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Absorption of Water and Lubricating Oils Into Porous Nylon

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Prepared for

NASA
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Development Group

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El Segundo, California

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Abstract

Oil and water absorption from air into sintered porous nylon can be described by infiltration into the pores of the material. This process can be modeled by a diffusion-like mechanism. For water absorption, we find a formal diffusion coefficient of 1.5×10^{-4} cm^2/min when the nylon is initially dry. The diffusion coefficient is 4×10^{-6} cm^2/min when the nylon is oil-impregnated prior to air exposure. In a 52% RH atmosphere, dry nylon absorbs 3% w/w water, and oil-impregnated nylon absorbs 0.6% w/w water. For oil absorption there are three steps: (1) surface absorption and infiltration into (2) larger and (3) smaller pores. Surface absorption is too fast to be measured in these experiments. The diffusion coefficient for the second step is 6×10^{-4} cm^2/min for SRG-60 oil into dry nylon and 4×10^{-4} cm^2/min for air-equilibrated nylon. The diffusion coefficient for the third step is about 1×10^{-6} cm^2/min for both cases. The total amount of oil absorbed is 31% w/w. The interaction between water and nylon is not as strong as that between water and cotton-phenolic: oil can replace water, and only a small amount of water can enter previously oil-impregnated nylon.

Acknowledgment

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1. Introduction

Porous nylon, also called "Nylasint," has been used for many years in bearing systems in both space and terrestrial applications. It is often used as a lubricant reservoir, and sometimes as a ball separator (retainer) in ball bearings. This report describes the processes by which both water from the atmosphere and lubricating oil enter the material. The effects of water on oil-filled nylon and of oil on air-equilibrated nylon are also described. The behavior of nylon with respect to water and oil is very different from that of cotton-phenolic, another commonly used retainer material, and similar to the behavior of porous polyimide.

Porous nylon materials are typically made from polyamide powders with particle sizes of 4 to 10 μm. The powders are cold-pressed and then sintered in an inert atmosphere to reduce oxidation of the polymer.[1] Variations in particle size and sintering processes will affect the porosity of the final material. It is well-known that nylon has many pores varying in diameter from 30 to 0.3 μm. The experiments reported herein were carried out on samples from a single nylon tube and with only one oil. In this way, any effects from process variation are minimized; the specific values for rate constants and absorption amounts are, of course, specific to this particular piece of material and this oil.

2. Experimental

The nylon used in these experiments was from a single piece of tube stock that had been made to a specification of 25 to 50% porosity. The material was cleaned by Soxhlet extraction in ethanol overnight, drying in a vacuum oven at 105°C overnight, Soxhlet extraction in heptane overnight, and then again drying in the vacuum oven overnight. Samples were cut with a hand saw from the piece of tube stock. Eight large samples were cut, with heights of about 1.4 to 1.5 cm along the axis of the tube and lengths of about 1.0 to 1.2 cm along the outer curved circumference of the tube and 0.6 to 0.8 cm along the inner curved circumference of the tube. The tube was 0.75 cm thick. These specimens are referred to as samples 1 through 8. Three small samples were cut, one with a height of 1.4 cm and length of about 0.4 cm on each curved edge, and two with heights of about 0.6 cm and lengths of about 0.4 cm on each curved edge. These are referred to as samples 9, 10, and 11. The samples were rinsed in heptane after cutting to remove any loose particles and baked in the vacuum oven overnight immediately before use.

Four sets of experiments were performed.

Set 1: Samples 1, 2, 3, 4, 9, 10, and 11 were exposed to laboratory air (RH ~ 50%), and weighed periodically.

Set 2: Samples 5, 6, 7, 8, 9, 10, and 11 were weighed immediately after removal from the oven (9, 10, and 11 had been baked again), then immersed in SRG-60 oil. SRG-60 is a highly refined mineral oil with a viscosity of 77.6 cS at 100°F and a density of 0.8770 g/cm^3. The samples were removed periodically, wiped carefully with a lint-free cloth, and weighed.

Set 3: After samples 1 and 2 had equilibrated with air (i.e., their weight no longer changed with continued exposure), they were immersed in SRG-60 oil, and their absorption of oil was monitored.

Set 4: After samples 7 and 8 had equilibrated with oil, they were placed in a controlled-humidity environment. The relative humidity of 52% was controlled by a saturated aqueous solution of $NaHSO_4{\bullet}H_2O$. They were removed periodically, wiped, and weighed.

