Durability of High Early Strength Concrete

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The need of the construction industry today is faster speed of construction. This leads to demand of high early strength concrete. We will see whether faster rate of construction does lead to problems in concrete from a durability point of view. This demand of high speed construction is fulfilled by high early strength cement and use of low water/cement ratio, which means reduced water content and increased cement content.

The above practice results in higher thermal shrinkage, drying shrinkage, modulus of elasticity and lower creep coefficients. The concrete with higher quantity of cement exhibits greater cracking tendencies because of increased thermal and drying shrinkage. As the creep coefficient is low in such concrete, there is not much scope for relaxation of stresses. Thus, it can be said that high early strength concretes are comparatively more prone to cracking. These cracks can however be controlled by use of sufficient steel reinforcements. But again, more steel means conversion of these bigger cracks in to smaller cracks. These smaller cracks are sufficient enough to allow passage of environmental agents like carbon dioxide and moisture in to the concrete thereby affecting the long term durability of concrete.

However, there is another school of thoughts with respect of the above. High early strength concrete has high cement content and low water content. As a result of low water content, only surface hydration of the cement grain takes place leaving considerable amount of unhydrated core of cement grain. When micro cracks develop, moisture penetrates through them. This moisture is utilized by the unhydrated core of cement to further develop strength. The hydration products thus generated seal the cracks and enhance the long term durability of concrete.

As per *Aiticin*, the quality of products of hydration gel formed in case of low water/cement ratio is superior to the quality of gel formed in case of high water/cement ratio. This is as in low water/cement ratio concrete or high early strength concrete, the weak transition zone between aggregate and hydrated cement paste does not exist. Also, the microstructure of concrete in low water/cement ratio is much stronger and less permeable. The interconnected network of capillaries is so fine that water cannot flow any more through them. It is reported that when tested for Chloride ion permeability, it showed 10-50 times slower penetration than high water cement ratio concrete. Thus, it really remains a topic of debate and research whether the micro cracks in high early strength concrete reduces the long term durability or the delayed hydration of unhydrated core of cement grains increase the long term durability by healing up the micro cracks. Therefore, when long term durability is one of the major goals for high early strength concrete, we should have a proper balance between high and low cement content. One of the solutions would be use of Fly Ash along with the finer OPC (Ordinary Portland cement) of 400 kg/m3 or more, which is required for high early strength concrete.

We will now have a look that if and how, the use of Fly Ash aids in improving the properties of high early strength concrete.

Modulus of Elasticity

The relationship of Stress to Strain on application of load is the Modulus of Elasticity. The Modulus of Elasticity of concrete is expressed in terms of compressive strength in concrete. It is known that concrete exhibits a very complex behaviour, it being a heterogeneous material where in the elastic properties are influenced by that of the constituent materials and the gels formed. However, Modulus of Elasticity of concrete is a key factor to determine the deformation in members of structures. It is observed that at the same stress-strength ratio, stronger concrete has higher strain. Fig. 1 gives the values of modulus of Elasticity for various strengths of concrete. But, the capacity of concrete to handle or restrain the deformation depends upon the strength of the gels formed. Therefore, the stronger the concrete, the higher is the Modulus of Elasticity. Thus it can be said that the lower the water/cement ratio, the higher is the Modulus of Elasticity. In high early strength concrete, the water/cement ratio is already pretty low, but use of Fly ash further reduces the water demand and increases the Modulus of Elasticity. It is seen that Modulus of Elasticity of concrete is lower at early ages and higher at later ages. Also, the Modulus of Elasticity of Fly ash concrete is more than that of pure OPC concrete of the same strength.

Drying Shrinkage

The changes in volume or the shrinkage due to drying or the loss of water/moisture in concrete is termed as “Drying shrinkage”. Drying shrinkage occurs after concrete has reached its initial set. Drying Shrinkage occurs if the tensile stresses developed are of higher magnitude than the tensile strength of concrete. This is where a certain amount of “CREEP” in concrete comes in handy. Whenever, there is a deformation in concrete due to load applied or any shrinkage, there is a stage when the strain increases gradually without any increase in stress. Under sustained stress, with time, the gel, the water held in gel pores yields, flows and readjusts themselves. This behaviour of concrete is termed as Creep. A certain amount of creep is essential to allow for relaxation of stresses developed in concrete.

As mentioned above, cracking due to drying shrinkage is one of the greatest problems encountered in high early strength concrete or any concrete. One important factor affecting the drying shrinkage is the drying condition or the relative humidity of the atmosphere that the concrete is exposed to. But, another important factor that influences the extent of drying shrinkage is water/cement ratio of concrete. It is seen that at a constant water/cement ratio, shrinkage increases with an increase in cement content. But, at constant water content, shrinkage does not increase with increased cement content. The lower the water/cement ratio, the lesser is the amount of shrinkage. Fig. 2 shows the shrinkage relationship with cement content, water/cement ratio and water content.

