

Full Length Research Paper

Studies on influence of water-cement ratio on the early age shrinkage cracking of concrete systems

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Concrete is sensitive to environmental changes, especially during the first few days after casting. Volumetric changes due to drying, temperature, plastic and autogenous shrinkage are often experienced. These changes are critical during early ages when the concrete is most vulnerable to cracking. Reinforcement and joints are used to control shrinkage and leads to cracking. Bad cracking leaves the reinforcement exposed to air and moisture, which may cause it to rust and weaken concrete. Plastic shrinkage is the result of a very rapid loss of moisture from freshly laid concrete within a few hours of placement, while the concrete is still plastic and before it gains any significant strength. This loss is generally caused by various material parameters such as cement content, aggregate content, water-cement ratio and the admixtures. In addition to these environmental factors such as air and concrete temperature, relative humidity (RH) and wind velocity also cater to shrinkage. When the moisture from the surface of freshly placed concrete evaporates faster than the moisture which is replaced by bleed water, the surface concrete shrinks. Plastic shrinkage cracking of concrete is a widespread problem in concrete construction, particularly in thin applications such as highway pavements, slabs cast on grade, surface repairs, overlays, patching, and shotcrete tunnel linings. If premature surface cracks occur, they may accelerate the ingress of aggressive agents, salts and moisture and reduce long-term durability. The current research is motivated to study the influence of various material parameters on the degree of plastic shrinkage cracking in concrete and to quantify more reliable crack estimation.

Key words: Plastic shrinkage, concrete, cracks.

INTRODUCTION

Plastic shrinkage occurs at early age and when bleeding rate is less than evaporation rate (Senthilkumar and Natesan, 2005). It is a type of shrinkage which occurs soon after the concrete is placed in the forms while the concrete is still in the plastic state (Chengqing et al., 2000). A negative capillary pressure will develop within the pore structure of hydrating concrete as water evaporates from the capillary pores (Sivakumar and Manu Santhanam, 2007). This negative pressure results in the development of an overall compressive force within the dehydrating surface, ultimately causing the top layer of fresh concrete to shrink (Anna et al., 1995). Once the fresh concrete's tensile strength is exceeded, shallow cracks of varying depth and length develop throughout

the surface (Mane et al., 2003). Plastic shrinkage cracks are typically observed in thin concrete elements with a high surface area to volume ratio (Zhen et al., 2004). It is of major importance because it impairs the structural integrity. These cracks are going to cause further growth due to structural overloading.

Plastic shrinkage cracking does not initially affect the structural capacity but it may lead to accelerated corrosion of embedded reinforcing steel, compromising the structural capacity of the product at a later age. Plastic shrinkage cracks are the short irregular cracks that form on the surfaces of fresh concrete. The present study aimed at studying the degree of early age cracking in cementitious systems and the methodology adopted

Table 1. Concrete mixture proportions used in the study.

Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (10 mm) (kg/m ³)	Water (kg/m ³)	Superplasticizer (kg/m ³)
350	810	1218	168	8

Table 2. Mix proportions of the plain concrete.

Mix ID	Material proportions			
	Cement	Fine aggregate	Coarse aggregate	Water-cement ratio
M1	1	2.051	3.093	0.3
M2	1	2.051	3.093	0.4
M3	1	2.051	3.093	0.5

**Figure 1.** Shrinkage crack of Mix 1.

includes slabs with stress concentrators, a bolt and nut arrangement was provided at the ends. Image analysis was done using PCI Geomatics software and used to report the cracked area in a more appropriate method than manual crack measurement to study cracking at different scales. With the use of image analysis, it becomes easier and reliable for monitoring the crack development. A commercially available image analysis software (PCI Geomatica) was used in the present study for measuring the crack parameters such as crack width and crack length.

EXPERIMENTAL METHODOLOGY

Ordinary Portland cement conforming to IS 12269 of 53 grade was used for producing concrete admixtures and the specific gravity was found to be 3.37. River sand with a specific gravity of 2.69 with

fineness modulus of 2.55 was used as fine aggregate. Coarse aggregates of 10 mm size and of specific gravity 2.75 was used. A naphthalene based Super plasticizer was used to obtain desired workability in the range of 50 to 75 mm. The concrete mixture proportions used in the study are provided in Tables 1 and 2.