3. Results and Discussion

3.1 Infiltration Model

Infiltration into isotropic porous media with interconnected pores can be modeled in a formal sense as a diffusion process. In the process under study here, the absorption of either water from the air or oil continues until the sample is saturated. The appropriate solution of the diffusion equation for saturation of a plane sheet is[2]

$$\frac{M_t}{M_{sat}} = 1 - \frac{8}{\pi^2} \sum_{m=0}^{\infty} \frac{1}{(2m+1)^2} \exp \frac{-D(2m+1)^2 \pi^2 t}{\ell^2}$$

where M_t is the uptake at time t, M_{sat} is the saturation uptake, ℓ is the sample thickness (in these experiments, half the sample thickness since the sample fills from both sides and we ignore the edge effects), D is the formal diffusion coefficient, and m is an index. D is related to the porosity of the matrix and the permeability of the matrix-fluid system, which may be related to the viscosity. The specific dependence of D on the viscosity is influenced by the exact flow process (whether it is viscous and whether there are capillary, electrical, chemical, or other forces involved) and is not predictable in most cases.

3.2 Water Absorption into Dry Nylon

The absorption of water from laboratory air is illustrated in Figure 1. The weight increase can be fit by the infiltration model with a formal diffusion coefficient of 1.5×10^{-4} cm^2/min. Figure 1a shows the results for the large samples (numbers 1, 2, 3, and 4), with $\ell = 0.38$ cm. Figure 1b shows the results for the small samples (numbers 9, 10, and 11), with $\ell = 0.2$ cm. The data for the small samples are more scattered than those for the large samples because the amount of water absorbed is very small. However, the infiltration model with the same diffusion coefficient as for the large samples clearly fits the data.

The amount of water in nylon at equilibrium with 50% RH air is 2.8% w/w. This is similar to porous polyimide[3] (2.2% w/w) and different from cotton-phenolic[4] (4.6% w/w).

3.3 Oil Absorption into Dry Nylon

Over a limited period of time, diffusion-like processes can be fit to a simple absorption amount vs. $t^{1/2}$ relationship. Oil uptake data for Sample 5, which are typical of all the samples, are presented in this way in Figure 2. The absorption appears to be a three-step process. The line representing the second step intersects the ordinate at a non-zero value; this is probably due to a very fast first step, probably adsorption on the external surfaces as well as in very large pores. It amounts to 10 to 40 mg in the large samples and 6 to 13 mg in the small samples, or about 10% of the final saturation amount of oil absorbed. The line representing the third step intersects the ordinate at the weight of oil present at saturation of the second step. This is 185 to 210 mg for the large samples and 37 to 75 mg for the small samples (these numbers include the initial surface absorption and represent about 85% of the saturation amount of oil absorbed). The last few points (corresponding to times greater than 40,000 min) do not lie on the second line. This shows saturation of the sample with oil. Each step will be examined separately below.

