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Effects of improper moist curing on flexural strength of slabs cast under hot weather conditions

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HIGHLIGHTS

- Effects of inadequate curing in hot weather on flexure in RC slabs are investigated.
- Inadequate curing adversely affected concrete mechanical and structural properties.
- Flexural strength was reduced by 6–29% and deflections were considerably increased.
- Compressive strength of cores drilled from slabs was reduced by 12–39%.
- Calculations using strength of cores do not capture reduction in flexural strength.

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ABSTRACT

Inadequate moist curing can have adverse effects on the properties of concrete, especially during hot weather concreting (HWC). This research aims at gaining a better understanding of the effects of inadequate moist curing on the flexural behavior of reinforced concrete (RC) slabs cast during severe HWC. Five RC slabs and field-cured cylinders and cubes were cast and cured under peak temperatures as high as 50 °C, relative humidity as low as 6%, and relatively strong winds. Two additional slabs were control specimens which were cast and cured under lab conditions. The slabs were tested in a four-point loading setup to study their flexural behavior. The experimental results showed a general reduction in the properties of the concrete cast and cured outdoors, especially the concrete which did not receive adequate moist curing. The flexural strengths of the slabs cured outdoor were smaller than those of the lab-cured slabs by 6–29%. In addition, considerable decreases in the flexural stiffness were observed. The compressive strength of cores drilled from the slabs cast outdoors and not cured with moisture was smaller than that of the lab-cured control slab by 39%. The flexural strength of the slabs was calculated using the flexure theory and ACI code equations based on the compressive strength of the drilled cores and the field-cured cylinders. Using the reduced compressive strengths for the outdoor slabs did not lead to capturing the actual reduction in the flexural strength. However, the strength calculations remained conservative for all slabs, with strain hardening in the tension reinforcement being one of the contributors to this conservatism.

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1. Introduction

Hot weather concreting (HWC) is associated with the conditions leading to increased loss of moisture from the surface and increased speed of hydration of fresh concrete [1]. These conditions can be caused by various combinations of high concrete and ambient temperatures, low relative humidity, direct solar radiation and high wind speed.

These severe conditions are common in some countries around the world. Fig. 1 shows the variation of the maximum daily temperature and the minimum relative humidity measured at the Kuwait International Airport in 2014. The figure shows that the summer peak daily temperatures can reach 45 °C and the relative humidity can drop below 10%. This combination represents severe HWC conditions, where very special precautions need to be taken to minimize the adverse effects on the properties of concrete.

However, it is not uncommon in some projects that concrete does not receive adequate care, especially in terms of moist curing. Fig. 2 shows shrinkage cracks in a supported slab which was cast and cured under severe HWC without taking the necessary precautions. In addition to the surface cracks, excessive deflections are common.

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Notations

E_c	modulus of elasticity of concrete
E_{c0}	modulus of elasticity of concrete of control slab
f_{core}	compressive strength of drilled cores (series UR)
f_{core0}	compressive strength of drilled cores (series UR) of control slab
f_{cu}	compressive strength of concrete cube at day of testing of slab
f_{cu0}	compressive strength of concrete cube at day of testing of control slab
f_{cy}	compressive strength of concrete cylinder at day of testing of slab
f_{cy0}	compressive strength of concrete cylinder at day of testing of control slab
f_u	ultimate strength of longitudinal reinforcement
f_y	yield strength of longitudinal reinforcement
M	bending moment in test region
M_u	observed ultimate flexural moment
M_y	observed flexural moment at yield of reinforcement
$M_{n\text{-ACI}}$	ACI calculated nominal flexural resistance
M_{n-p}	calculated flexural resistance assuming no strain hardening in steel
M_{n-sh}	calculated flexural resistance considering strain hardening in steel
P	total applied load
P_u	observed ultimate total load
P_{u0}	observed ultimate total load of control slab
P_y	observed total load at yield of reinforcement
P_{y0}	observed total load at yield of reinforcement of control slab
RH_0	minimum relative humidity on day of casting
RH_{avg}	average of minimum relative humidity over first week of age of slabs
T_0	maximum temperature on day of casting
T_{avg}	average of maximum temperature over first week of age of slabs
Δ_{mid}	measured vertical deflection at midspan
ρ	ratio of tensile reinforcement in slab

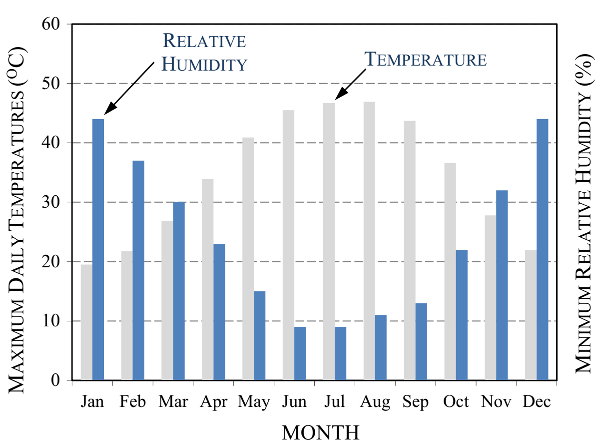

Fig. 1. Maximum daily temperatures and minimum relative humidity in 2014 in Kuwait.

Fig. 2. Shrinkage in slab due to inadequate moist curing in severe hot weather conditions.

Numerous studies have been conducted to investigate the effects of severe hot weather conditions and the various curing methods on the key concrete properties such as compressive strength [2–11], permeability [1,6,11,12], corrosion resistance [13,14], shrinkage [15] and other physical properties [16]. The results proved the detrimental effects of inadequate moist curing and high temperatures on these properties. However, the bulk of these studies focused on small size samples such as cubes, cylinders and prisms. There is a lack of experimental data on the effects of inadequate curing on the flexural behavior of slabs cast under severe hot weather conditions.

To evaluate the effect of inadequate concrete strength on the flexural strength and deflections of slabs, cores are typically drilled and tested in compression. Their compressive strength is used to evaluate the effect of the strength reduction on the structural performance of the elements. Experience shows that the reductions in the compressive strength which are obtained from by the results of the drilled cores do not explain the excessive deflections nor the reduction in flexural strength commonly encountered in such slabs. Research is needed in order to gain a better understanding of the effects of inadequate moist curing and hot weather concreting on the flexural strength of slabs.

This paper reports the results of an experimental investigation of the effect of four different moist curing conditions on the flexural behavior and strength of RC slabs cast and cured under HWC conditions. Seven slabs grouped in two series were cast and tested in a four-point loading setup. The difference between the specimens of the two series was the amount of longitudinal reinforcement and the severity of the HWC conditions. In each series, one of the slabs was cast and cured in the laboratory to act as a control slab. The remaining slabs were cast outdoors under relatively severe HWC conditions, and were subjected to moist curing regimes ranging from seven days of continuous moist curing to no moist curing.

2. Experimental program

A total of seven slabs were cast and tested in the four-point loading setup. Fig. 3 shows the test setup and the slab dimensions and reinforcement. Table 1 gives other details of the slab specimens.

The slabs were grouped in two series: the under-reinforced series (UR) and the relatively heavily-reinforced series (HR). The difference between the specimens of the same series is the curing conditions. The difference between series UR and series HR is the amount of reinforcement in the slabs. The specimens of the UR were reinforced with three 12-mm longitudinal tension reinforcing bars (reinforcing

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