Original Research Article

Influence of mixing time on fresh and hardened cast-in-place concrete

ABSTRACT

An adequate mixing time in concrete casting allows to achieve a homogeneous mass and improve compressive strength and durability. However, the lack of standards for cast-in-place concrete causes that the builders use different mixing times according to the locality usages and customs, which results in a high variability of the expected quality. In this paper, fresh and hardened cast-in-place concrete was evaluated. Seven samples were tested with different mixing time using portable rotary drum mixer. The used materials were ordinary portland cement, water and high absorption aggregates, fine and coarse, coming from a limestone crushing process. The results of the research showed that the mixing time and environmental temperature had no apparent influence on the slump of the mixtures, and trapped air and compressive strength increased slightly with increasing mixing time. Finally, it was found that the recommended mixing time, with rotation speed of 28 RPM, is 2.5 minutes, which differs from the common practice in the study area.

Keywords: Mixing time, cast-in-place concrete, rotation speed, compressive strength, slump.

1. INTRODUCTION

Concrete is a composite material that contains cement, water, aggregates and often, additives or additions. When these materials have been mixed and hydrated, they generate a chemical reaction forming a homogenous mass, a quality that improve compressive strength and durability. In addition to the water/cement ratio, and the quality of the materials, an important factor that influences the behavior of hardened concrete is the mixing time. The optimum mixing time depends in turn on the type and conditions of the mixer, rotation speed, load size, nature of the materials, and the environmental temperature, therefore, the most efficient mixing time should be determined in the field considering these variables [1]. In Mexico, the recommended mixing time by the NMX C-159-ONNCCE-1999 standard [2] is five minutes after all the materials were loaded, however, in the works, it is almost always about mixing the concrete as quickly as possible, which is due to economic issues, so determining the necessary minimum time is very important. Some minimum mixing times have been specified in several standards and regulations according to the capacity of the mixer, but generally refer to ready-mix concrete. The recommended minimum mixing times for low capacity mixers, are indicated in Table 1.

Table 1. Minimum mixing times for low capacity mixers

Loading capacity (m^3)	Minimum time (min)	Reference
0.76	1.0	[3, 4]
<1.5	1.5	[5]
--	1.5	[6]

UNDER PEER REVIEW

According to Neville and Brooks [7], a mixing time of less than one minute causes problems of uniformity and low strength in the concrete. Conversely, a greater time than two minutes does not necessarily means that there is an improvement in those properties. Other authors such as Charonnat and Beitzel [8] in countries of the European Union, as well as Trejo and Chen [9] in the United States, have focused on the study of time and efficiency of the mixing process in prolonged periods because the use of ready-mixed concrete has a high demand. However, in many countries with less technological development, cast-in-place concrete for medium and small works is a frequent practice, carried out in various ways due to the lack of precise specifications to achieve adequate characteristics of workability and compressive strength. This has led to the development of this research, whose main objective was to determine the most efficient mixing time and its relationship with the properties of fresh and hardened cast-in-place concrete, based on a field study, carried out to determine times and rotation speed of the portable mixers used in the works.

2. MATERIALS AND METHODS

2.1 Previous field study

This stage was aimed to obtain reliable information about mixing times, rotation speeds and the characteristics of the used mixers. Also, direct interviews were applicated to local builders and construction workers for detect those works where cast-in-place concrete was being used, which constituted the size of the population to be observed, using an intentional deterministic sampling. The study was carried out in Chetumal City, located in Mexico's southeastern region, whose population is 151,243 inhabitants [10]. It has sub-humid warm weather most of the year, being the average annual temperature of 26.4° C. The technical data of the portable rotary drum mixer and concrete casting practices were determined by direct observation. Mixing times were measured with a stopwatch from which last material was discharged into the mixer. The technical data were processed in those cases where some external factors modified the continuity of the work, such as workers distractions, lack of material and other delays, in this way the averages of rotation speed and mixing time were obtained for the control specimens. The location of the monitored works in the city territorial extension can be seen in Figure 1.

Figure 1. Monitored works location

2.2 Materials

The used materials were ordinary portland cement, water, and fine and coarse aggregates, both obtained by crushing limestone from a local quarry, whose properties were determined according to ASTM standards [11], summarized in Table 2.

