Studies on Soil Cements : 2 — Physicochemical Properties of the Hardened Soil Cement Pastes.

by

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ABSTRACT

Various hardened soil-cement pastes were prepared from dry mixtures of montmorillonite clay and portland cement clinker by using different W/C ratios of 0.20, 40, 0.60 and 0.80 and cured in air for various ages. Compressive strength tests were done on the hardened fresh pastes, while the nitrogen adsorption studies were carried out on the D-dried specimens. The variations in compressive strength could be related to the physicochemical properties and the pore structure of the hardened pastes. The optimum W/C ratio suitable for any given soil-cement mixture was regarded as the ratio which yields a hardened paste showing no regression in compressive strength at the various curing ages.

Introduction

On the basis of compressive strength of soil cements, a minor controversy concerning the relative effectiveness of different kinds of lime for soil stabilization has been bubbling since 1956; the papers presented indicated that the monohydrate dolomitic variety, containing equal mole fractions of $MgO + Ca(OH)_2$, is more effective than pure hydrated lime, $Ca(OH)_2$, for producing strength.[1]

This was further investigated and reported in a series of papers (listed in reference 2), which concluded that the dolomitic monohydrate gives long-term strengths as high as those obtained with like amounts of portland cement[2]. Other investigators[3-5] investigated the stabilization effects of soil by various additives including either chemicals, cement, gypsum or hydrosilicates; stabilization with cement was improved by an admixture of gypsum not exceeding 3 wt. % of the soil. Further studies regarding the effect of cement and lime on the strength of some soil minerals, and its relevance to the stabilization of these soils were also reported in the literature[6]. In addition, the effect of soil mineralogical composition on cement stabilization was studied by X-ray analysis and D.T.A. on clay-cement mixtures[7].

The object of this paper is to study the physico-chemical properties of the hardened soil-cement pastes made from montmorillonite clay and portland cement clinker. The strength results obtained could be correlated to the pore structure of the hardened pastes.

Experimental

Soil-cement mixtures were first prepared by using various proportions of portland cement clinker: montmorillonite clay of 5:95, 10:90, 15:85, and 25:75. Mixing was done in the dry state using a limited amount of ethanol for one hour in order to ascertain a complete homogeneity of the mix. The soil-cement mixtures thus produced after evaporation of ethanol, are designated as I, II, III, and IV for the clinker contents of 5, 10, 15 and 25, respectively.

The pastes were then prepared from the various soil-cement mixtures using different initial water/soil cement (W/C) ratios of 0.20, 0.40, 0.60 and 0.80; the symbols A, B, C and D should be added to the above designation of each paste in order to represent the W/C ratios of 0.20, 0.40, 0.60 and 0.80, respectively. Mixing was done for 4 minutes continuously.

The pastes were moulded in inch cubes and then cured in air (CO_2 — free atmosphere) at room temperature for various ages of 1, 3, 7, and 28 days.

At the end of each curing age compressive strength test was done on the fresh hardened paste. A part of the resulting crushed paste was first ground and then treated with acetone/methonol mixture (1:1 by volume) for stopping of hydration. The solid was filtered off, washed with methanol and then dried at 80°C. The dried powdered specimens were used for nitrogen adsorption by using a volumetric BET apparatus of the conventional type.

Results and Discussion

Compressive strength :

Compressive strength results of the various hardened soil-cement pastes prepared at various W/C ratios and cured for various ages, are shown in Figs. 1, 2, 3 and 4 for the hardened pastes I, II, III and IV, respectively.

The results of Figs (1 — 4) demonstrate the following important characteristics for the hardened soil-cement pastes :

1. For the soil-cement pastes prepared by using a low portland cement content (pastes I) the compressive strength was found to increase continuously with age of the paste up to 7 days hydration. Beyond this age of 7 days, certain pastes namely those prepared with initial water/solid ratios of 0.4 and 0.80 (pastes I B and I D) showed some regression in the compressive strength. However, the strengths were found to increase continuously for pastes IA and IC prepared with initial water/solid ratios of 0.20 and 0.60 respectively. It is interesting to report that the paste prepared with the lowest water/solid ratio (Paste IA) possesses higher compressive strength values only during the early stages of hydration (one and three days). After 7 days hydration, however, the paste IC, prepared with an initial water/solid ratio of 0.60, possesses the highest compressive strength values among all pastes investigated using a low portland cement content of 5 % by weight of the soil. Therefore, the optimum water/solid ratio for these low portland cement soil pastes required to produce sufficient strength values is 0.60 (cf. Fig. 1). The pastes prepared with water/solid ratio lower than 0.60 have lower strength values beyond 7 days hydration; and this is attributed to the fact that the soil-rich pastes need more water for hydration than the normal portland cement pastes. The hydration products obtained during the hydration of soil-rich pastes are richer in the water content than the hydration products of portland cement pastes.