Experimental setup

The slab mould shown in Figure 1 of dimension 500 × 250 × 75 mm was fabricated as per ASTM-C1579 using a wooden board. The slabs were provided with a stress riser of 55 mm height at the center and two base restraints of 35 mm height at 35 mm from both ends, along the transverse direction. An additional of a bolt and nut arrangement was provided at the ends to restrict the longitudinal movement of the concrete slab from the edges and to provide additional restraint, increasing the potential of cracking at the notch. The slabs were checked visually for any signs of cracking at approximately 60-min intervals. For a concrete mix with fine aggregate/coarse aggregate ratio of unity concrete mix was chosen and listed in Table 2. This rare type of concrete mixture has been considered because it produced more plastic shrinkage cracks. The degree of cracking in various concrete systems is shown in Figures 2, 3 and 4.

RESULTS AND DISCUSSION

Crack observations

The time of occurrence of first crack was noted for all slabs during the experiments and the crack measurements are provided in Table 3. In the case of plain concrete, approximately 180 min after mixing with water, a fine hairline crack running throughout the width of the slab was observed above the central stress riser. This fine crack, which is caused due to settlement was found to widen upon further drying. In the case of plain concrete, a single crack over the central stress riser was found to run almost straight throughout the width of the specimen. The experiments were conducted under realistic on site conditions where temperature and humidity parameters fluctuate. Plastic shrinkage cracks occurred during the first few hours after the casting of



Figure 2. Shrinkage crack of Mix 1.



Figure 3. Shrinkage crack of Mix 2.

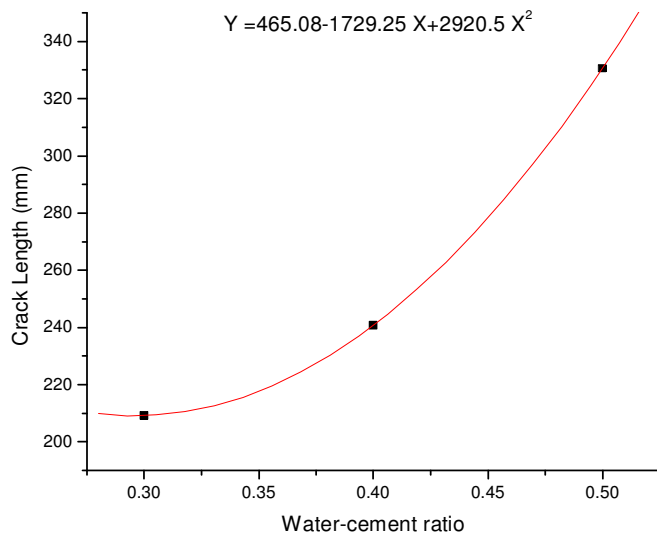
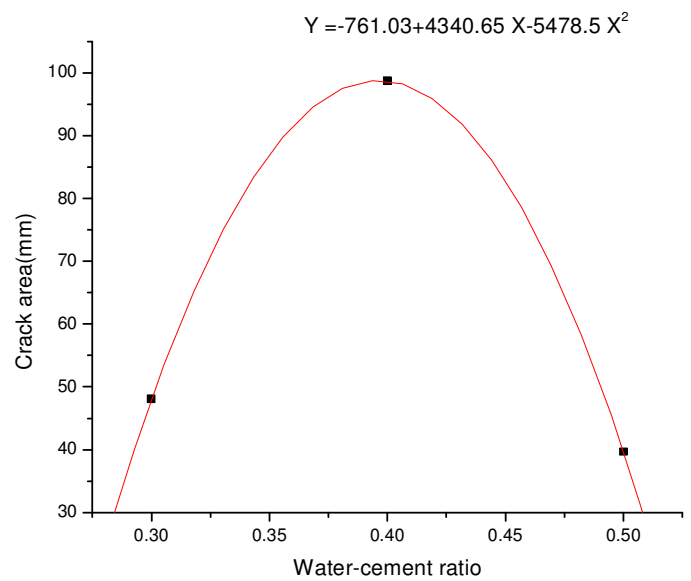
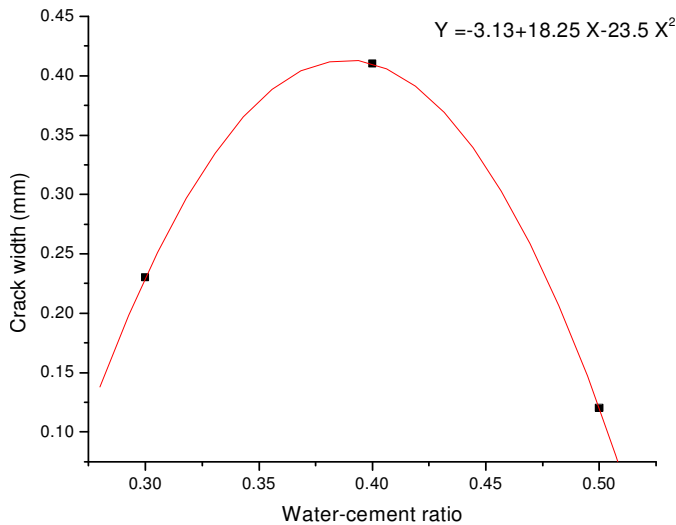


