ISSN (online): 2349-784X

Assessment of Water Film Thickness, Paste Film Thickness and the Fresh Properties of Cement Mortar

Smit Kotak
PG Student
Department of Civil Engineering
L.J.I.E.T., Ahmedabad

Parth Thaker
Faculty
Department of Civil Engineering
S.B.S.T., C.E.P.T. University, Ahmedabad

Abstract

The fresh properties of concrete are mostly dependent on the fresh properties of its mortar portion; therefore, the mortar design can be taken as an initiative in the mix design of concrete. In the mortar phase of a concrete mix, the water content must be more than enough to fill the voids between the cement and fine aggregate particles. The paste content must be more than enough to fill the voids of fine aggregate particles, so that the excess water can cover each solid particle and excess paste can cover each fine aggregate particle. The combined effects of excess water, excess paste and surface area of cement and fine aggregate are determined in terms of water film thickness (WFT) and paste film thickness (PFT). In this study, wet packing method was used to measure the packing density of fine aggregate and mortar. The water film thickness, paste film thickness, flow ability, cohesiveness and adhesiveness of mortar shall be determined at maximum dosage of superplasticizer (SP) by varying water cement ratio and cement fine aggregate proportions. Test results indicates that water film thickness results were varied from 0.003 µm to 0.388 µm while the paste film thickness results were varied from 50.5 µm to 127.9 µm.
Keywords: packing density, mortar, fresh properties, water film thickness, paste film thickness, fine aggregate

I. INTRODUCTION

The concrete includes a mortar phase and a coarse aggregate phase in it. The workability of concrete is closely dependent on the mortar phase. The mix design of concrete can be carried out by considering its paste and mortar phases. Here, it is proposed a three step method: The first step includes the materials such as cementitious materials and microfillers. This material forms the paste together with water to fill the voids of materials of second step. The second step includes the materials such as fine aggregate and particles of similar or smaller size than fine aggregate. This material form mortar after mixing with paste to fill the voids of the materials of third step. At last, the third step includes to add coarse aggregate particles.[13]

This research is intended to study the mortar phase of concrete. In a concrete mix, the mortar portion should be thick and flow able to cover every coarse aggregate particle. The fresh properties of concrete and the fresh properties of mortar are closely related to each other. Earlier in 2011, Albert Kwan and Leo Li have suggested to design mortar portion first.[3] As the concrete has to flow up to long distance without causing segregation, the mortar phase must possess higher flowability and cohesiveness. It has to be highly adhesive to avoid its separation from coarse aggregate or in case of plaster works. It is difficult to achieve all these properties at the same time. One method to increase the flow ability is by adding a superplasticizer, but it might results into decrease of cohesiveness and adhesiveness. A highly adhesive mortar is useful in many construction works, but there is no any standard method available to measure its adhesiveness.

II. HISTORICAL BACKGROUND

There are so many research works which were intended to study the fresh properties and rheology of mortar. In 2011, Kwan and Chen found that superfine cement improves the flow ability, strength and packing density of cement paste.[22] Kwan and Leo Li have developed a mix design method of mortar based on its water film thickness.[3] In 2011, Kwan and Fung found that the flowability and packing density increases by adding condensed silica fume in the mortar.[12] In 2012,Kwan, Chen and Fung found that addition of superplasticizer would improve the rheology, flow ability and packing density of cement paste.[23] In 2014, Kwan and Leo Li developed a mix design method based on water film thickness, paste film thickness and mortar film thickness in the mix design of concrete. In 2014, Kwan and McKinely found that adding of limestone fines increases the water film thickness, paste film thickness, flowability, packing density and strength of the mortar.[20] In 2015, Kwan and Leo Li found that adding of limestone fines increases cube strength, tensile strength, stiffness and durability of concrete.[21] Therefore packing density has certain effects on the fresh properties of mortar.

Earlier, problems were faced in finding the packing density because of the limitations of dry packing method, as it was too sensitive to the applied compaction. In 2008, Wong and Kwan suggested a new wet packing method, which directly determines the packing density of fine aggregate, mortar, cement paste and concrete. This wet packing method was advantageous in the sense that it impacts on actual cement paste or mortar and this method also allows the use of superplasticizer which increases the packing density. A number of researches were done with the use of the new wet packing method. These researches concluded that volume of water, surface area of solid particles and packing density are evaluated in terms of water film thickness and this is a key parameter governing the fresh properties of cement paste and mortar.

