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OUTGASSING OF WATER VAPOR FROM CONCRETE SURFACES IN VACUUM ENVIRONMENT

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SUMMARY

The amount of water loss by outgassing from two borated and two nonborated concrete blocks was measured at vacuum levels of 0.1 and 30 torr ($1.3x10^1$ and $3.9x10^3$ N/m^2). The nonborated blocks were also baked out in a furnace and subsequently placed in a 100-percent humidity chamber to investigate the reabsorption power of the concrete. The amount of water loss proved to be approximately 0.06 lb/ft^2 (0.03 kg/m^2) for the nonborated and 0.320 lb/ft^2 (0.16 kg/m^2) for the borated blocks. The concrete reabsorbed 70 percent of the water loss within the first 20 hours in the 100-percent humidity chamber.

INTRODUCTION

Because large space simulators expose a large area to atmospheric pressure, structural integrity and cost of the facility are critical. Concrete is now being considered as a building material for vacuum chambers (ref. 1) in the order of 500000 cubic feet ($1.4x10^4$ m^3) and larger, such as the Space Power Facility (formerly Space Propulsion Facility) at the Lewis Research Center's Plum Brook Station (ref. 2).

The vacuum chamber at the Space Power Facility consists of an aluminum shell enveloped by an outer concrete enclosure which serves as a combined biological shield (ref. 3) and pressure vessel. The annular space between the aluminum chamber and concrete enclosure is evacuated to 25 torr ($3.3x10^3$ N/m^2) in order to minimize the pressure loading on the aluminum chamber. The biological shield is necessary for radiation protection from nuclear power sources which may be part of the system under test.

Water vaporizing from the concrete surfaces exposed to low pressure is a problem associated with using concrete at low pressure levels. Because of contamination of the oil used in the vacuum pumping system, large quantities of water vapor will prevent the attainment of designed vacuum levels. Data on the amount of water released from concrete surfaces subjected to low pressure are presented herein and aid in the sizing of vacuum equipment necessary for pumping on these surfaces.

Concrete blocks were cast at the Plum Brook Station and stored outdoors for several weeks before shipment to Lewis Research Center where they were stored in the test cell for several more weeks prior to testing. Outgassing tests were conducted first in a stainless steel bell-jar on two borated and two nonborated blocks at vacuum levels of 0.1 and 30 torr ($1.3x10^1$ and $3.9x10^3$ N/m^2). After outgassing the blocks were placed in a furnace and baked at 250° F (394° K) for 162 hours to determine the total amount of free water. Water absorption characteristics were determined by weighing the baked specimens after exposure to a 100-percent-humidity environment for periods up to 6 days.

EXPERIMENTAL PROCEDURE

Four concrete blocks, 1- by 1- by 0.5 foot (0.3- by 0.3- by 0.15 m) and weighing approximately 74 pounds (33 kg) each were tested. Composition of the concrete is presented in table I. Two blocks were borated with an admixture of boron frits (a granular boron compound), and two blocks were nonborated. In addition, two coats of a chlorinated rubber sealer were brushed onto one of the borated blocks to retard outgassing of the free water (water which does not enter into reaction) in the concrete.

To determine the amount of free water released from concrete at reduced pressures, a 36-inch (0.9-m) diameter by 42-inch (1.1-m) high stainless steel vacuum chamber (fig. 1) was employed to produce vacuum levels of 0.1 and 30 torr. The specimens were placed on a balance scale located inside the vacuum chamber and the weight loss against time was recorded for each block. The scale was calibrated against a set of analytical weights before starting the tests. A mechanical arm (feed through) was used to adjust the balance weights on the scale. Evacuation was accomplished by a 140-cfm ($6.5\text{-m}^3/s$) mechanical pump.

The vacuum level of approximately 30 torr was maintained by bleeding air through an on-off solenoid valve electrically connected to a mercury manometer tube while the 0.1 torr vacuum was the ultimate vacuum reached during the test with a concrete block in the chamber.

The total amount of free water was determined by baking the nonborated blocks in an oven (fig. 2) at 250° F (394° K) for 162 hours following the outgassing under vacuum. Weight of each block was recorded periodically during the test run. Immediately after the bakeout these two blocks were placed in a 100-percent-humidity steam bath and the amount of water reabsorbed was recorded by weighing the block periodically.

