CASTING MOLD INFLUENCE ON CONCRETE STRENGTH

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There was a 7% increase in strength of concrete cast in plexiglass molds compared to concrete cast in paper molds. This correction should be made when concrete cast in paper molds is used to calculate the strength of concrete models cast in plexiglass forms. Steel and plexiglass molds can be used interchangeably, if the 5% confidence level is acceptable. Steel and paper molds can also be used interchangeably, if the 5% confidence level is acceptable. Each type of paper mold should be tested by statistically comparing the strength of concrete cast in them to the strength of concrete cast in steel molds. Concrete cast in steel seems to give a more predictable average strength than does concrete cast in paper or plexiglass molds. Conclusions drawn from this pilot study, in which few samples were tested, need to be verified by additional research.

Concrete is a non-homogenous and nonelastic material. To determine the behavior of a concrete structure, empirical equations must be used. When empirical equations are not available and a definite failure mechanism must be obtained, models may be tested. The mechanics of models can be related to the mechanics of similar prototypes.

Construction of a typical concrete prototype generally proceeds with the concrete poured into a form, then rodded or vibrated to remove entrapped air and to compact the concrete into a continuous solid matrix. The procedure of rodding and vibrating fresh concrete is not completely successful since voids continue to exist. This is usually not critical since the voids represent a small percentage of the total cross-sectional area. However, the behavior of a model is more sensitive to voids because they represent a potentially high percent of the cross-sectional area.

One technique used to help eliminate voids in concrete models is the use of transparent forms. When the concrete is cast in a transparent form, such as a plexiglass, the voids can be seen and removed by rodding or vibrating.

The finish surface texture of concrete cast in plexiglass forms is different from concrete cast in conventional wood or steel forms. The plexiglass form causes a smooth, glass-like finish, whereas concrete cast in conventional forms has a granular appearance. It is reasonable to question if forms also effect other properties of the concrete.

The standard method of determining the strength of concrete is to cast a sample in a cylindrical mold with a length to diameter ratio of two to one. After the concrete hardens the sample is compressively loaded to failure.

Steel has traditionally been used for these cylindrical molds, but recently paper molds have been used. Paper molds are disposable and need not be cleaned or maintained and, therefore, are very popular. A paper mold of nominal 3 inch diameter and 6 inch height (actual size, 3⅜ inch diameter by 6¼ inch height) is commercially available in Oklahoma. Concrete cast in these paper molds has been used to predict the strength of concrete models cast in plexiglass forms.

In order to predict the effect which mold materials have on the mechanical properties, concrete was cast in plexiglass, steel and paper cylinder molds. The hardened concrete was then compressively loaded to failure.

The significance of mold material on concrete strength can be demonstrated by statistical analysis of compressive strength test results. If the concrete from the various molds can be shown to come from the same statistical population, then the mold would have insignificant effect on the concrete strength. However, the influence of a mold must be considered in the analysis of strength data if the statistical populations are significantly different.

MATERIALS AND METHODS

Three concrete mixes were cast in molds of paper, steel and plexiglass. Mixes were designed with three water-cement ratios of 0.40, 0.50, and 0.60. A total of nine batches of concrete were tested.

Type III cement (high early strength) and a maximum size of aggregate of ½ inch were used throughout the test.

The concrete was removed from the molds at 24 hr and then air dried for 6 days. The cylinders were capped with concrete capping compound and tested in compression at 7 days.

RESULTS AND DISCUSSION

Statistical analysis

The strength of concrete cast in steel and plexiglass molds came from the same statistical population at the 5% confidence level. If the 10% confidence level is used, the strength of the concrete cast in plexiglass molds and in steel molds did not come from the same statistical population. Also, the strength of concrete cast in plexiglass molds and paper molds came from a different statistical population at the 5% confidence level.

Burmeister (1) compared concrete cast in two types of paper molds to concrete cast in steel molds. It can be demonstrated from his data that the concrete cast in one type of paper molds versus that cast in the steel molds came from the same statistical population. The concrete cast in the other type of paper molds, when compared to steel molds, came from a different statistical population. Considering all his data, concrete cast in paper molds had 9.5% lower strength than had concrete cast in steel molds. Price (2) verified this trend by showing a 3.5% decrease in strength of concrete cast in paper molds compared to that of concrete cast in steel molds.

Results reported here show that concrete cast in paper molds was 3.4% lower in strength than concrete cast in steel molds. Concrete cast in plexiglass molds was 3.7% stronger than concrete cast in steel molds. These results are shown in Figure 1.

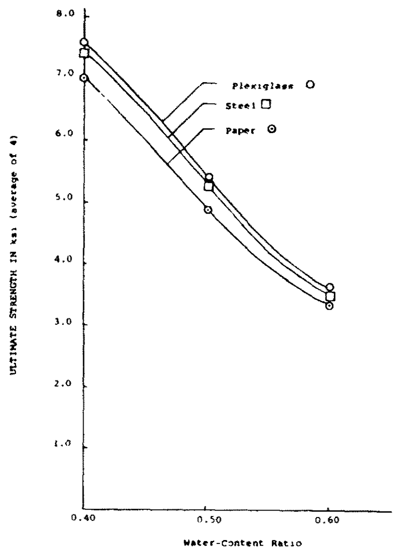

FIGURE 1. Ultimate strength versus water-cement ratio for concrete cast in plexiglass, steel, and paper molds.