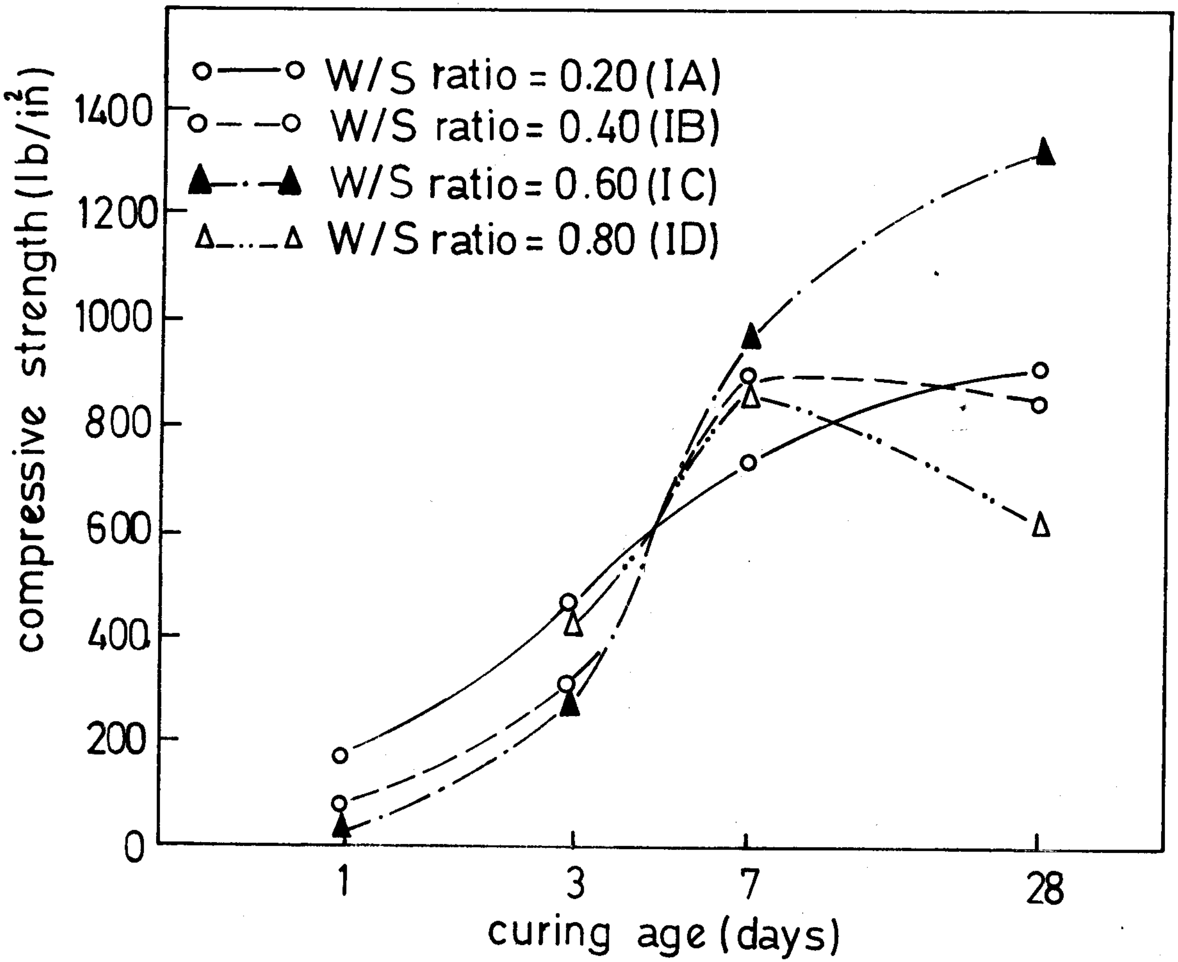

Fig. 1: Compressive strength as a function of age for soil-cement pastes (I) using different water/solid ratios.