The total water content of the blocks before mixing is seen in table I to be 6.6 percent by weight and the ratio of water to cement is approximately 6.5 gallons per sack ($2.4x10^{-2}$ m^3/sack). Free water content of the test blocks was determined by calculating the amount of water needed in the reaction between cement and water (ref. 4) and subtracting it from the weight of the total water used before mixing. The amount of premix water for a 74 pound (33 kg) block of concrete is 4.9 pounds (2.2 kg) and the calculated water required for complete reaction is 2.2 pounds (1.0 kg) per concrete block.

RESULTS AND DISCUSSIONS

Concrete derives its strength primarily from the tobermorite gel ($3CaO \cdot 2SiO_2 \cdot 3H_2O$) which is produced from the chemical reaction between cement and water (ref. 4). The water-to-cement ratio of a concrete mix may be taken as the most important factor in the strength of concrete (refs. 4 and 5); the lower the ratio the stronger the concrete. The quantity of water going into a mix is therefore closely measured and recorded. The amount of free water in a concrete mix after hardening, however, is not easy to measure. The amount of free water which may be released from the concrete under vacuum conditions is even more difficult to predict.

Results of the vacuum tests are shown in figure 3. Weight loss per unit of exposed area and total weight loss per block are plotted against total time under vacuum. The nonborated blocks were tested at different vacuum levels, 0.1 and 30 torr (1.3×10^1 and 3.9×10^3 N/m^2). The total weight loss was approximately the same, 0.21 and 0.18 pound, (0.95 and 0.81 kg), respectively; however, the rate of water loss was greater at the lower pressure by a factor of 2 or 3.

The borated blocks exhibited a greater weight loss, 0.95 and 0.96 pound (0.42 and 0.43 kg). This may be attributed to the boron frits (which retard the setting of portland cement (ref. 6)). The chlorinated rubber sealer applied to one of the borated blocks appeared to have little, if any, effect on the total weight loss.

When placed in the oven, the nonborated blocks continued to lose water and appeared to have reached a maximum weight loss of 2 pounds (0.9 kg) after 161 hours of bakeout at 250° F (394° K) (fig. 4). This is somewhat less than the calculated 2.7 pounds (1.3 kg) of free water for each block. The difference between the calculated free water and the actual weight loss can be attributed to normal water-vapor emission from concrete during curing and storage at ambient conditions.

All of the water loss from vacuum outgassing and over bakeout was recovered during the 100-percent-humidity steam bath as shown in figure 5. Seventy percent of the weight loss was achieved during the first 20 hours and complete recovery occurred between 75 and 85 hours.

There are a number of parameters which influence the rate of water being released from concrete which could be investigated in future work. These include: (1) the shape (ft^2 surface/ft^3 volume) of the test specimen, (2) the pressure level, (3) admixtures in the concrete, and (4) coatings applied to the outside surfaces of the concrete. Reabsorption rates could also be determined at several humidity levels. The effect of water loss on the strength of the concrete would also prove useful in designing large vacuum chambers.

CONCLUDING REMARKS

Four concrete blocks, two borated and two nonborated, were tested at vaccum levels of 0.1 and 30 torr ($1.3x10^1$ and $3.9x10^3$ N/m^2) and the following was observed:

1. The borated concrete blocks lost more water than the nonborated blocks.

2. The amount of water removed is approximately 7 to 8 percent of the calculated free water content of the nonborated concrete blocks, and about 35 percent of the calculated free water content of the borated blocks.

3. The water is released faster at the lower vacuum level, however, the total amount of water removed is approximately the same.

4. Seventy percent of the water loss is reabsorbed during the first 20 hours of exposure to 100-percent humidity, and complete recovery occurred between 75 to 85 hours.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 5, 1967,
120-27-01-03-22.

