INFLUENCE OF W/C RATIO AND AGE ON PORE SIZE DISTRIBUTION OF OPC AND FLY ASH PASTES AND MORTARS

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CERTIFICATE

This is to certify that the thesis entitled **“Influence of W/C Ratio and Age on Pore Size Distribution of OPC and Fly Ash Pastes and Mortars”**, being submitted by **Mr. Kondraivendhan. B** to the Indian Institute of Technology Delhi, India, for the award of the degree of “**DOCTOR OF PHILOSOPHY** in Civil Engineering”, is a record of original bonafide research work carried out by him under my guidance and supervision. To the best of my knowledge, the thesis has reached the requisite standard. The material contained in this thesis has not been submitted, in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The characteristics of the pore system which affect the properties of cement based materials mostly are the porosity and pore sizes. The pore structure affects the behavior of cement based material perhaps more than any other characteristics of the material. It governs the physical and chemical resistance of cement based material to deterioration i.e. durability, strength, thermal conductivity, and other mechanical properties. The pore size characteristics of porous materials are commonly expressed in terms of pore size distribution (PSD), either in the form of cumulative pore size distribution or differential pore size distribution curves. Pores in porous material are dispersed over a range of pore sizes. The PSD may be characterized by mode, median, and mean of pore size together with a parameter representing the dispersion. A general form of PSD curve for various construction materials has already been proposed by Patil and Bhattacharjee that involves porosity (P), median pore radius ($r_{0.5}$) and the dispersion coefficient (d). For cement based chemically combined ceramics, these parameters are likely to be governed by w/c ratio, age, particle size and nature of the binder material. Thus in this research work an attempt is made to investigate on the influence of w/c ratio and age that controls the degree of hydration and nature of the cementing material on PSD parameters namely P, $r_{0.5}$ and d for paste and mortar prepared with cements and cement-fly ash combinations. This is accomplished through an experimental scheme, and appropriate relationships for PSD parameters are developed.

The reason for restricting the scope of the work to paste and mortar stems from the fact that no investigations of this nature are reported in the literature. Therefore, one

has to start with simplest possible case. Concrete is a composite having coarse aggregate, fine aggregate and hardened paste in its finally set state. The pore size distribution of concrete is influenced by characteristics and volumetric concentration of aggregates (both fine and coarse aggregates). Therefore, the investigation on PSD of concrete would require choice of aggregates and its volumetric concentration as experimental factors and their several levels making the scope of the work unmanageable over a limited duration of time. Thus the scope of this work is restricted to paste and mortar with one level of volumetric concentration of fine aggregate. The nature of the paste however depends on binder type and thus mainly two binder types namely cements and cement fly ash combinations are chosen in the present research scheme.

To measure the porosity and pore size distribution, Mercury Intrusion Porosimetry (MIP) is adopted in this work. For this purpose, experimental work is divided into four phases, experimental investigations on OPC (Ordinary Portland Cement) paste and OPC sand mortar mixes are carried out in the first and second phases respectively. Cement fly ash paste and cement fly ash sand mortar mixes correspond to the third and fourth phases of the experimental investigation.

In the first phase of experimental work on OPC paste, five paste mixes with water to cement ratio of 0.2, 0.3, 0.4, 0.5 and 0.6 were used. Seven ages of curing at 1, 3, 7, 28, 56, 90 and 150 days and OPC with two different fineness and composition were also adopted. For a total of 10 pastes mixes with three replicates results in 210 specimens (i.e., 2 x 5 x 7 x 3 = 210). The size of the specimen for the test is governed by the size of the sample cell used in porosimeter i.e. 25 mm length and 9.5 mm diameter.

Therefore, brass cylindrical moulds of size 9.5mm diameter with 23mm height were fabricated.

For second phase of experimental work on cement sand mortar, two locally available sands were selected for the mortar mixes. Mass fractions of 0.6 and 0.4 respectively of these two sands resulted in maximum packing density and minimum voids content as determined from a set of preliminary investigations. Paste content 20% in excess of void content for all five water to cement ratios was considered to obtain adequate workability and avoid shrinkage cracks. A total of 10 mortar mixes were prepared using corresponding optimal super plasticizer dosage. Moist curing was used throughout for all specimens. Specimens were cured for 1, 3, 7, 28, 56 and 90 days. For MIP test, a total of 180 (2 x 5 x 6 x 3) cylindrical specimens were prepared.

For the third phase of experimental work on cement-fly ash paste, twenty paste mixes with water to cementitious ratio of 0.25, 0.35, 0.45 and 0.55 with fly ash incorporation (f/c ratio) of 0%, 10%, 20%, 30% and 40% were used. Three ages of curing at 7, 28, and 90 days were adopted. For a total of 20 pastes mixes with three replicates for each mix (i.e. 4 x 5 x 3 x 3), results in 180 specimens. Cubes with 50 mm side length were also cast for all these mixes to determine the compressive strength of the cement blended fly ash paste specimens.

For fourth phase of experimental work on cement-fly ash sand mortar, two locally available sands but different from that of the second phase with maximum grain size of 4.75mm and the other with maximum grain size of 600 micron were selected for the mortar mixes. Mass fractions of 0.7 and 0.3 respectively of these two sands resulted in maximum packing density and minimum voids content as determined from a set of preliminary investigations. Paste content 20% in excess of void content for all four water to cementitious ratios was considered to obtain adequate workability and avoid shrinkage cracks. The total number of specimens considering 3 ages and 3 replicates for 20 mixes were 180. Moist curing was used for these specimens as well. Cubes with 50 mm side length were also cast for these 20 mixes to determine the compressive strength of the cement blended fly ash sand mortar specimens.

By using the curve expert 1.3 software, the averages of three replicate of each mix, the cumulative intruded volume versus pressure curves are obtained. The porosity, $r_{0.5}$ and dispersion coefficient are obtained through the procedure proposed by Patil and Bhattacharjee. Separate relationships for degree of hydration of cement paste with and without fly ash are proposed through the non-evaporable water content measurements. Separate semi empirical relationships are developed for $r_{0.5}$ of OPC paste, cement fly ash paste and empirical relationships are developed for $r_{0.5}$ of OPC sand mortar with and without fly ash. Separate empirical relationships are also developed for dispersion coefficient for all cases.

The utility of these pore size distribution parameter relationships for OPC paste and OPC sand mortar, cement fly ash paste and cement fly ash sand mortar in estimating the compressive strength, permeability and hydraulic diffusivity are also demonstrated elaborately. By using these proposed compressive strength, permeability and hydraulic diffusivity relationships, one can predict the strength, permeability and hydraulic diffusivity for cement paste and cement sand mortar with and without fly ash directly from the knowledge of mix factors such as w/c or w/(c+f) ratio, curing age, f/c ratio and mean cement particle diameter.

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