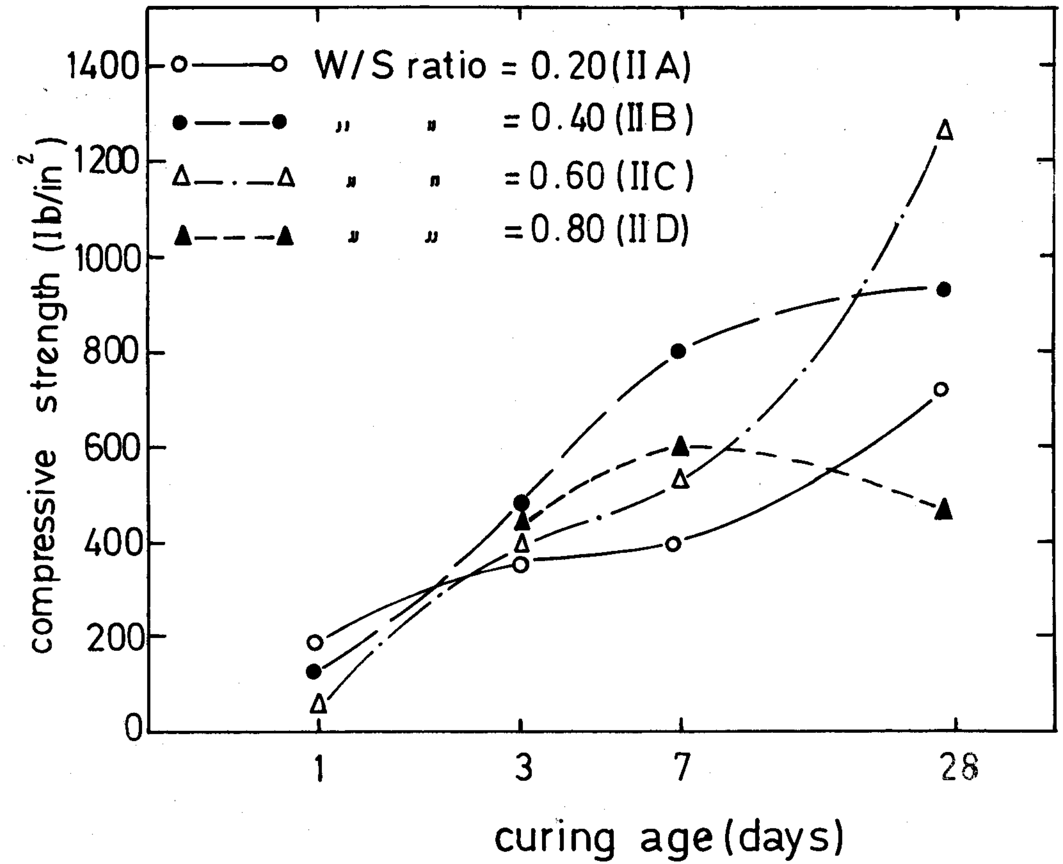

Fig. 2: **Compressive strength as a function of age for soil-cement pastes (II) using different water/-solid ratios.**