Figure 4. Shrinkage crack of Mix 3.

concrete was completed, and the concrete is still in plastic state. The width and the length of cracks were measured after 14 h. In the initial period, the specimen has sufficient moisture stored in the capillary pores, which is being used for hydration process. Thereby stresses may initiate and propagate cracks. Early age cracks are severe for low water cement ratio systems. It can be observed from experimental results that at low water cement ratio, the cracks occurs at 4 h and the crack at later stage are stabilized. The crack after a day was observed to be slightly lower than higher water cement systems. The crack length increased with the increase in water-cement ratio which is evident from Figure 5. The increase in crack length for high water content in the concrete systems could be due to continuous propagation of cracks. It can be observed from Figure 6 that, in high water cement ratio systems cracking width of concrete was observed to be less than at low water cement ratio systems. This could be possible due to enough water available for evaporation and provides better residual strength before complete drying. After 8 h the cracking propagated and later stabilized. However the cracking width increased at lower water cement ratio systems. This has resulted in higher crack width and corresponding for a medium water cement ratio concrete systems. The cracking in concrete specimen is a function of water cement ratio and the subsequent bleeding in the concrete. So it can be realized that at low water cement ratio the bleeding is less compared to high. Hence cracking is severe in low water cement ratio systems than high water cement ratio due to inadequate strength in concrete. When concrete has high water cement ratio systems the drying of concrete takes longer time and this can an advantage to gain sufficient tensile strength in plastic state. The crack width increases from 0.3 water cement ratio and reaches a maximum value at 0.4 water cement ratio and starts decreasing with an increase in water content which can be observed from Figure 5. This could be due to the reason that concrete attains early age cracking whereas in 0.5 the concrete has lesser crack width comparatively as it has sufficient water which does not lead to the formation of early age cracks. The cracks are highly tortuous for high water cement ratio systems compared to low water cement ratio systems since cracks occur at delayed time and has attained sufficient strength, this results in for a longer path taken by the cracks which can be observed from Table 3. The total crack area is the product of total crack length and mean crack width and the experimental results exhibited an increase in crack area with an increase in water cement ratio (Figure 7). It can be concluded that early age cracking is phenomenal for low water cementitious systems due to less bleed water available for compensating evaporation. Whereas in the case of high water cementitious systems enough water is available on the top surface and also results in the reduction of crack width as well as crack area. Crack length depends on the tortuosity of initiation and

Table 3. Crack measurements on the concrete slabs.

Specimen ID	Total crack length (mm)	Mean crack width (mm)	Total crack area (mm ²)	Standard deviation	Coefficient of variance (%)
M1	209.15	0.23	48.10	0.35	1.52
M2	240.66	0.41	98.67	0.52	1.26
M3	330.58	0.12	39.67	0.27	2.25

**Figure 5.** Water cement ratio versus Crack length.**Figure 7.** Water cement ratio versus Crack area.**Figure 6.** Water cement ratio versus width.

propagation and this certainly high for low water cementitious systems than for high water cementitious systems. This results in continuous propagation of cracks without any discontinuity in concrete systems with high water content.

Conclusions

The following observations are derived from the present study:

1. The image analysis measurement technique was capable of assessing the shrinkage characteristics of any concrete system.
2. Plastic shrinkage cracking is greatly influenced by the cement/total aggregate ratio. As the water cement ratio increases the total crack length increases whereas the mean crack width is not increased.
3. The maximum width of crack is moderate for any type of concrete mix with different water/cement ratios subjected to realistic site conditions.
4. The increase in fineness of the material will often reduce the amount of bleed water that will reach the concrete's surface.
5. The present experimental method is appropriate for drying that takes place on the site conditions and subsequent propensity for the formation of plastic shrinkage cracking in concrete.
6. Image analysis was found to be an effective tool for the bias free estimation of plastic shrinkage cracking.

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