III. EXPERIMENTAL PROGRAM

An experimental program designed to include five mortar mixes which were produced by varying cement sand proportion 1:1 to 1:2 with increment of 0.25 in sand portion for zone 1. For the mortar mixes of 1:1(C/A=1), 1:1.25(C/A=0.8), and 1:1.75(C/A=0.67) the W/C ratios were kept as 0.28, 0.30 and 0.35, while for the mixes 1:1.75(C/A=0.57) and 1:2(C/A=0.5), the W/C ratios were kept 0.4, 0.45 and 0.5[1]. For the fine aggregate, the W/S ratio were kept 0.55, 0.6 and 0.65 for the packing density test.[4].A maximum of 1.32% polycarboxylate-based superplasticizer was added to each mix. Each mix was given a sample number as A-B where A indicates C/A ratio and B denotes the W/C ratio. The packing density was determined by wet packing method, while the fresh properties of mortar such as flowability, cohesiveness and adhesiveness were measured by mini flow table test, sieve segregation test and stone-rod adhesion test.

A. *Materials*

An ordinary portland cement of 53 grade was used. Its blaine fineness was 314 m²/kg. It fulfilled all the requirements of IS 12269:2013. The solid density of cement was 3.15, and that of fine aggregate(IS 2386 part III) of zone 1 was 2.55[16]. The specific surface area of fine aggregate of zone was determined by the particle analyzer cam sizer XT, which was 10285m²/m³ for the zone 1. A polycarboxylated-based SP with a solid mass content of 5% and relative density of 1.103 was used based on its compatibility study. The SP of maximum 1.32% of the mass of cement content was used. The SP was compatible for the given cement. The SP fulfilled all the requirements of IS 9103:1999.

B. *Sample preparation and measurement of packing density:[8]*

A Hobart mixer was used to mix the ingredients of mortar.To keep the mixture most of the time saturated, a special mixing procedure was adopted. The procedure of wet packing method is given below:

- First mix the cement and fine aggregate in dry.
- Set the W/S ratio(volumetric ratio of water to solids).
- At first, add all the water, 50% of superplasticizer and 50% of the dry mix and run the mixer at normal speed for 3 minutes.
- Add the remaining portion of superplasticizer and dry mix in four equal parts, and each time run the mixer for 3 minutes.
- After the mixing process of 15 minutes, transfer the mix into a cylindrical mould(62mm dia,60mm height) of known volume, upto top level. Weigh the mortar in the mould to measure the bulk density.
- The packing density is worked out from the following formula:

$$\phi = \frac{\text{wet bulk density}}{\text{Solid density}} \quad (1)$$

[19]

Therefore,

$$\phi = M/V/ (\rho_w u_w+\rho_c F_c+\rho_f F_f) \quad (2)$$

- Take lower W/S ratio and follow the same steps till the solid concentration is found as maximum.

in which ρ_w is the density of water,
ρc and ρf are the solid densities of cement and fine aggregate,
F_c and F_f are the volumetric ratios of cement and fine aggregates to the total solid content.
For the fine aggregate same mixing procedure was adopted for fine aggregate, water and SP. And the packing density was directly determined from the ratio of wet bulk density and solid density of fine aggregate.[5]

C. *The concept of water film thickness(WFT) and paste film thickness (PFT):*

For the determination of water film thickness of mortar, it is necessary to measure the packing density ϕ of mortar. From the packing density of mortar, the void ratio is determined as

$$r = (1 - \phi) \div \phi$$

After that, the excess water ratio is determined as the ratio of excess water volume to the total solid volume

$$r' = r_w - r$$

where, r_w= water/solids ratio by volume used for packing density measurement
The water film thickness covering each solid particle is determined as

$$WFT = \frac{r'}{A} \quad [1] \qquad (3)$$

where, A=Specific surface area of total solid particles = $A_c.F_c+A_{FA}.F_{FA}$

F_C= ratio of the cement volume to the total solid volume

F_{FA}= ratio of the fine aggregate volume to the total solid volume

Similarly, the paste film thickness can be determined from the packing density of the fine aggregate particles(ϕ_1), paste ratio p_w and the specific surface area of fine aggregate.