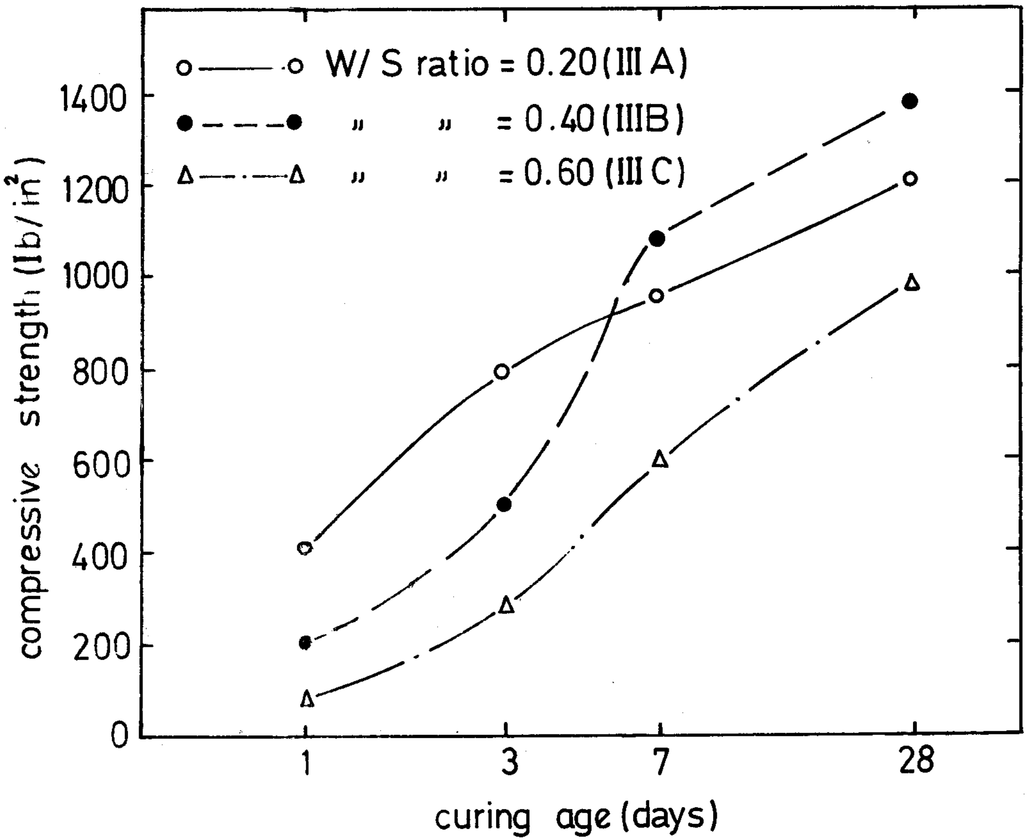

Fig. 3: Compressive strength as a function of age for soil-cement pastes (III) using different water/-solid ratios.

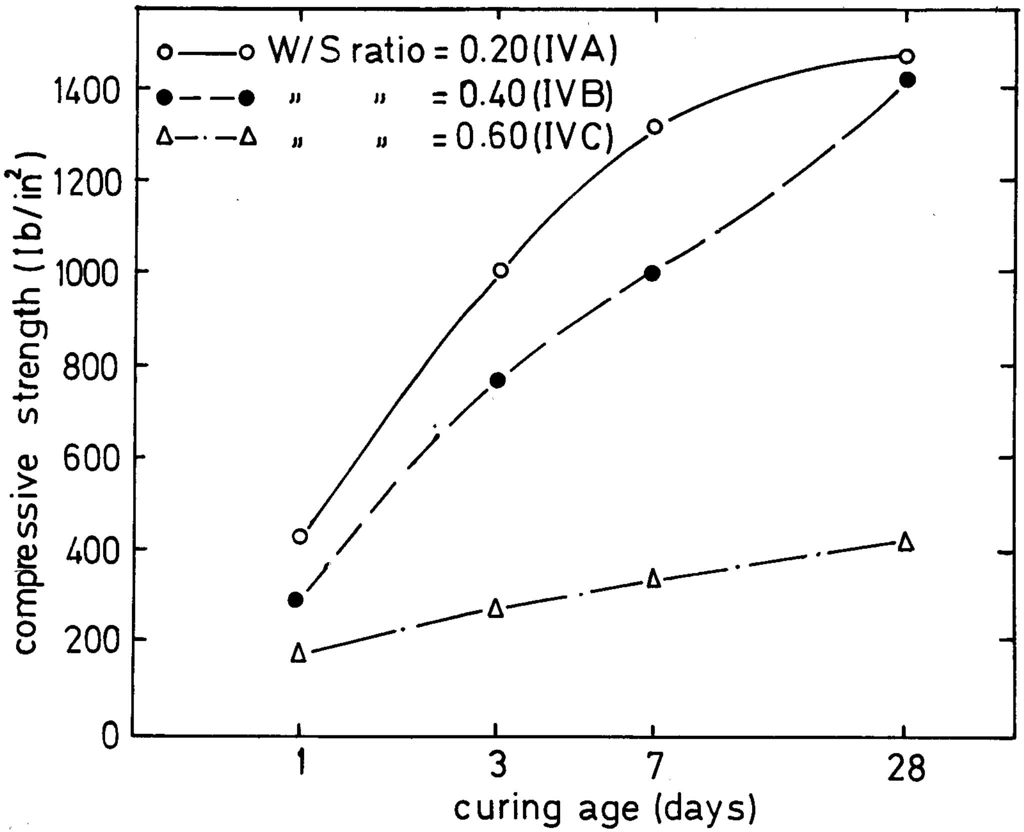

Fig. 4: **Cmpressive strength as a function of age for soil-cement pastes (IV) using different water/solid ratios.**

2. With increasing the cement content in the soil-cement, the pastes prepared with initial water/solid ratio of 0.40 give normal behaviour showing no regression in compressive strength and this ratio seems to represent the optimum water/solid ratio of pastes made by using a portland cement content of 10 % by weight of the soil (cf. Fig. 2) for pastes made from soil-cement (II).

3. By using a portland cement content of 15 %, the optimum water/solid ratio seems to be between 0.20 and 0.40 (cf. Fig. 3). The pastes made with water/solid ratio of 0.20 (IIIA) possess higher strength values during the early stages of hydration while in the later stages the pastes made with a water/solid ratio of 0.40 (IIIB) give higher strength results.

