Short Communication

WETTING OF IMMOBILISING PLASTER BANDAGES BY IMMERSION BEFORE APPLICATION

Andrej Fojkar and Aleksander Pavko*

Faculty of Chemistry and Chemical Technology, University of Ljubljana, Aškerčeva 5, 1000 Ljubljana, Slovenia

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Abstract

Samples of Vivagyps® immobilising plaster bandages with three different porosities were prepared. Their wetting rate before application was investigated at several water bath depths. The wetting rate can be described by Darcy's law for liquid flow through porous beds, which is proportional to the material permeability and water bath depth and inversely proportional to the material thickness and liquid viscosity. Addition of surfactant to the plaster bandage before wetting substantially improves the wetting rate.

Key words: wetting, plaster bandages

Introduction

Medical plaster bandages are used in hospitals as an orthopaedic utility for the immobilisation of injured parts of the body. Before application, the dry plaster bandage is immersed in a water bath, where it should be completely wetted in a few seconds. It should be applied with wet gloves in approximately two minutes because it starts to solidify. The cast is firm in an hour. Wetting time in the water bath is a very important property of the gypsum bandage and also a competitive advantage on the market. For this reason, the influence of some dry plaster bandage properties on the wetting time was investigated in this research.

The plaster fabric is made of thin-woven cotton fabric in a continuous production process. Briefly, the cotton fabric is immersed into a plaster suspension in methylene chloride with additives, wrung in a drum press to the desired plaster content on the fabric surface and dried. The final product, plaster bandages of desired width, are then made by cutting and coiling up the plaster fabric on a hollow plastic cylinder 20 mm in diameter. A bandage of 50 mm diameter consists of approximately 20 layers of plaster fabric, which form a porous structure.[1] Therefore, wetting before application means that water must permeate through the porous material. In this case, wetting takes place by two different but simultaneously acting processes caused by the pressure difference and by surface tension.

Laminar liquid flow through the porous bed can be expressed by Darcy's law with the following equation:

$$u_c = B\frac{\Delta P}{l\mu} \qquad (1)$$

where u_c means the average liquid velocity, B is the material permeability, l the material thickness, ΔP denotes the pressure difference and μ the fluid viscosity.[2]

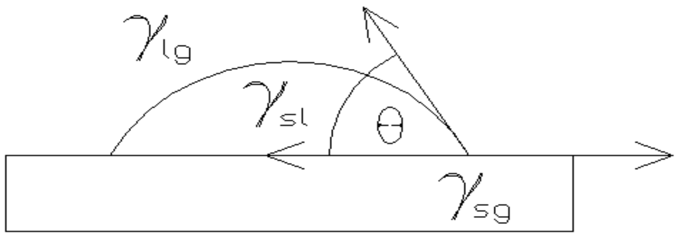

Figure 1. Schematic presentation of the Young's equation.

Wetting can be also described by Young's law, which is schematically shown in Figure 1, and takes into account the effect of surface tension on the liquid-solid contact angle. The situation at equilibrium is presented by the following equation:

$$\gamma_{sg} - \gamma_{sl} = \gamma_{lg} \cos\theta \qquad (2)$$

The symbols are as follows: γ_{sg} – solid-gas interfacial tension, γ_{sl} – solid-liquid interfacial tension and γ_{lg} – liquid-gas interfacial tension, while θ is the liquid-solid contact angle, which is a measure of wetting efficiency. Wetting is perfect at θ close to 0° while wetting is bad at θ between 90° and 180°.[3]

Experimental

Plaster bandage sample preparation

Plaster fabric with different surface contents of plaster was prepared during the production process at three different conditions of the drum press. The difference is evident from Figure 2. Plaster bandage samples of cylindrical shape, which simulated the different plaster bandage properties, were carefully prepared from plaster fabric. Circles of 25 mm diameter were cut out of the plaster fabric. Each plaster bandage sample was prepared from 25 circles by careful laying them one on another into a measuring tube and gentle presure by a piston to obtain the desired sample thickness. Variation of the quality of the plaster fabric and sample thickness in the range between 15 and 25 mm gave the range of material porosity and density investigated here.

Figure 2. Samples of plaster fabric with low, standard and high surface contents of plaster.