Here, v= voids ratio of fine aggregate particles

$$= \frac{(1-\phi_1)}{\phi_1}$$

After obtaining the void ratio, the excess paste ratio is determined. The excess paste ratio is the ratio of the volume of excess paste and specific surface area of fine aggregate.

$$p' = p_w - v$$

Here p_w is the paste ratio which is obtained from the ratio of paste volume to the volume of fine aggregate particles.
The paste film thickness is obtained from the following formula:

$$PFT = \frac{p'}{A_{FA}} \quad [1] \qquad (4)$$

D. Measurement of flow Spread: [24]

The flow spread of the mortar mixes was measured by mini flow table test as given in europian standard EN 1015:3. A truncated cone of base diameter 70 mm, upper diameter 100mm and height 50mm was filled with mortar sample. After lifting it, 15 blows were given to the mortar sample. The flow spread was measured along four sides and the average diameter was taken as flow spread of the mortar sample.

E. Measurement of Cohesiveness: [15]

The cohesiveness of the mortar samples was determined by a sieve seggregation test which is same as given in europian guidelines of self-compacting concrete, only the change is that a 4.75mm sieve was used instead of 5mm. In this test, 500 gm of mortar mix is flown from 300mm height, some of the mortar started to drip. The dripped mortar collected in a pan was wighted. Then, the sieve seggregation index (SSI) of the mortar was taken as a portion of mortar passing from the 4.75mm sieve expressed as percentage by mass. Therefore, the cohesiveness is measured by inverse of SSI.

F. Measurement of Adhesiveness:[1]

The test setup consists of 6 stone rods vertically fixed on a stone plate. The stone rods were made of crushed rock granite which is a common rock of aggregate. Each stone rod was of 10mm diameter and 110mm length. For the test, the stone rods were wetted initially and cleaned to become saturated and surface dry. The stone rods were kept immersed in mortar until the immersion depth was reached at 100mm, and they left immersed for 1 minute and thereafter pulled out gently. When the rods were taken out, the mortar adhered on it started dripping downwards. After 2 minutes, when the dripping stops, the increase in the weight of the stone rod apparatus was taken as stone rod adhesion which indicates the adhesiveness of mortar.

G. Sieve Analysis of Fine Aggregate

Fine aggregate of different size classes from 150µm to 4.75mm were sieved and segregate first, as 4.75mm to 2.36mm, 2.36mm to 1.18mm, 1.18mm to 600 µm, 600µm to 300µm and 300µm to 150µm respectively. Then, the fine aggregate were blended in accordance with zones of India as per IS:383-1970. Each size class contained the mean of the percentage range of that given in IS:383-1970. The particle size distribution of the zone 1 is given below in the Fig. 1.

Table – 1
mix proportions of blended fine aggregate of zone 1[17]

particle size(mm)	*cum. % volume passing for zone 1*
4.75	*100*
2.36	*80.5*
1.18	*51*
0.600	*23.5*
0.300	*9.5*

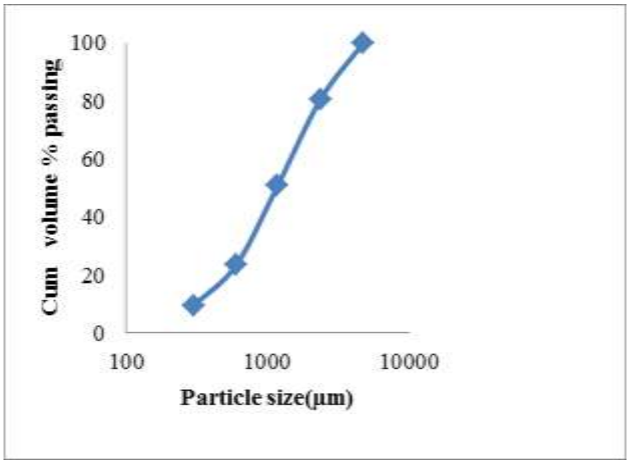

Fig. 1: Particle size distribution of zone 1 fine aggregate

IV. RESULTS AND DISCUSSION

The mortar mixes with different W/C ratio and C/A ratio were tested for mini flow table test, sieve seggregation test and stone rod adhesion test. The flow spread, SSI and stone rod adhesion results are given below. The water film thickness and paste film thickness are determined from the packing densities of mortar and fine aggregate and the specific surface area of cement and fine aggregate. The test results for zone 1 are given below in Table II.