4. With soil-cement IV, which contains higher portland cement content of 25 % by weight of the soil, the optimum water/solid ratio seems to be 0.20 and the results show similar behaviour to the normal cement pastes (cf. Fig. 4). Therefore, at higher cement content of the soil-cement the normal expected behaviour predominates, namely, the low porosity pastes prepared with a lower water/solid ratio showed greater strength results than the high porosity pastes made with higher water/solid ratios.

The results show conclusively that the presence of soil in soil-cement could cause some regression in compressive strength with age, and that this regression decreases as the cement content increases. In the mean time, the results also indicate that the optimum water/cement ratio required to obtain the highest compressive strength, decreases as the cement content increases in the soil-cement mixture.

Surface Properties and Pore Structure :

Adsorption-desorption isotherms of nitrogen gas at liquid nitrogen temperature (−195.8°C) were measured out volumetrically on the montmorillonite clay and the air cured soil-cement pastes after hardening at various ages. Four typical isotherms are shown in Figs. 5, 6, 7 and 8 for the samples montmorillonite, III A-28, IIIB-28 and IIIC-28 as representatives of all pastes investigated. The hardened pastes IIIA-28, IIIB-28 and IIIC-28 were obtained from of the soil cement (Mix III) containing a weight proportion of portland cement clinker : montmorillonite of 15:85 by mixing with water using a W/C ratio of 0.20, 0.40 and 0.60 and curing in air for 28 days.

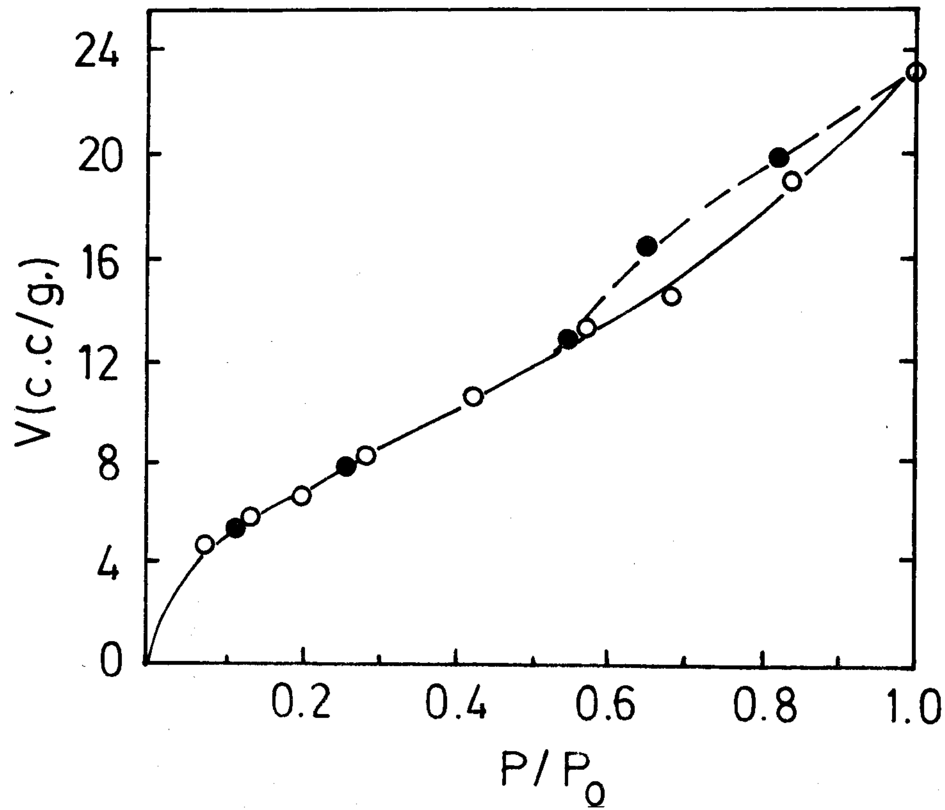

Fig. 5: Adsorption-desorption isotherms of nitrogen gas at-195.8 °C on montmorillonite clay.