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TABLE I. - COMPOSITION OF CONCRETE BLOCKS TESTED IN VACUUM

Material	Nonborated	Borated
	Composition, lb/yd^3 (kg/m^3)	
Cement (type II grey)	470 (280) (5 sacks)	470 (280) (5 sacks)
Sand (Lake Erie)	1357 (805)	978 (580)
Coarse aggregate (crushed limestone)	2032 (1200)	2032 (1200)
Water	272 (160) (32 gal)	272 (160) (32 gal)
Boron frit (Chicago vitreous no. S-85)	---- ------	379 (225)
Total	4131 (2450)	4131 (2450)

Water ratio by weight $= \frac{272}{4131} \times 100 = 6.6$ percent

Water ratio per sack of cement $= \frac{32}{5} = 6.4$ gal/sack ($0.024\ m^3$/sack)

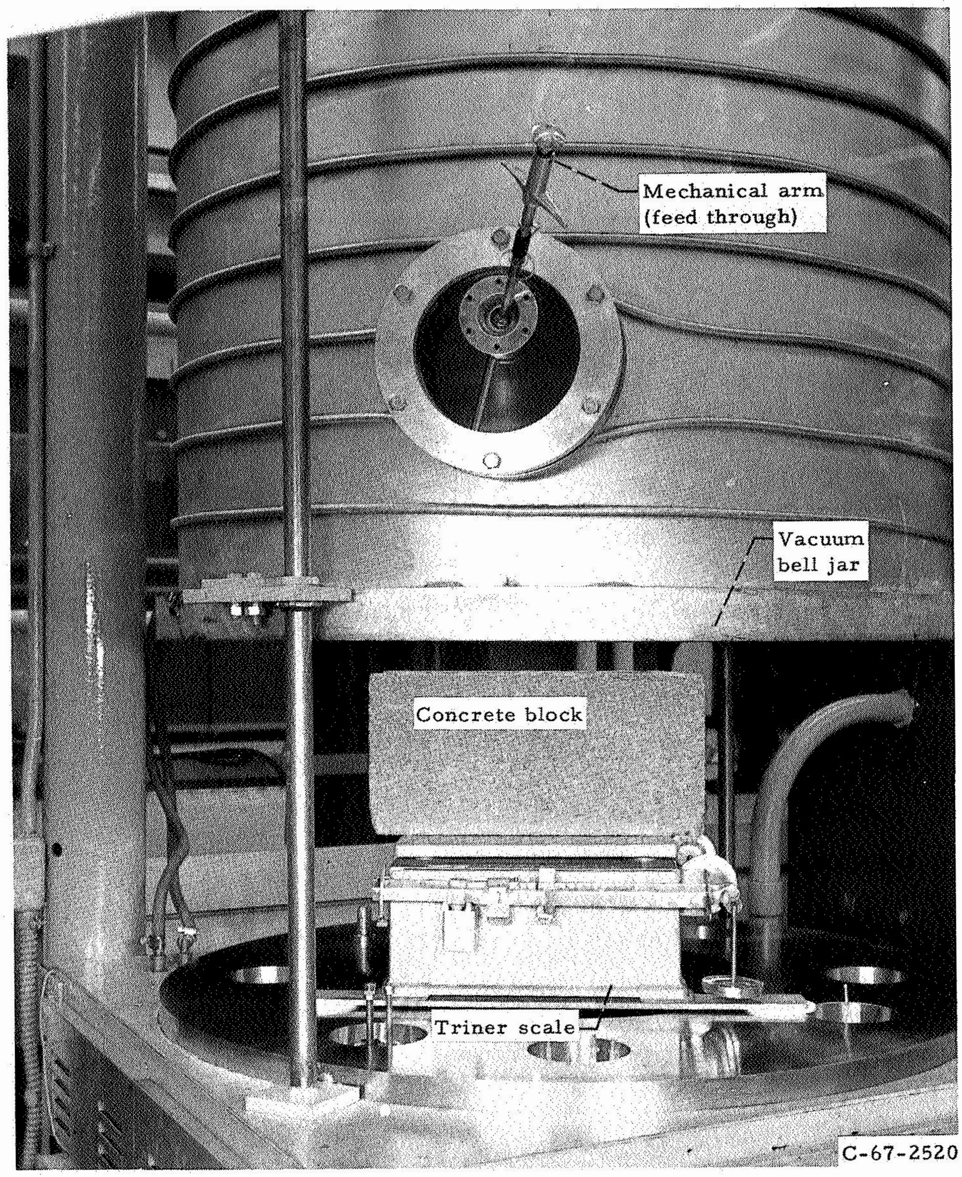

Figure 1. - Stainless steel bell jar and balance scale.