Table – 2
Flowability, cohesiveness and adhesiveness Results of mortar mixes

Sample number	*Flow spread (mm)*	*SSI(%)*	*Stone rod adhesion(gm)*
1-0.28	351.75	42.5	30.8
1-0.3	355	47.6	9.65
1-0.35	367.5	52.2	6.75
0.8-0.28	321	4.8	34.98
0.8-0.3	332	10.2	20.98
0.8-0.35	365.75	51.6	6.04
0.67-0.28	305.25	0.3	23.12
0.67-0.3	311.25	9.1	21.7
0.67-0.35	348.25	14.7	13
0.57-0.4	363.5	19.4	3.95
0.57-0.45	379.75	19.6	3.3
0.57-0.5	420.5	28.6	1.3
0.5-0.4	338.17	0.4	5.9
0.5-0.45	352.5	0.6	2.4
0.5-0.5	374.50	4.9	1.05

From the test results of mortar mixes, various observations were made. The flow spread of the mortar had an increasing value with increase in W/C ratio and decreasing value with decrease in C/A ratio. The flow spread results were varied from 305.25mm to 420.5mm.

From the SSI results of all the zones it can be seen that at a lower C/A ratio, the SSI was also very low(around zero), and with increasing C/A ratio, the SSI also started to increase depending upon the W/C ratios. At a higher W/C ratio, C/A ratio at which the increase of SSI was lower was corresponded to higher SSI value. So cohesiveness is lower in both cases at higher C/A ratio and lower W/C ratios. Seggregation was found when the SSI value was increased at more than 10%.

From the adhesiveness results, it could be noted that at constant W/C ratio, the adhesiveness results changed with C/A ratio, in a manner that adhesiveness was lower at lower C/A ratio, and had an increasing value with increase in C/A ratio. But after a certain value, the adhesiveness had begun to decrease with further increase in C/A ratio. The highest adhesiveness value was varied with W/C ratio and the highest value was found at W/C ratio of 0.28. From these results, it was noted that the adhesiveness is highest at optimum W/C ratio.

Table – 3
Water film thickness of mortar mixes

Sample number	*packing density of mortar*	*excess water ratio*	*specific surface area of solid particles(m^2/m^3)*	*WFT(µm)*
1-0.28	0.760	0.08	455638.93	0.177
1-0.3	0.760	0.08	455638.93	0.171
1-0.35	0.760	0.05	455638.93	0.103
0.8-0.28	0.785	0.06	401827.46	0.154
0.8-0.3	0.785	0.10	401827.46	0.248

0.8-0.35	*0.785*	*0.03*	*401827.46*	*0.071*
0.67-0.28	*0.798*	*0.06*	*359731.02*	*0.164*
0.67-0.3	*0.798*	*0.07*	*359618.06*	*0.181*
0.67-0.35	*0.798*	*0.06*	*359618.06*	*0.169*
0.57-0.4	*0.755*	*0.08*	*325623.65*	*0.239*
0.57-0.45	*0.755*	*0.00*	*325623.65*	*-0.003*
0.57-0.5	*0.755*	*0.13*	*325623.65*	*0.388*
0.5-0.4	*0.749*	*0.03*	*297658.65*	*0.107*
0.5-0.45	*0.749*	*0.00*	*297658.65*	*0.012*
0.5-0.5	*0.749*	*0.01*	*297658.65*	*0.045*

The packing densities of mortar mixes and their water film thickness are given in Table III. The packing density of the mixes varied from 0.749 to 0.798. This difference was quite small but their difference of water film thickness was from -0.003 µm to 0.388 µm, which affects the flowability of mortar.

For the measurement of fine aggregate, the water/solid ratio by volume were taken as 0.55, 0.60 and 0.65 respectively [4]. For each mix, a polycarboxylated superplasticizer was added of maximum 1.32% of the mass of fine aggregate. The packing densities were accessed from the plot of solid concentration against the W/S ratio as shown in Fig. 2. From the results, it is found that the packing density of zone 1 was found 0.711.