Wetting time determination

Wetting time of plaster bandage samples was measured in the simple device shown in Figure 3 and designed by the authors of this research. Its main part is a vertical 150 mm long plastic tube (25 mm ID) with a bottom perforated lid and a top perforated lid with a stick holder. The tube is mounted on a solid stand. To determine the wetting time, the tube with a plaster sample was immersed into the water bath and the top surface was observed. The wetting time was estimated with a stop watch as the time interval between the moment of immersion and the moment when water appeared on the surface of the sample. According to Darcy’s law, the pressure difference during wetting experiments was varied by changing the height of water above the bottom of the sample in the range between 30 and 90 mm. Each experiment was performed at least three times and the deviation between measured times was less than 10%.

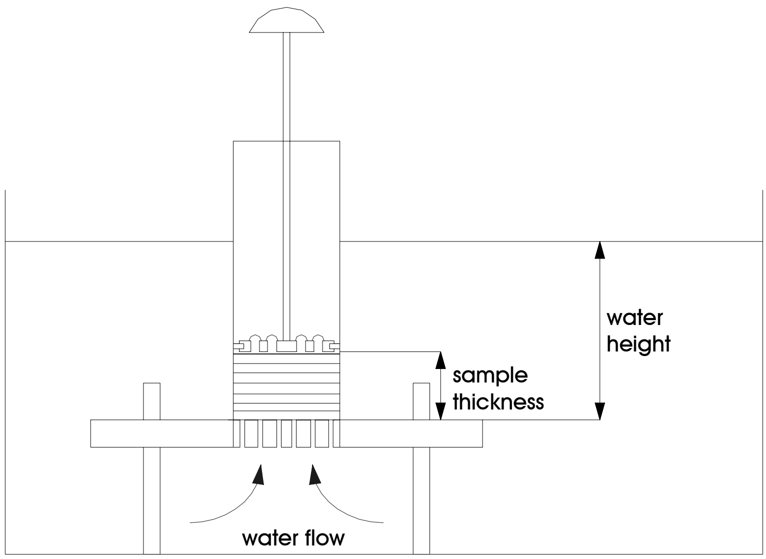

Figure 3. Schematic diagram of the wetting time measuring device.

The effect of surfactants

The effect of three commercial and chemically different surfactants was also tested. Already described circles of plaster fabric were put into a 0.2% solution of each surfactant in methylene chloride for 10 seconds and then dried. Samples were then carefully laid on the water surface and the time when the samples began to sink was estimated. It was found that the combined surfactant with ionic and non-ionic properties had a substantial effect. The time of the sample to start sinking was reduced from 500 seconds to less than 10 seconds. The wetting time of samples prepared with this surfactant was then measured as described above.

Results and discussion

The average wetting rate for each experiment was determined by dividing the sample thickness by the estimated wetting time. Results of wetting rate at different water depths for samples with low, standard and high density, prepared with the plaster fabric with standard surface contents of plaster, are shown in Figure 4. Generally, we can assume that for a sample which is prepared in the described way, the permeability is proportional to porosity and inversely proportional to the sample density. It may be seen that the wetting rate of a sample linearly increases with the water depth i.e. pressure difference ΔP. Furthermore, the wetting rate at given a water depth is higher at higher material porosity. This is in good agreement with Darcy's law. However, the wetting rate approaches zero when the water depth is less than approximately 30 mm (close to sample thickness). Here, the surface tension is probably the prevailing mechanism, which prevents wetting.

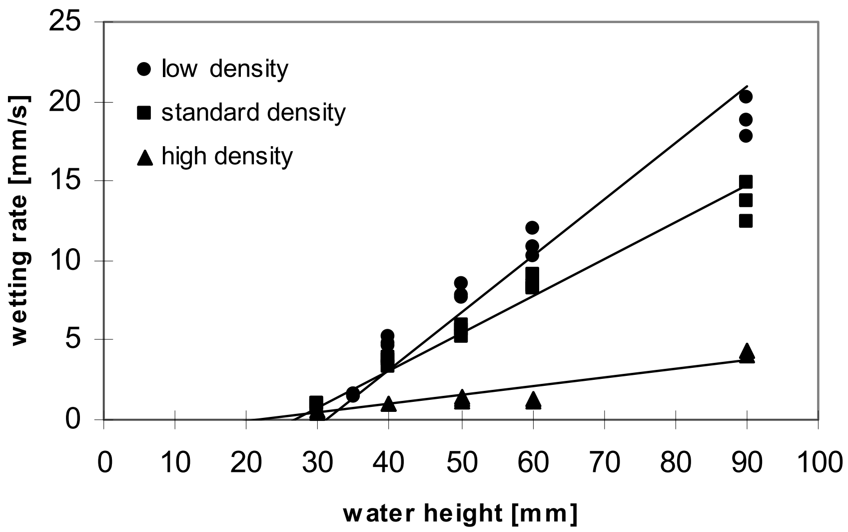

Figure 4. Wetting rate for different samples at different water heights.