UNDER PEER REVIEW

Table 2. Aggregates properties

Property	Coarse aggregate	Fine aggregate
Loose unit weight (kg/m^3)	1265	1462
Compact unit weight (kg/m^3)	1343	--
Specific gravity	2.5	2.7
Absorption (%)	4.3	1.4
Abrasion (%)	35	--
Maximum size (mm)	19	--
Fineness modulus	--	2.9

As expected, the characteristics of the aggregates showed typical unfavorable conditions of the materials of limestone origin [12]. On the other hand, the granulometric study of the coarse aggregate indicated a reduced amount of particles that pass the 9.5 mm sieve (Figure 2). The selected fine aggregate for this investigation had an acceptable granulometry, except for the amount of material that passes the No. 50 sieve equivalent to 50 µm (Figure 3).

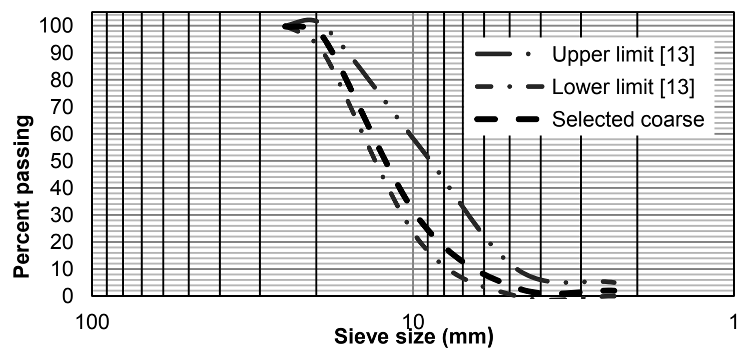

Figure 2. Granulometry of coarse aggregate

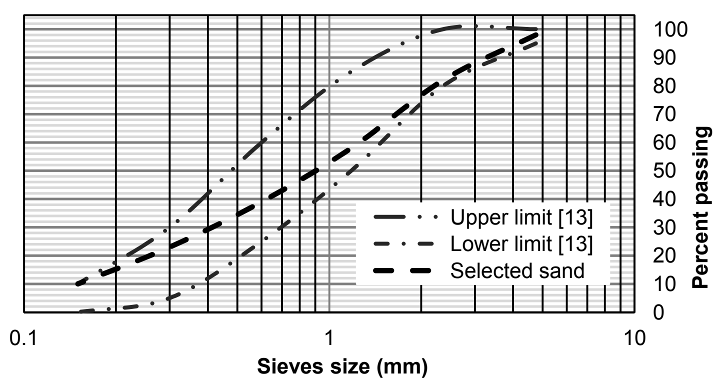

Figure 3. Granulometry of fine aggregate

2.3 Experimental Details

The selected rotation speeds according the previous field study, were 25, 70, 90, 100, 110, 120 and 140 RPM, each with its equivalent mixing time. These values were considered as independent variables; to identify them they were assigned the letter S (sample) followed by a consecutive number, where *S1* corresponded to the control sample. The dependent variable was compressive strength (*Fc*). Mixture design was performed based on ACI method [14], where the water/cement ratio (w/c) was 0.45 with 75 mm of slump. The relative amounts of the materials, before daily moisture corrections, are indicated in Table 3. The fresh concrete tests were slump and trapped air. For *Fc* tests, cylindrical specimens of 15 x 30 cm were cast, which were subjected previously to a process of moist curing by immersion for 28 days at 3, 7, 14, 28 and 90 age days.

Table 3. Mixtures design

Material	Relative amounts (kg/m^3)
Water	205
Cement	456
Coarse aggregate	822
Fine aggregate	862

3. RESULTS AND DISCUSSION

In the preliminary field study, fourteen works were observed, where the average time for casting was 0.9 minutes with a rotation speed of 25 RPM in each batch. A rotary drum portable mixer with 50 kg load capacity and 28 RPM speed was used. This information was useful to set the concrete mixing time and choose the laboratory equipment. The obtained results for the fresh concrete, including the environmental temperature during the casting, as well as the rotation speeds and equivalent mixing times are indicated in Table 4.

Table 4. Fresh concrete properties

Sample	RPM	Mixing time (min)	Slump (mm)	Trapped air (%)	Environmental Temperature (°C)
S1	25	0.9	50	3.4	27
S2	70	2.5	50	3.1	29
S3	90	3.2	55	3.6	29
S4	100	3.6	40	3.7	27
S5	110	3.9	30	3.2	28
S6	120	4.3	46	3.4	31
S7	140	5.0	40	3.4	31

As can be seen in Table 4, trapped air varied slightly, with no apparent influence of mixing time. Regarding the slump, it is observed that all the samples were below the design value, being more evident in those with longer mixing time. Similar values were found by Gonzalez et al. [15] when w/c ratios were less than 0.47. The ambient temperature varied in a range of 4 °C without showing any influence on the properties.
The *Fc* results at different ages, revealed a rapid growth tendency, because on the seventh day, they reached more than 80% of their optimum resistance, which denotes good efficiency of the mixing process. The sample with the longest mixing time (*S7*) was the one that reached the highest *Fc* at the age of 28 days, 20% more than the control sample (*S1*), which can be seen in Figure 4.