WFT thickness was increased with both higher W/C ratios and higher C/A ratios. In addition, when C/A ratio was very low at 0.5, the WFT started to increase sharply with C/A ratio, but when C/A ratio was very high, the WFT was increased very steadily. The WFT & PFT were increased linearly with C/A and W/C ratios. This variation are observed due to the relative changes in the packing density, excess water and surface area of solid particles. The paste film thickness results were varied from 50.5 µm to 127.9 µm. The packing density of fine aggregate and paste film thickness results for zone 1 are given in Table IV.

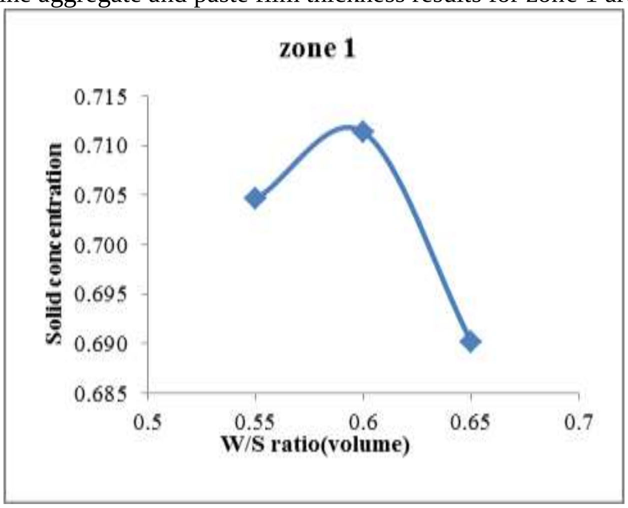

Fig. 2: Solid concentration versus W/S ratio for zone 1

Table – 4
Paste film thickness of mortar mixes

mix no.	*packing density of fine aggregate*	*excess paste ratio*	*Specific surface area of fine aggregate(m²/m³)*	*PFT(µm)*
1-0.28	*0.711*	*1.135*	*10285*	*110.4*
1-0.3	*0.711*	*1.187*	*10285*	*115.4*
1-0.3	*0.711*	*1.316*	*10285*	*127.9*
0.8-0.28	*0.711*	*0.827*	*10285*	*80.4*
0.8-0.3	*0.711*	*0.868*	*10285*	*84.4*
0.8-0.35	*0.711*	*0.971*	*10285*	*94.4*
0.67-0.28	*0.711*	*0.622*	*10285*	*60.4*
0.67-0.3	*0.711*	*0.656*	*10285*	*63.7*
0.67-0.35	*0.711*	*0.742*	*10285*	*72.1*
0.57-0.4	*0.711*	*0.651*	*10285*	*63.3*
0.57-0.45	*0.711*	*0.725*	*10285*	*70.5*
0.57-0.5	*0.711*	*0.799*	*10285*	*77.7*
0.5-0.4	*0.711*	*0.519*	*10285*	*50.5*
0.5-0.45	*0.711*	*0.584*	*10285*	*56.7*
0.5-0.5	*0.711*	*0.648*	*10285*	*63.0*

V. CONCLUSIONS

The flow spread results were varied from 305.25mm to 420.5mm. SSI results were varied from 0.3 to 52.2. Segregation was found at the sieve segregation index greater than 10%. The stone rod adhesion results were found between 1.08gm to 34.98gm. For constant W/C ratio, the adhesion was lower at lower C/A ratio and was increased with increase in C/A ratio upto certain limit and then it decreased. The packing density of fine aggregate of zone 1 was found as 0.711. The packing density of mortar mixes of zone 1 was in the range of 0.749-0.798. The WFT and PFT were increased linearly with C/A ratio and W/C ratio. The water film thickness results were varied from -0.003 µm to 0.388 µm while the paste film thickness results were varied from 50.5 µm to 127.9 µm. The negative value of WFT indicates voids in the mortar mix, and it is required to have positive water film thickness. To achieve good adhesiveness, minimum required WFT is 0.071 µm.

ACKNOWLEDGEMENT

Smit Kotak would like to thank Professor Parth Thaker and Professor Vaibhav Doshi for their useful guidance and support throughout the work. The author also would like to thank the C.E.P.T. University for their support and providing useful resources for the research work.