A similar situation is seen in Figure 5. The wetting rate at a given water depth decreases with increasing material density. The effect of water depth is more pronounced at lower material densities and higher water depths according to Darcy's law. The wetting rate at standard material density and 50 mm water depth is approximately 5.5 mms^{-1}. At the lowest water depth, which is close to the material thickness, the wetting rate substantially decreased to a value around 1mms^{-1} due to the retarding effect of surface tension. The estimated material permeabilities B in the case of high, standard and low density of plaster samples are $0.8\times10^{-10}m^2$, $4.7\times10^{-10}m^2$ and $9.0\times10^{-10}m^2$, respectively.

The effect of the surfactant on wetting time, especially at low water depths, is seen from Figure 6. At water depths of around 50–60 mm, where wetting usually takes place, it was reduced from approximately 5 seconds to approximately 2.5 seconds. Accordingly, the wetting rate shown in Figure 7. increased from 5 mm s^{-1} to approximately 10 mm s^{-1}, while the corresponding material permeability rose from

$4.7\times10^{-10}m^2$ to 6.7×10^{-10} m^2. From the same figure it is seen that the intercept on the abscissa is shorter in the case of surfactant addition. This confirms the previous assumption about the retarding role of surface tension. Namely, the energy necessary for wetting by immersion consists of the energy due to the pressure difference which causes flow through the porous material, and the surface energy which prevents wetting. When the surface energy is reduced by the addition of a surfactant, lower energies are necessary for wetting by immersion which therefore occurs at lower depths.

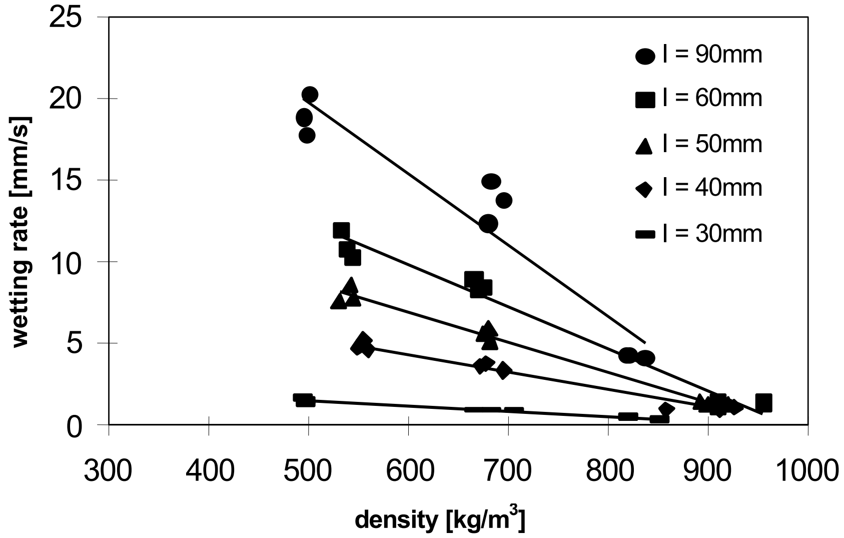

Figure 5. Wetting rate at different water depths as a function of sample density.