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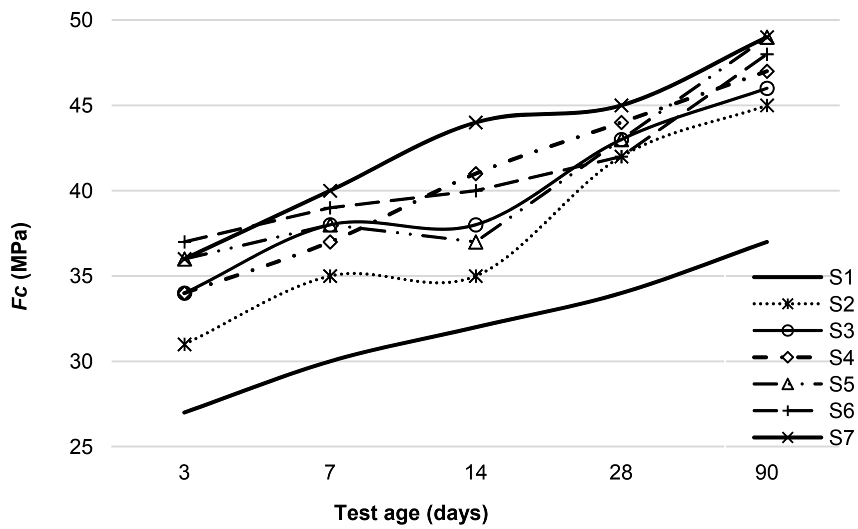

Figure 4. Compressive strength at different ages

These results can be contrasted with the ready-mix concrete data, informed by Kirca et al. [16] and Trejo and Chen [17], who also reported increases in the *Fc* when the mixing time was increasing. According Equation 1, the real influence of the mixing time on the *Fc* was determined with an Efficiency Index (*EI*), which was calculated from the ratio between *Fc* differentials (Δ*Fc*) and mixing time differentials (Δt) of each sample under study compared to the control sample.

$$EI = \Delta Fc/\Delta t \quad (1)$$

The complete outcomes at the age of 28 days can be seen in Table 5, where the most recommended mixing time is 2.5 minutes (*S2*) according *EI*.

Table 5. Efficiency index of the samples

Sample	*Fc* (MPa)	Time (min)	Δ*Fc*	Δt	*EI*
S1	34	0.9	--	--	--
S2	42	2.5	8	1.6	5.0
S3	43	3.2	9	2.3	3.9
S4	44	3.6	10	2.7	3.7
S5	43	3.9	9	3.0	3.0
S6	42	4.3	8	3.4	2.4
S7	45	5.0	11	4.1	2.7

Lastly, a statistical analysis for *Fc* data was carried out. The normality was verified with shape coefficients: -1.85 for asymmetry and -0.18 for kurtosis, which were within the expected range of a normal distribution (± 2). Subsequently, the results for ANOVA showed that $P < .001$. Since the significance was less than .05, indicating the difference between the means of the seven variables or samples under study, a multiple-rank test was performed using the LSD method to identify homogeneous groups among the means [18]. As result, a marked difference was observed between the control samples (*S1*) and the rest, a strong

UNDER PEER REVIEW

similarity between the samples *S3*, *S4*, and *S5*, and some similarity of the samples *S6* and *S7* with the three previous ones.

4. CONCLUSIONS

The present work constitutes one of the first efforts in establishing appropriate mixing times for cast-in place concrete, using high absorption limestone aggregates. According to the results of the research, the following conclusions can be drawn:
The mixing time and environmental temperature had no apparent influence on the slump of the mixtures. Trapped air and compressive strength increased slightly with increasing mixing time. In statistical terms, between 3.2 and 3.9 minutes of mixing time, the same quality results are achieved. The most efficient mixing time corresponded to 2.5 minutes with a speed of 28 RPM, which differs from the referenced standards and the common practice established in the previous field study.

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UNDER PEER REVIEW

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