The standard deviation of the concrete cast in paper molds was larger than that of concrete cast in either plexiglass or steel molds. Concrete cast in steel had the smallest standard deviation and, therefore, gave a more consistent average strength.

Thermal consideration

The reaction of cement with water is an exothermic reaction, with approximate 25 cal/gram of cement of heat given off in the first 3 hr period (3). A temperature gradient exists across a cylinder of concrete due to the intensity of the hydration process and to heat transfer out of the cylinder. A value of heat transfer (4) through the mold can be calculated by,

$$\frac{q}{L} = \frac{2\pi K}{\log_e} \frac{(t_1 - t_2)}{(R_2/R_1)}$$

q = heat flow per unit time
L = length of cylinder
K = thermal conductivity of the material
K (steel) = 35.0 BTU/hr-ft-F°
K (plexiglass) = 0.112 BTU/hr-ft-F°
K (paper) = 0.1 - 0.3 BTU/hr-ft-F°
R_1 = inside radius of cylinder
R_2 = outside radius of cylinder
t_1 = temperature at R_1
t_2 = temperature at R_2

If this expression is solved for $(t_1 - t_2)$, or Δt, the following values are found

(Δt) steel = 0.006°F
(Δt) paper = -0.42°F
(Δt) plexiglass = 3.7°F

The thickness of each kind of cylinder mold was different; therefore, Δt is not a simple inverse relation. The above calculations were verified by placing a thermocouple in the concrete while in the mold. The concrete cast in the plexiglass mold was 4°F higher than concrete cast in the steel mold after 3 hr.

Concrete in the plexiglass mold had a small temperature gradient; the plexiglass, acting as an insulator, allowed the concrete to establish a more constant temperature. Steel conducts heat from the concrete, thus establishing a larger temperature gradient within the concrete. Thermal stresses (5) are induced in the concrete by this temperature gradient, which may be found by:

$$\sigma_{rr} = \alpha E \left[\frac{1}{b^2} \int_0^b T_r dr - \frac{1}{r^2} \int_0^r T_r dr \right]$$

σ_{rr} = thermal stress, in r direction
α = thermal expansion coefficient
E = modulus of elasticity
b = radius
r = radius at any point in concrete
T_r = temperature as a function of the radius

If the temperature is constant, no thermal stress is induced.

Concrete in the plexiglass molds had the smallest heat gradient; therefore, the temperature approaches a constant value. Under these conditions, smaller thermal stresses and fewer micro-cracks would develop in the concrete as compared to concrete in steel molds. Since the concrete strength is lowered by micro-cracks (6), concrete cylinders that have a significant temperature gradient would likely have lower strength.

The temperature gradient also removes energy from the concrete. This energy loss decreases the kinetic energy of the reaction and slows the hydration process. Since concrete strength increases with the extent of hydration (7), the temperature gradient would have a detrimental effect on early strength (8).

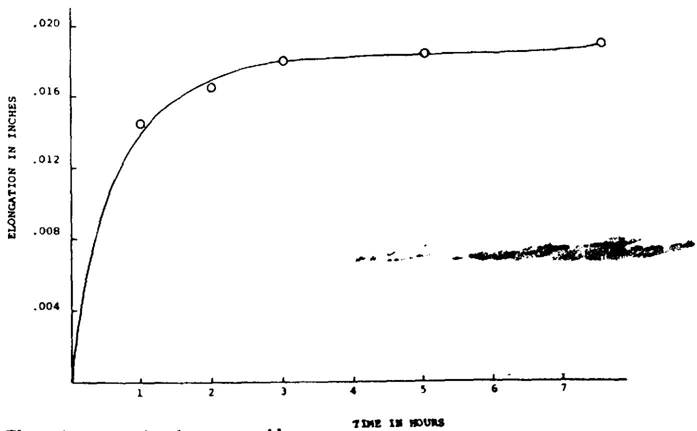

FIGURE 2. Elongation versus time for paper molds.

Mold-wall effect

Concrete cast in a paper mold loses some of its free water through absorption into the mold, thus lowering the water-cement ratio. This type of water loss does not occur in the concrete cast in steel or plexiglass molds. Figure I shows that concrete strength increases as water-cement ratio decreases. Therefore, concrete cast in paper should have greater strength than concrete cast in plexiglass or steel molds. Review of Figure I, however, shows the opposite trend.

Possible reasons for the results with paper molds, which indicated low strength, were investigated with the following findings. The paper molds were tested by the procedure of ASTM C470-67T and were found to absorb 8.6% of their weight. Their elongation-time curve is shown in Figure 2.

Inspection of the concrete cast in paper molds showed significant adhesion between concrete and paper. When the free water of the concrete was absorbed into the mold, the cylinder elongated. This elongation, plus the adhesion, placed the concrete in a non-uniform tensile condition and resulted in the formation of obvious surface cracking, both 'micro' and 'macro' in size. The same observation was made by Burmeister (1). The reduction in strength due to mold elongation and cracking is evidently not off-set by the increase in strength due to the lowering of the water-cement ratio or the insulation property of the paper mold.

Fracture mechanics

Concepts of fracture mechanics (9) show that imperfections reduce strength. As previously noted, concrete cast in plexiglass had a smooth glass-like finish that was relatively free from imperfection. Both concrete cast in steel and paper had visible imperfections. Thus, less strength might be expected in the latter two instances than for concrete cast in plexiglass. However, evidence from the results presented here does not coincide with this expectation.

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