The loss of free water contained in hardened concrete does not really cause any change in the dimensions or Shrinkage. It is the loss of water that is held in the gel pores that causes the change in the volume. Fly ash due to its filler effect improves the particle packing in the concrete and reduces the voids, thus preventing the loss of water from the gel pores. It is known that Cement paste shrinks more than the mortar or the concrete. Also, Concrete made with smaller size aggregates shrink more than concrete made with bigger aggregates. Fly ash particles being perfectly spherical in shape produces more cohesive mix. As a result, the amount of fine aggregates in Fly ash concrete is lesser than pure cement concrete. Thus, Fly ash reduces the shrinkage in concrete. Furthermore, it is right that with high early strength, the water/cement ratio is already low, but as mentioned higher cement content as is the case in high early strength concrete means higher shrinkage. Thus, the use of Fly ash definitely brings down the water demand further, thereby reducing the shrinkage.

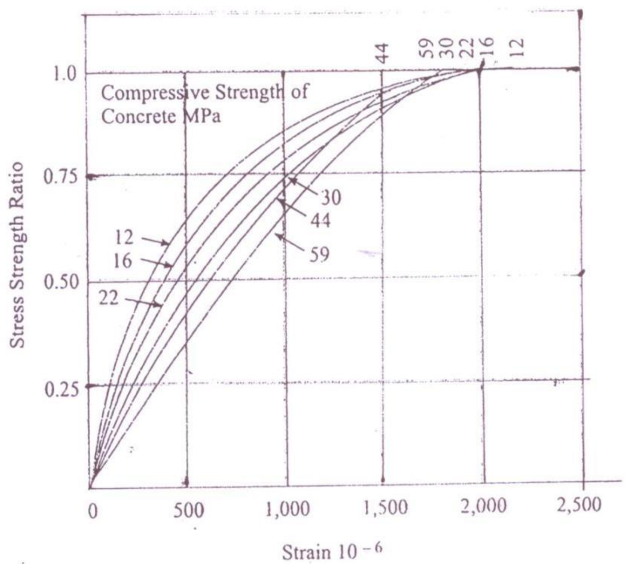

Fig. 1. Relationship between Stress / Strength Ratio and Strain for concretes at different strengths

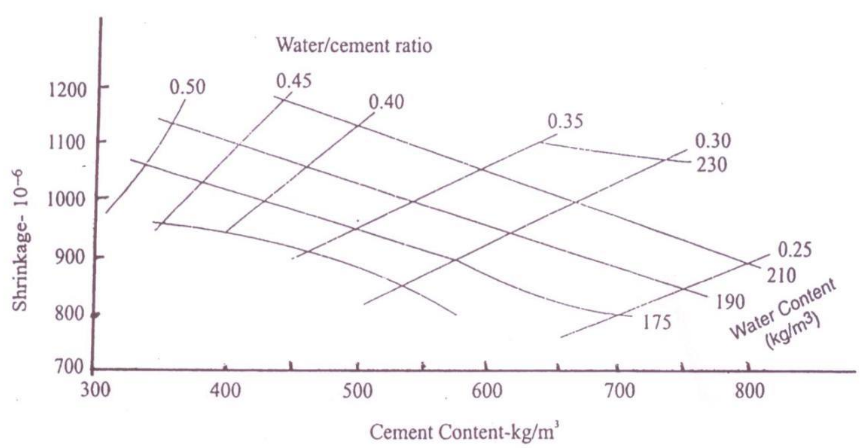

Fig. 2. Shrinkage relationship with Cement content, water content and water/cement ratio; concrete moist cured for 28 days, thereafter dried for 450 days

Thermal Shrinkage

Temperature in concrete rises due to generation of heat due to hydration of cement. The amount of heat generated is in the range of 120 cal/gm or higher in case of high early strength concrete as the cement content is high. The thermal conductivity of concrete is very low which results in high temperatures in the interior of concrete. Although this phenomenon is more prominent in mass concrete, it cannot be overlooked in thicker concrete sections , particularly in case of high early strength concrete. At the same time,the outer surface concrete loses heat. This results in a high temperature difference between the interior and the outer surface. When the interior of concrete subsequently cools, it cracks due to the thermal shrinkage.

Thermal Shrinkage is a property dependent on the amount and the speed or the rate of heat generated during hydration. The rate of liberation of heat depends on the composition of compounds in cement. Tri-calcium Silicate (C3S) and Tri-calcium Aluminate (C3A) produce large amount of heat in smaller time ie the rate of heat development is higher which is more detrimental than the total heat of hydration which develops slowly. The cement used for high early strength concrete needs to have high C3S and C3A content to realize early formation of primary Calcium Silicate Hydrate gel (C-S-H) for early strength. To add to it, higher cement contents would be more harmful from this point of view. This further advocates the need to use Fly Ash as partial cement replacement in High early strength concrete. The use of Fly ash reduces the rate of heat of hydration, thereby giving more time for the heat to be dissipated and thereby reducing the cracks due to thermal shrinkage.

Conclusion

The use of high early strength cement is the need of the current times to keep up with the growing demand for faster construction. It is however seen that although high early strength can be achieved, whilst it is difficult to sustain the concrete structure for a longer term OR In other words, high early strength concrete does not really mean durable concrete. The use of Pozzolanic material like Fly Ash along with finer high early strength cement can help us achieve more durable concrete structures without compromising on the required high early strengths of concrete. The reactive silica in Fly Ash keeps on forming delayed C-S-H gel as long as there is availability of free lime (Ca(OH)2 due to hydration of cement. This obviously means that the use of Fly Ash in High early strength concrete not only enhances the durability, but also the delayed or long term strength of concrete.

Reference: **Concrete Technology (Theory and Practice) - By Prof. M. S. Shetty**