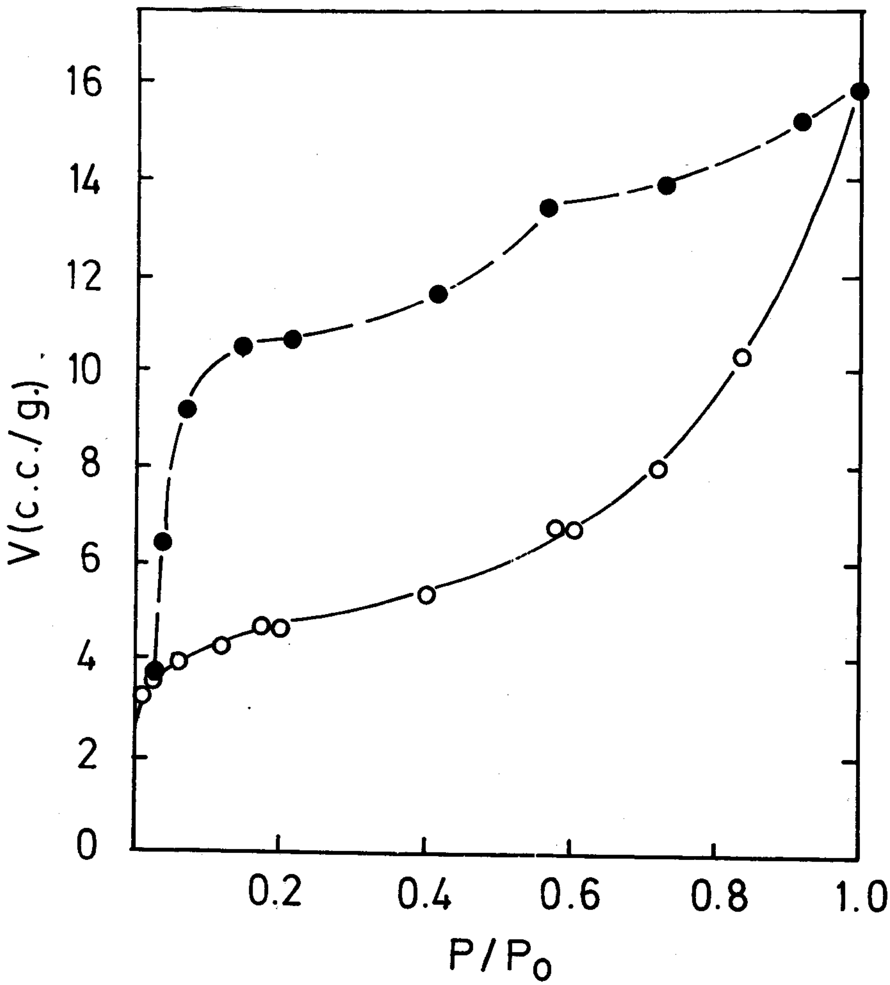

Fig. 6: Adsorption-desorption isotherms of nitrogen gas at-195.8 °C on sample (III A-28).