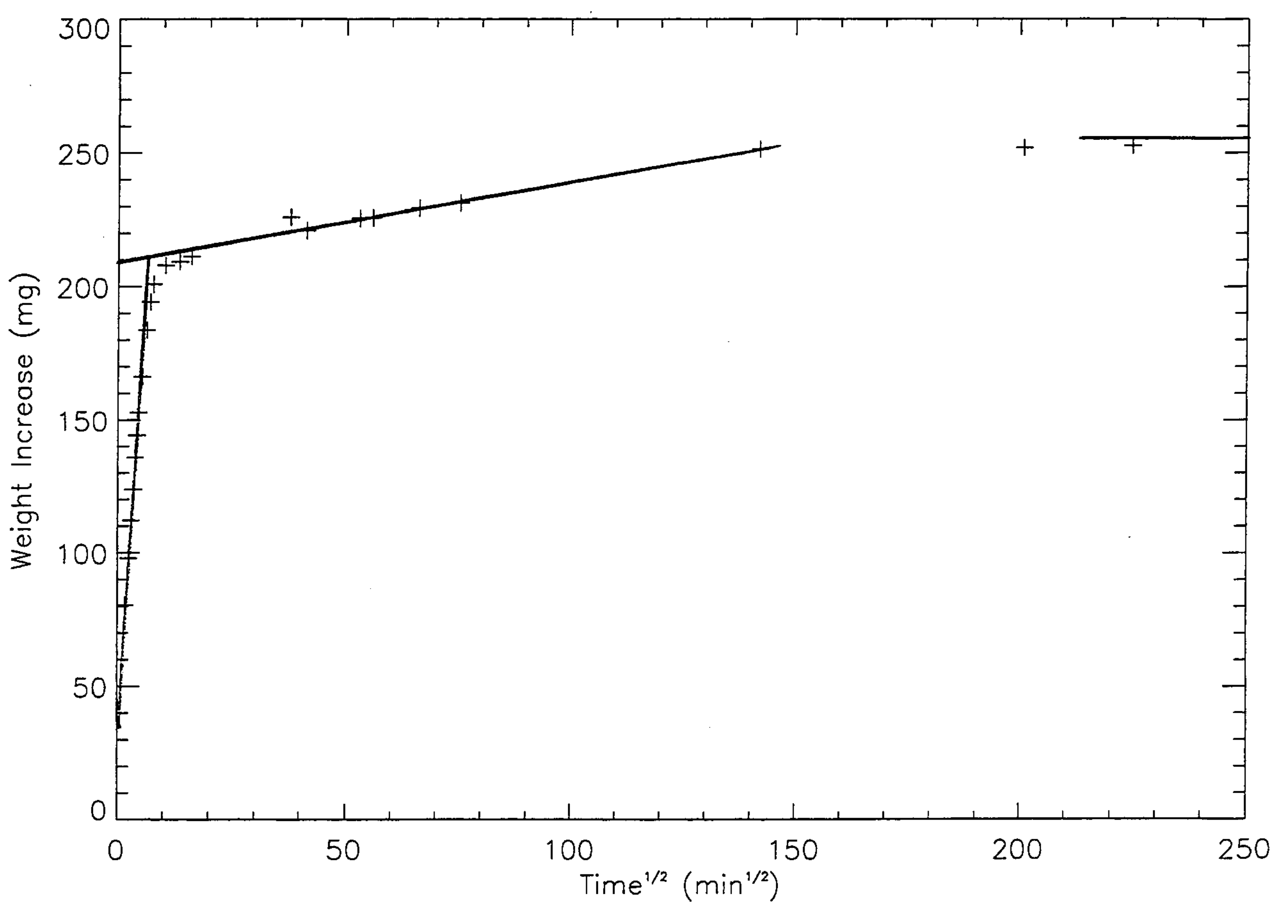

Figure 2. Oil absorption into a typical sample (sample 5) of dry nylon.

