogo. To je po našem mnenju zanimiv tehnološki postopek, ki pa trenutno v Sloveniji nima ustreznih pogojev za uveljavitev. Predpostavljamo, da so takšen postopek kaširanja osvojili tudi proizvajalci tovrstnih materialov, saj je patent brez ustrezne zaščite na voljo že od leta 1994. Ne glede na to, da gre za razmeroma stare preizkuse, je po našem mnenju tematika še vedno dovolj pomembna. Izdelovalci tovrstnih materialov rezultatov tehnoloških raziskav ne objavljajo na znanstvenih simpozijih in strokovnih revijah, temveč le njihove uporabe. Gre namreč za specifična tehnološka znanja, ki jih ljubosumno skrivajo. Mnenja smo, da je obravnavana problematika kljub temu dovolj zanimiva tudi za znanstvene kroge, saj se m PTFE membranski filtri zelo pogosto uporabljajo v znanstvenih raziskavah, prikazana pa je tudi inovativna rešitev kaširanja, ki ne zmanjšuje prepustnosti PTFE membrane.

both a suitable membrane permeability and good adhesion between the textile backing and the membrane itself. We find our approach to be very suitable for industry-wide use. Due to the fact that this patent was first published in 1994, we assume that the main manufacturers have by now already started to implement this process into regular production. Although the experiments described in this paper were conducted over a decade ago, we find them to be of great industrial and research significance to this day. Membrane manufacturers do not usually present the results of their research in scientific journals or at conferences; rather they present only their applications and jealously hide the results. Although the topic of this article is mainly of significance to the chemical industry, we believe it is scientifically significant also for two reasons: (a) a new, innovative lamination technique that does not reduce PTFE membrane permeability is described and (b) PTFE membrane filters are very often an integral experimental part in many examples of scientific research.

3 LITERATURA
3 REFERENCES

[1] R.J. Schul, S.J. Pearton (2000) Handbook of advanced plasma processing techniques, *Springer Verlag* Berlin, Heidelberg, New York.
[2] J.Nentwig (2000) Kunststoff – Folien. Herstellung – Eigenschaften – Anwendung, *Hauser*, München.
[3] O.Schwarz, F.W.Eberling (2002) Kunststoffverarbeitung, *Vogel Bucherverlag*.

[4] H.Saechting, K.Oberbach (1998) Kunststoff – Taschenbuch, *Hauser*, München.
[5] D. Drev (1994) Nov način kaširanja PTFE membran in folij na tekstilno podlogo : *Urad za intelektualno lastnino Republike Slovenije*, patent št. SI-9200375 z dne 18. 10. 1994, Ljubljana.
[6] W.L.Gore and Associates Inc. (1975) Deutsches Patent, Auslegeschrift 2123316, P 21 23 316.9-16, Bekanntmachungstag 31.7.1975.
[7] R.W. Gore (1976) US Patent 3953556.
[8] Tetratec PTFE technologies begins construction of new headquartes and manufacturing facility (2000) *Donaldson Company, Inc.*
[9] W.R.Backer (2000) Membrane technology and applications, *Mc Graw – Hill*.
[10] H. Kirchenberger (1986) Spinnerei 2000, *Verlag Bondi*, Wien-Perchtoldsdorf.
[11] Podatki firme Tetratec Co.
[12] BIA – Hinweise Staubfiltermaterial 1/85
[13] DIN 24 184
[14] DIN 53 887
[15] S.Martin (2002) Filtration, Druckflüssigkeit und Reinheitsgrad in der Fluidtechnik, *Expert-Verlag*.
[16] M.D.Lechner, K.Gehrke, E.H.Nordmeier (1993) Makromolekulare Chemie, *Birkhäuser Verlag*.
[17] W.R.A.Vauck, H.A.Huller (2000) Grundoperationen Chemischer Verfahrenstechnik, *Wiley-VCH*.
[18] W.Michaeli (1999) Einführung in die Kunststoffverarbeitung, *Hauser*, München.
[19] M.C.Porter (1990) Handbook of industrial membrane technology, *William Andrew Publishing*.
[20] S.P.Nunes, K.V.Peinemann (2001) Membrane technology, *John Wiley & Sons Inc.*
[21] P.Albers, U.Lechner (1991) Zur chemische Fixierung von Silanen auf Feststoffoberflächen, Werkstofftechnik, *Carl Hauser Verlag*.
[22] C.Wargo, V.Kinney, J.Zahka (1994) Hard particle retention of PTFE membranes used for cemical filtration, *Semicon/Europa 94, Technical Conference*, April 12-13,1994 Genova.
[23] R.Mallouk, P.Branca, Composite membrane, US Patent 4902308.
[24] I.Tarsiche, E.Hoprtean, D.Ciurchea (199/) Least-squares analysis of ammonia diffusion through PTFE membranes, *Measurement Science Technology*, Volume 8, Number 11, 1997, pp. 1367-1371.
[25] R.A.Weker, M.A.Sabolefski (1995) Reactive membrane filter ring in microwave-assosted reaction, *Chemical&Engineering News*, 1995, Vol. 73, No. 25. pp.4.
[26] L. Bergmann (2003) Expanded PTFE membrane filtration media worldwide, *Filter Media Consulting Inc*.
[27] Z.Jianchun, H.Jizhi (2003) Processes technique of waterproof and permeable textile, *China Textile Press*.
[28] F.Liu, B.Yi, D.Xing, J.Yu, Z.Hou, Y.Fu (2003) Development of novel self-humidifying composite membranes for fuel cells, *Journal of Power Sources* 124 (2003) 81 – 89.
[29] K.Schwister (2005) Taschenbuch der Verfahrungstechnik, *Carl Hanser GmbH&Co*.
[30] K.N.Werner (2004) Membranfiltration und verwandte molekulare Separationsverfahren, *Fischer Verlag*.
[31] K.P.Müller (2003) Praktische Oberflächentechnik, *JOT Fachbuch*.
[32] E.Ruppelt (2003) Druckluft Handbuch, *Vulkan – Verlag GmbH*.

Avtorjev naslov: dr. Darko Drev
Univerza v Ljubljani
Fakulteta za gradbeništvo in geodezijo
Hajdrihova 28
1000 Ljubljana

Author's Address: Dr. Darko Drev
University of Ljubljana
Faculty of Civil Engineering and Geodesy
Hajdrihova 28
1000 Ljubljana, Slovenia

Prejeto: / Received: 20.9.2005
Sprejeto: / Accepted: 22.6.2006
Odprto za diskusijo: 1 leto
Open for discussion: 1 year