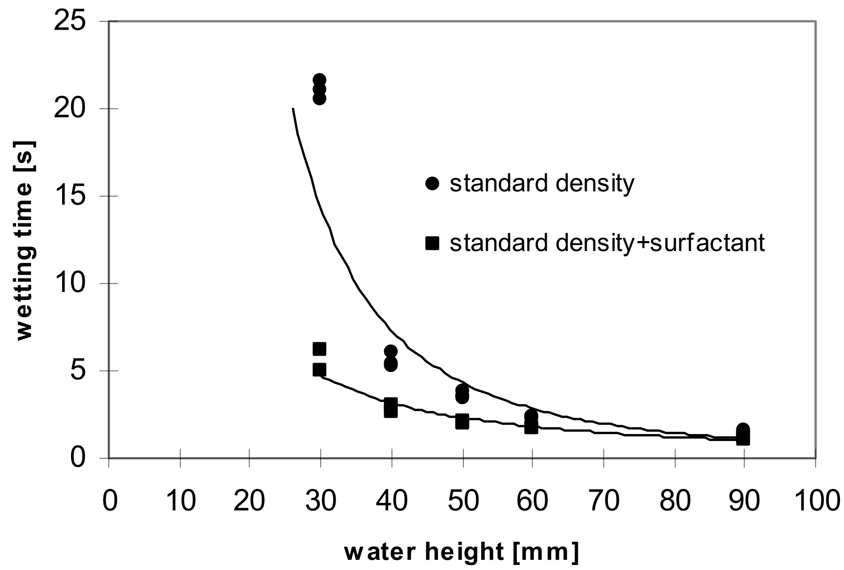

Figure 6. Effect of surfactant on wetting time for standard density sample.

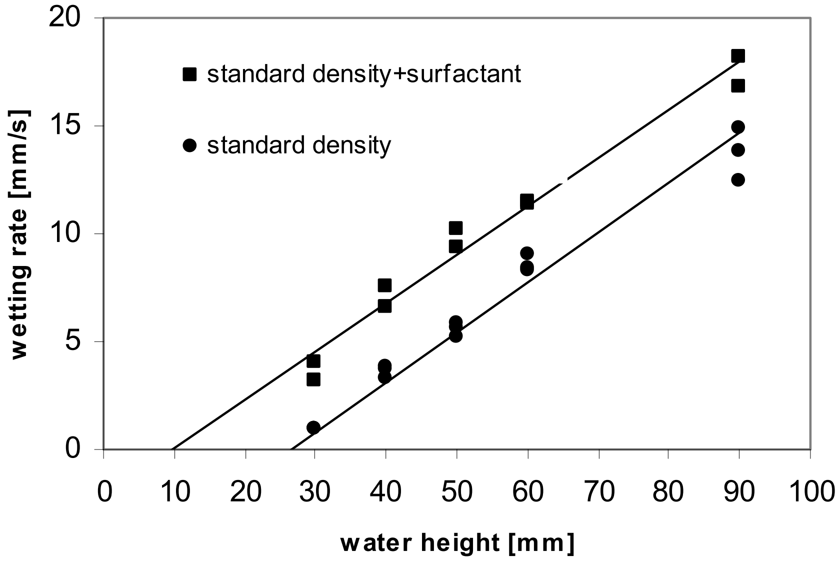

Figure 7. Effect of surfactant on wetting rate for standard density sample.

Conclusions

When a plaster bandage is immersed in a liquid, it becomes wet due to the hydrostatic pressure difference which excludes air and causes liquid flow through the porous material. The wetting rate can be well described by Darcy's law and is proportional to the material permeability and water bath depth, but inversely proportional to the material thickness and liquid viscosity. However, solid-liquid surface tension generally prevents wetting. This effect can be overcome by the addition of a surfactant during the plaster bandage production process. In this way, the wetting rate before application is substantially improved.

Acknowledgements

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Nomenclature

B	- material permeability [m^2]
L	- material thickness [mm]
ΔP	- pressure difference [Pa]
u_c	- average liquid velocity [mms^{-1}]
μ	- the fluid viscosity [mPas]
γ_{sg}	- solid-gas interfacial tension [Nm^{-1}]
γ_{sl}	- solid-liquid interfacial tension [Nm^{-1}]
γ_{lg}	- liquid-gas interfacial tension [Nm^{-1}]
θ	- liquid-solid contact angle [^{o}]

References

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Povzetek

Pripravljeni so bili vzorci mavčnih uravnalnih obvez Vivagyps® s tremi različnimi poroznostmi sloja. Proučevana je bila njihova hitrost omakanja pri različnih globinah potopitve pred uporabo. Hitrost omakanja lahko opišemo z Darcyjevim zakonom o pretoku tekočin skozi porozne sloje po katerem je pretok sorazmeren permeabilnosti materiala in tlačni razliki ter obratno sorazmeren debelini materiala in viskoznosti tekočine. Prepariranje mavčnega povoja s tenzidom zelo poveča hitrost omakanja.