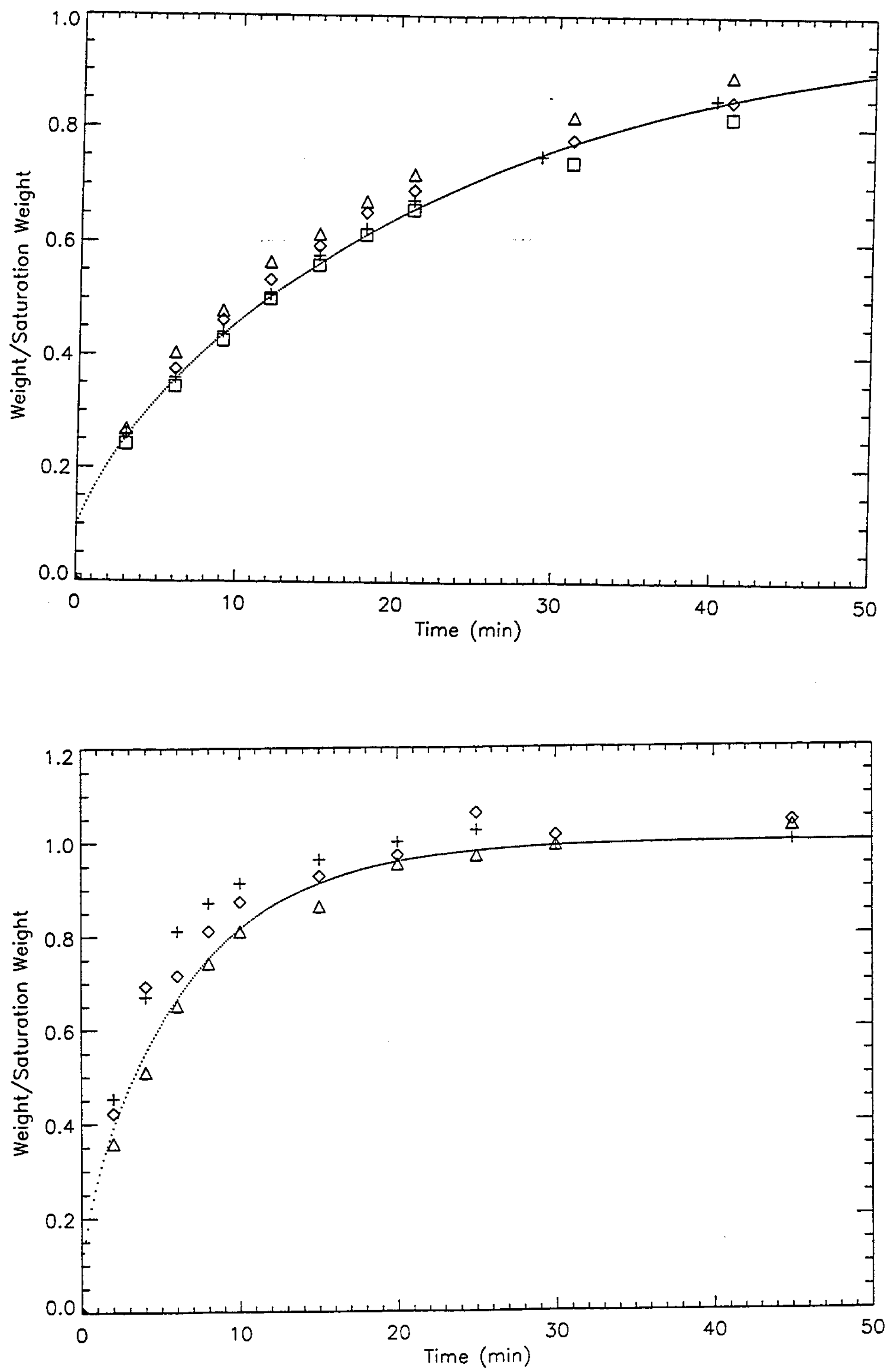

Figure 3. The second step of oil absorption into dry nylon. The curves are the best fit of a formal diffusion model to the data. (a) Samples with thickness 0.76 cm. Each symbol represents a different sample. (b) Samples with thickness 0.4 cm. Each symbol represents a different sample.

3.4 Oil Absorption into Air-equilibrated Nylon

Samples 1 and 2 were placed in a bath of SRG-60 oil after they had equilibrated with laboratory air (RH ~50%). The presence of water in the nylon slowed the absorption of oil, but did not significantly affect the overall amount of oil absorbed. Oil absorption remained a three-step process.

Figure 5 shows the data and model fit for the second step of oil absorption into air-equilibrated and dry nylon. The formal diffusion coefficient for the air-equilibrated case is 4×10^{-4} cm^2/min, which is ⅔ of that for the dry case. The weight gain (relative to dry nylon) in the air-equilibrated case is $26 \pm 1\%$ w/w, just as in the dry case. Either the water remained in the sample, and a lesser weight of oil was absorbed in the air-equilibrated case (i.e., 3% w/w water remained, and 23% w/w oil was absorbed), or the water was removed as the oil entered. The oil was probably dry since it had been stored in a desiccator for several weeks, and the absorption experiments were carried out in the desiccator, so it is highly likely that the water was removed in the course of the experiments.