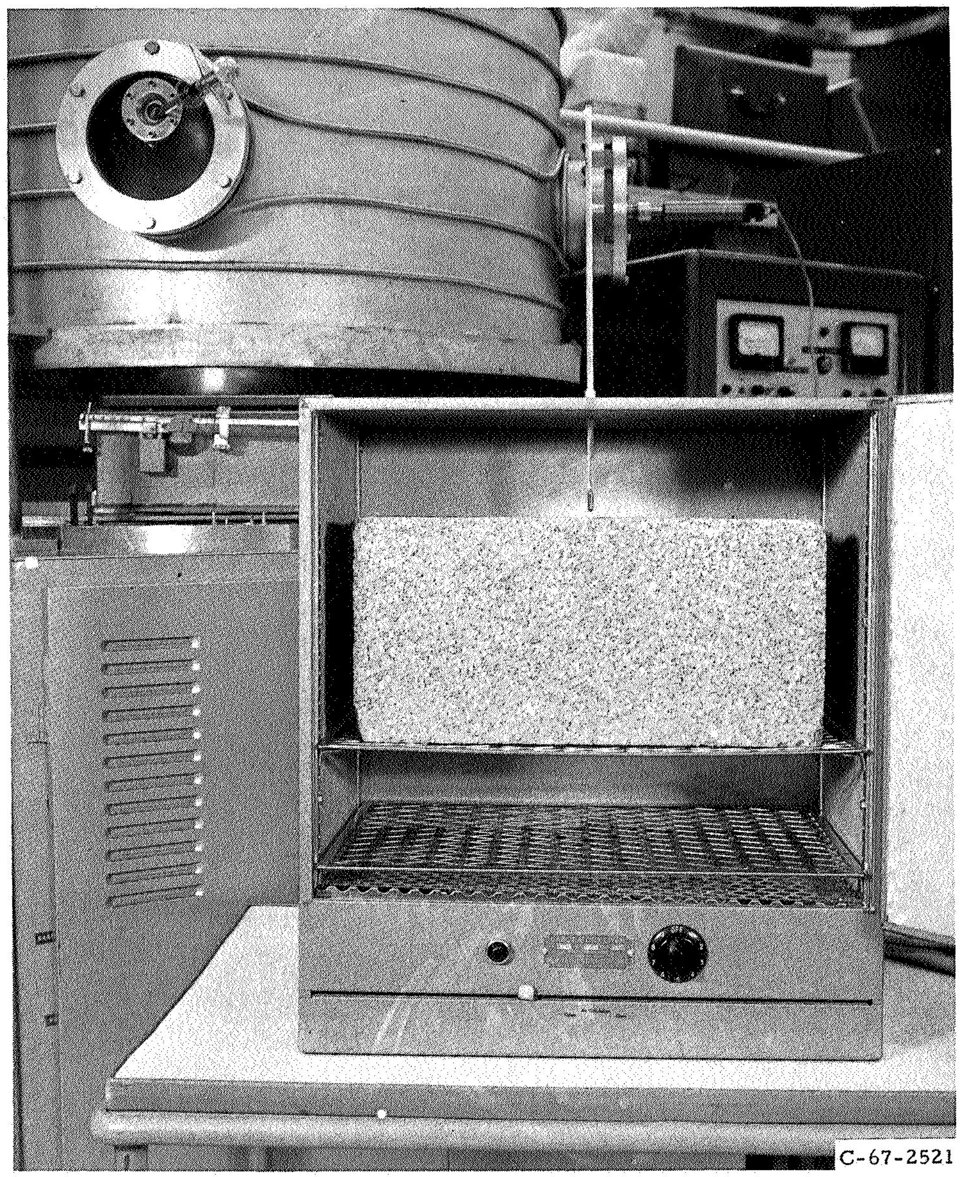

Figure 2. - Bakeout oven for concrete block.