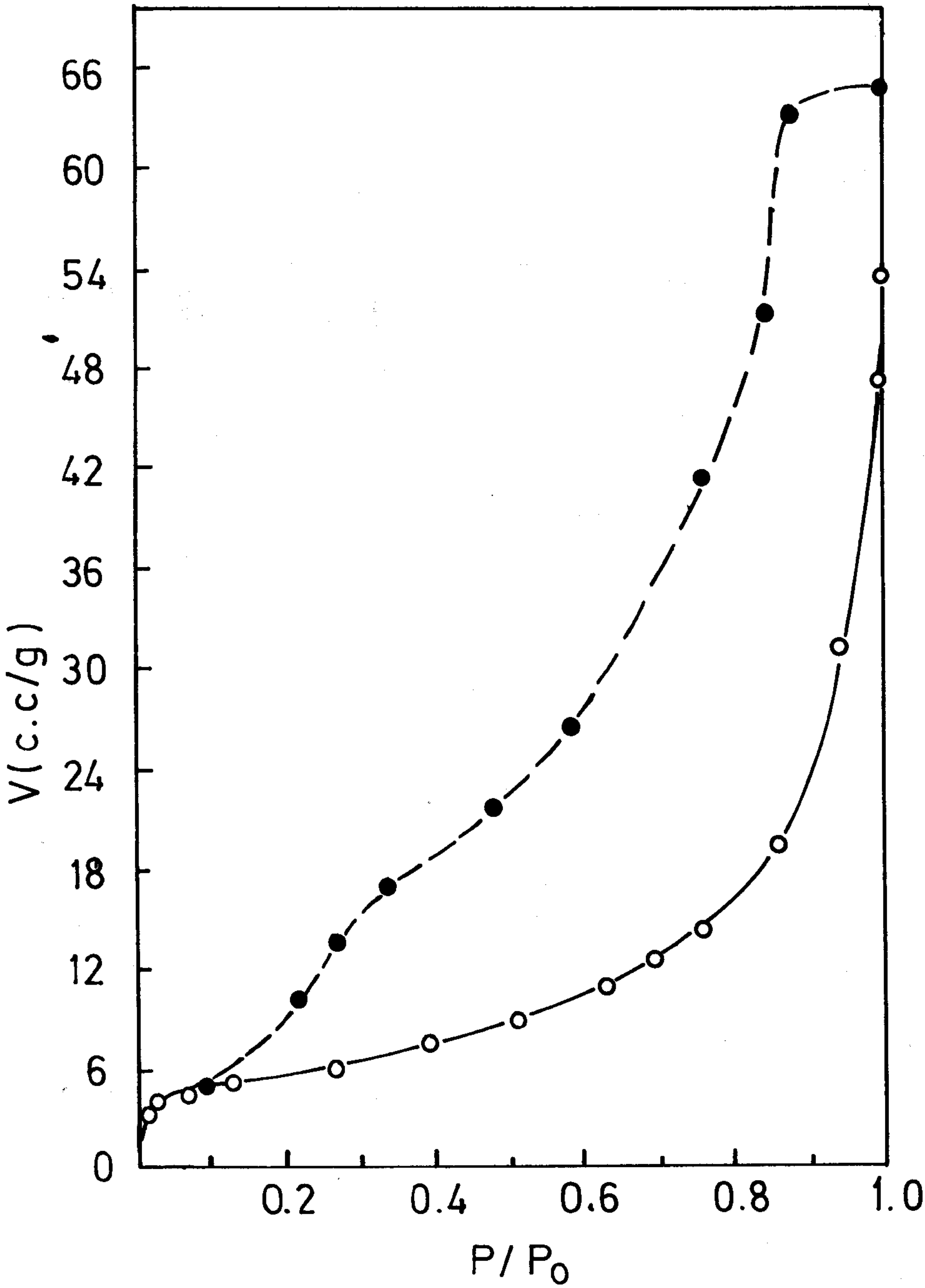

Fig. 7: Adsorption-desorption isotherms of nitrogen gas at-195.8 °C on sample (III B-28).

The adsorption-desorptions isotherms obtained for the air cured soil cement pastes show common characteristics and belong to type II of Brunauer's classification[8] with the existence of closed hysteresis loops.

From the adsorption isotherms, the specific surface areas, S_{BET} (m^2/g), could be evaluated by application of the BET-equation using the molecular area of nitrogen of 16.2 $\AA^2$ [9]. The total pore volumes, V_p (ml/g), were taken as the saturation values of the isotherms. The specific surface areas and the total pore volumes are given in Table (1).

Table 1

The specific surface areas (S_{BET}) and the total pore volumes (V_p) for montmorillonite and the hardened pastes IIIA—28, IIIB—28 and IIIC—28.

Sample	*S_{BET}(m^2/g)*	*V_p(ml/g)*
Montmorillonite	26.58	0.0363
III A-28	15.80	0.0248
III B-28	19.80	0.1014
III C-28	15.90	0.0154

Obviously, the surface area of the anhydrous clay (montmorillonite) is higher than the surface area of the hardened soil-cement pastes prepared from the clay and portland cement clinker. This result is mainly attributed to the accumulation of nearly amorphous hydration products within the pore spaces of the hardened clay-clinker pastes leading to a decrease in the accessibility of the pore system towards nitrogen molecules.

The presence of constricted pores could be indicated from the typical "ink-bottle" isotherms shown in Figs. (6), (7) and (8). In the "ink-bottle" hypothesis, hinted by Kraemer[10] and developed by McBain[11] and others, [12,13] which represents a variant of the Zsigmondy hypothesis, the pores are visualized as having a narrow neck of radius r_1, the radius of the wide body being r_2. Along the adsorption branch, condensation in the body of the pore will first occur when the