REFERENCES

[1] Kwan A. K. H., And Li L. G. "Combined Effects Of Water Film Thickness And Paste Film Thickness On Rheology Of Mortar", Materials And Structures, February 2012, 45, 1359-1374.
[2] Kwan A. K. H., And Li L. G, "Combined Effects Of Water Film, Paste Film And Mortar Film Thicknesses On Fresh Properties Of Concrete", Construction And Building Materials,2014, 50, 598–608.
[3] Li L. G., & Kwan A. K. H., "Mortar Design Based On Water Film Thickness", Construction And Building Materials, 2011,25, 2381-2390.
[4] Kwan, A. K. H., And Fung, W. W. S., "Packing Density Measurement And Modelling Of Fine Aggregate And Mortar", Cement And Concrete Composites, 2009, 31, 349–357.
[5] Kwan, A. K. H., Li, L. G., & Fung, W. W. S., "Wet Packing Of Blended Fine And Coarse Aggregate", Materials And Structures,2012, 45, 817–828.
[6] Wong H. H. C. And Kwan A. K. H., "Packing Density Of Cementitious Materials: Part 1—Measurement Using A Wet Packing Method", Materials And Structures, 2008, 41, 689–701.
[7] Kwan A.K.H. And Wong H.H.C., "Effects Of Packing Density, Excess Water And Solid Surface Area On Flowability Of Cement Paste", Advances In Cement Research, 2008,20, 1–11.
[8] Kwan A.K.H., Fung W.W.S. And Wong H.H.C., "Water Film Thickness, Flowability And Rheology Of Cement-Sand Mortar", Advances In Cement Research, 2010, 22, 3–14.
[9] Craus Joseph And Ilan Ishai, "A Method For The Determination Of The Surface Area Of Fine Aggregate In Bituminous Mixtures", Testing And Evaluation, 1977, 5, 284–291.
[10] Li L. G. And Kwan A. K. H. "Effects Of Superplasticizer Type On Packing Density, Water Film Thickness And Flowability Of Cementitious Paste", Construction And Building Materials, 2015, 86, 113–119.
[11] Jayasree C. And Gettu R. And Jayashree C.G.R. "Experimental Study Of The Flow Behaviour Of Superplasticized Cement Paste", Materials And Structures, 2008, 41, 1581–1593.
[12] Kwan A.K.H., Fung W.W.S., "Effects Of Csf Content On Rheology And Cohesiveness Of Mortar", Magazine Of Concrete Research, 2011, 63, 99–110.
[13] Kwan A.K.H. And Wong H.H.C., "Packing Density: A Key Concept For Mix Design Of High Performance Concrete", 2005, University Of Hong Kong.
[14] De Larrard F., "Concrete Optimisation With Regard To Packing Density And Rheology",Rilem,2009.
[15] The European Guidelines For Self-Compacting Concrete, 2005.
[16] Kisan M., Sangathan S., Nehru J. & Pitroda S. G.,Is 2386 (Part Iii), Method Of Test For Aggregates For Concrete,1963
[17] Is 383 Specification For Coarse And Fine Aggregate From Natural Sources For Concrete,1970.
[18] Cs(Construction Standards)-2013- Aggregates For Concrete.
[19] Raj N. G., Patil S., & Bhattacharjee B., "Concrete Mix Design By Packing Density Method", Iosr Journal Of Mechanical And Civil Engineering,2014, 11, 34–46.
[20] Kwan, A. K. H., & Mckinley, M., "Packing Density And Filling Effect Of Limestone Fines",2014, 3, 209–227.
[21] Li L. G., & Kwan A. K. H., "Adding Limestone Fines As Cementitious Paste Replacement To Improve Tensile Strength, Stiffness And Durability Of Concrete", Cement And Concrete Composites,2015, 60, 17–24.
[22] Chen J. J., & Kwan A. K. H., "Superfine Cement For Improving Packing Density, Rheology And Strength Of Cement Paste", Cement And Concrete Composites,2012,34, 1–10.
[23] Kwan A.K.H., Chen J.J., Fung, W," Effects Of Superplasticizer On Rheology And Cohesiveness Of Csf Cement Paste",2011, 24, 125–137.
[24] European Standard En 1015-3, Methods Of Test For Mortar For Masonry: Part 3: Determination Of Consistency Of Fresh Mortar (By Flow Table); 1999.