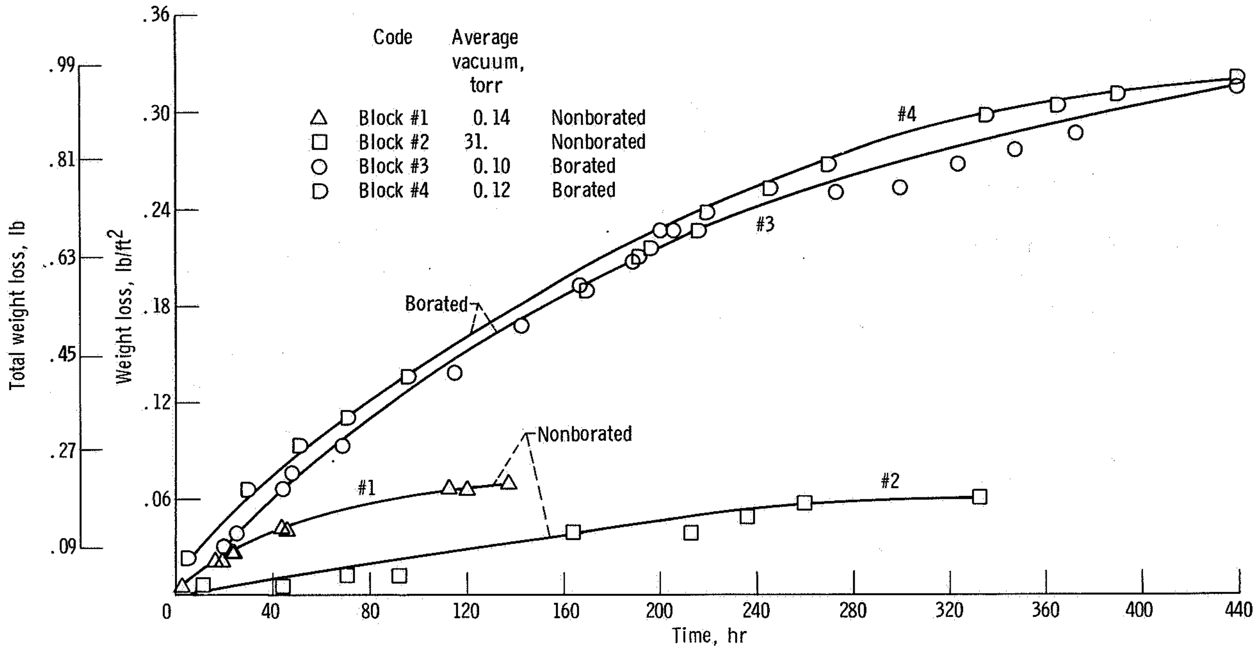

Figure 3. - Weight loss of concrete blocks in a vacuum chamber.

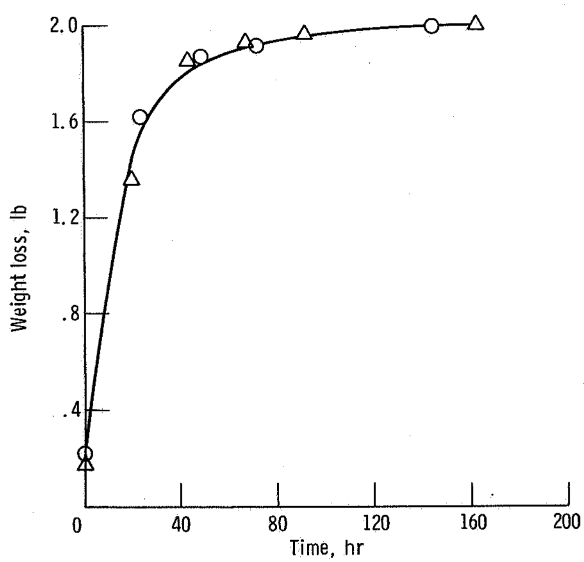

Figure 4. - Weight loss of nonborated concrete block in oven at 250° F (394° K).

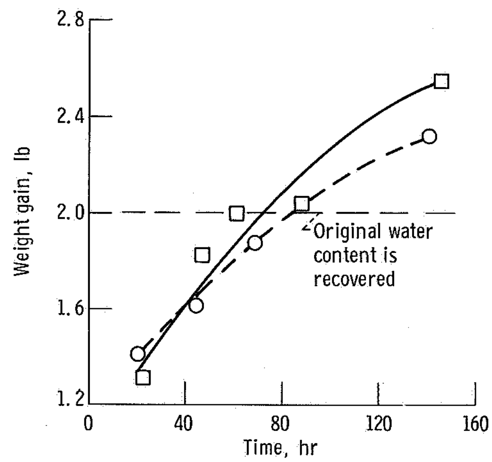

Figure 5. - Reabsorption of water into nonborated concrete block after vacuum outgassing and oven bakeout.

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