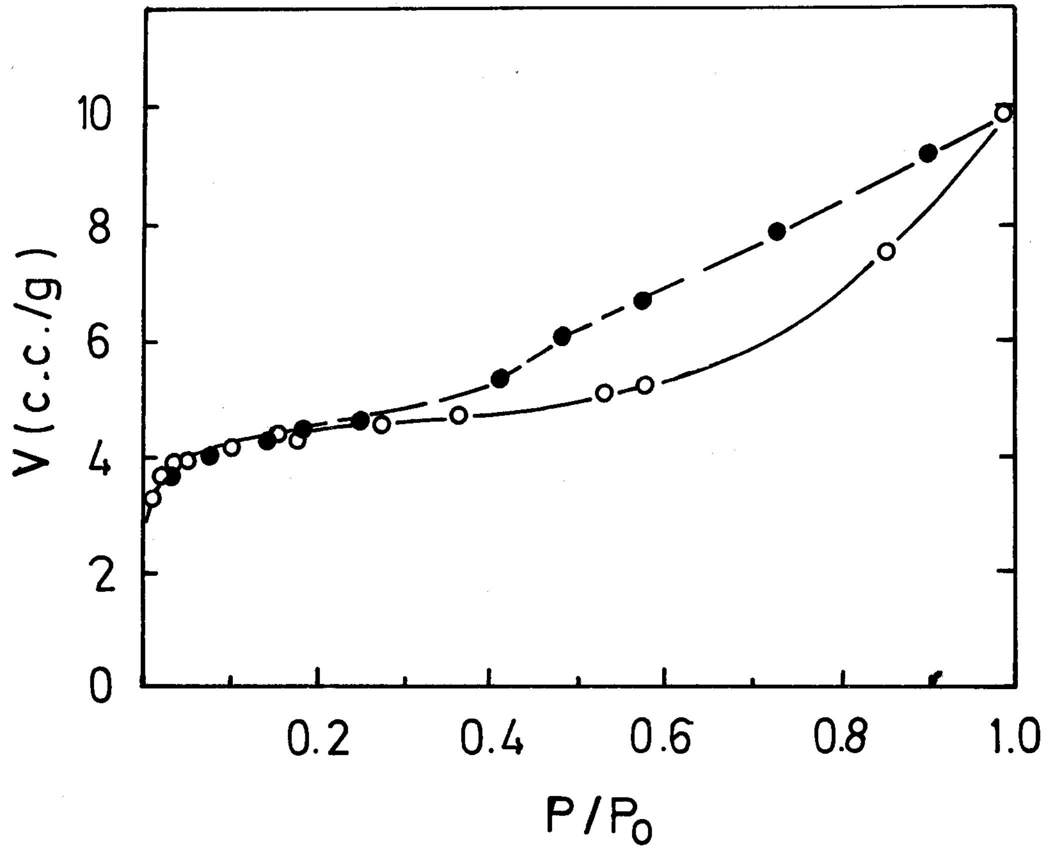

Fig. 8: Adsorption-desorption isotherms of nitrogen gas at-195.8 °C on sample (III C-28).

pressure reaches the value $P_2/P_0 = \exp(-2\gamma V/r_2 RT)$; where γ is the surface tension and V is the molar volume of the liquid. When the desorption branch is traversed, evaporation cannot occur at a pressure P_2 since the neck of the pore is blocked by a miniscus which can only evaporate when the pressure has fallen to $P_1/P_0 = \exp(-2\gamma V/r_1 RT)$, the whole pore then empties at once.

From the results shown is Figs. (6), (7) and (8) the values of r_1 and r_2 calculated were found to be 7.4 and 77.7 Å for the III A paste cured for 28 days using a low initial water/cement ratio of 0.20 (low porosity), 16.4 and 158.6 Å for the III B paste cured for 28 days using an initial water/cement ratio of 0.40 and 28.6 and 99.3 Å for the III C paste cured for 28 days using an initial water/cement ratio of 0.60, respectively. Therefore, the initial water/cement ratio affects markedly the width of the narrow neck of the ink-bottle pores. Hence, the pastes prepared with low initial water/cement ratio possess more constricted necks of pores than do the pastes prepared with higher initial water/cement ratios when cured at the same age (28 days).

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« دراســـات على أسمنت التربـــة »

٢ ـ الخواص الفيزيقوكيميائيـة لعجائن أسمنت التـربة المتصلدة

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ملخـــــص

تم تحضير عديـد من عجائن أسمنت التـربة المتصلـدة من مخاليط طفلـة المونتموريللونيت مع كلنكر الأسمنت البورتلاندي وذلك باستخدام نسب وزنية مختلفة من الماء للاسمنت تصل إلى ٢٠ر٠ ، ٤٠ر٠ ، ٦٠ر٠ ، ٨٠ر٠ ومعالجتهما في الهواء لاعمار مختلفة .

أجريت اختبارات قوة تحمل الضغط الميكانيكي على العجائن المتصلة الطازجة ، بينما أجريت دراسات امتزاز غاز النيتروجين على العينات المجففة . ولقد أمكن ربط التغيرات في قوة تحمل الضغط الميكانيكي بالخواص الفيزيقوكيمائية والتركيب المسامى للعجائن المتصلدة . ولقد تم تحديد النسبة المثلى المناسبة لخلط الماء بالاسمنت لكل مخلوط من أسمنت التربة وذلك بأنها النسبة التي تؤدي إلى عدم هبوط قيم تحمل الضغط الميكانيكي عند أعمار المعالجة المختلفة .