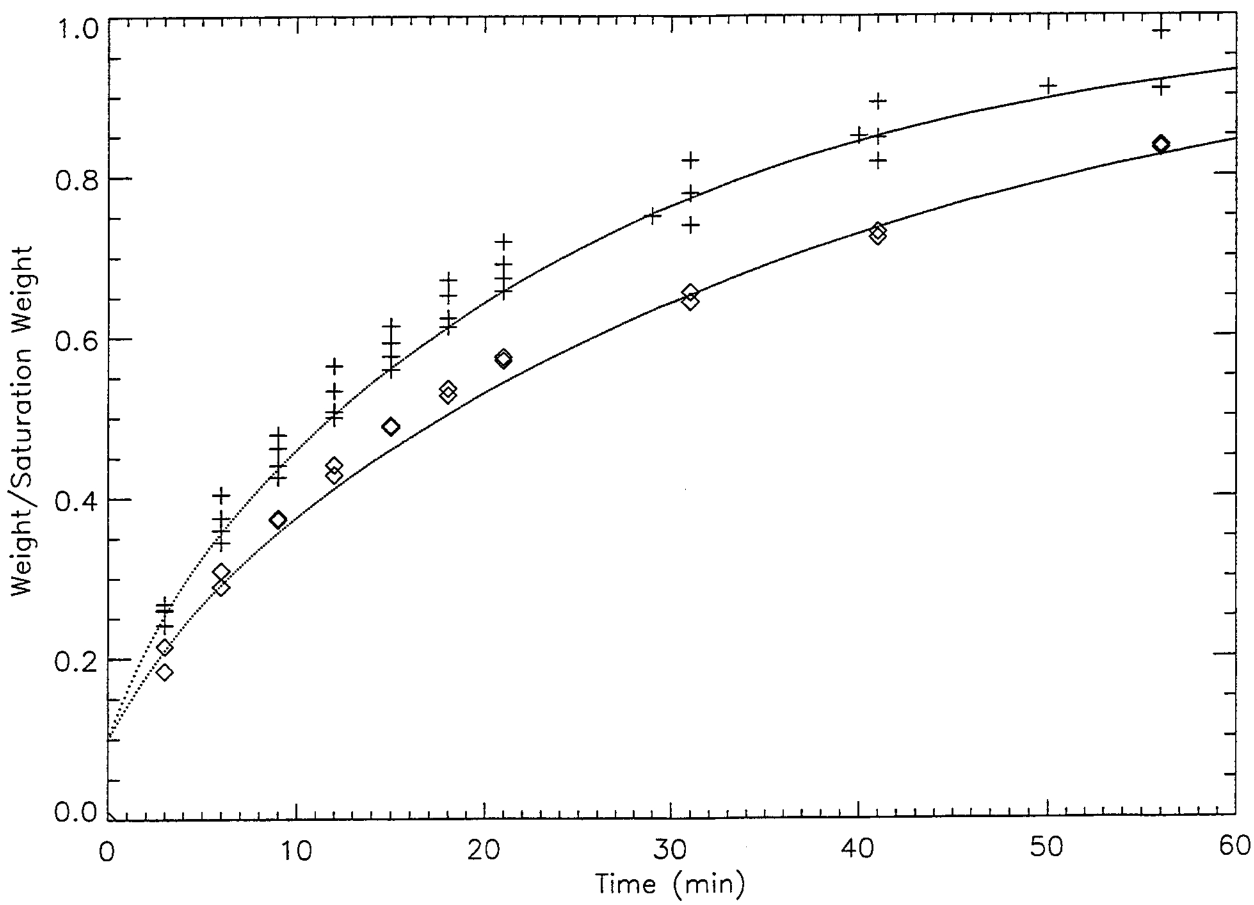

Figure 5. Oil absorption into nylon. + represents samples that were dry before oil absorption, ◊ represents samples that were equilibrated with room air at 50% RH before oil absorption. The curves are the best fit of a formal diffusion model to the data.

The fact that much less water is absorbed into oil-impregnated nylon is additional evidence that oil probably replaced most of the water in the air-equilibrated nylon that was subsequently placed in oil. This suggests that there is no strong interaction between nylon and water, unlike the very strong interaction between cotton-phenolic and water, which can prevent oil from entering the material at all and remove oil that has been previously absorbed.

When the samples were subsequently placed in a desiccator with $CaSO_4$ drying agent for a week, their weights returned to the values after filling with oil and before exposure to humid air. Thus, no measurable oil was removed by the water as it absorbed.

4. Conclusions

The absorption of water and oil into nylon is very different from that into cotton-phenolic and similar to that into porous polyimide. Oil and water absorption from air into porous nylon can be described by infiltration into the pores of the material. This process can be modeled by a diffusion-like mechanism. For water absorption, we find a formal diffusion coefficient of 1.5×10^{-4} cm^2/min when the nylon is initially dry. The diffusion coefficient is 4×10^{-6} cm^2/min when the nylon is oil-impregnated prior to exposure to moist air. In a 50% RH atmosphere, dry nylon absorbs 3%w/w water, and oil-impregnated nylon absorbs 0.6% w/w water. For oil absorption, there are three steps, which probably involve infiltration into pores of varying sizes. The first step, surface absorption and filling of very large pores, is too fast to be measured in these experiments. The diffusion coefficient for the second step, filling of large pores, is 6×10^{-4} cm^2/min for dry nylon and 4×10^{-4} cm^2/min for air-equilibrated nylon. The diffusion coefficient for the third step, filling of small pores, is about 1×10^{-6} cm^2/min for both cases. The total amount of oil absorbed is 31% w/w.

The interaction between water and nylon is not as strong as that between water and cotton-phenolic. Water can prevent the absorption of oil into cotton-phenolic and can drive out oil that has already been impregnated into the material. In nylon, oil can replace water, and only a small amount of water can enter previously impregnated nylon. Thus, the extremely rigorous precautions that must be taken to prevent water absorption by cotton-phenolic need not be taken with nylon unless the small amount of water retained even by impregnated material would cause problems for the final application.

References

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