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Is it possible to exceed the time limit specified by Brazilian Standard NBR 7212 for mixing and transporting concrete?

O limite de tempo especificado pela NBR 7212, para mistura e transporte do concreto, pode ser ultrapassado?

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Abstract

Brazilian standard NBR 7212 sets a time limit of 150 minutes for a concrete load to be discharged in full. In practice, situations arise where mixer trucks have to hold their load for much longer periods. The main aim of this paper is to assess changes in the compressive strength of concrete that is used when the time limit for mixing and transport specified by standard NBR7212 is exceeded. To this end, concrete was mixed for a period of 6 hours, and a superplasticizer was added at intervals to restore slump to its initial value. Results show that compressive strength is not affected by the prolongued mixing in the conditions of this research.

Keywords: prolonged mixing; ready-mixed concrete; compressive strength; superplasticizer.

Resumo

A norma NBR 7212, para execução de concreto dosado em central, estipula o tempo máximo para que o concreto seja descarregado (aplicado) completamente em 150 min; porém, na prática, ocorrem situações onde caminhões ficam carregados por tempos bem acima desse limite. O objetivo principal deste artigo consiste na avaliação do comportamento do concreto em relação à sua resistência à compressão, quando utilizado posterior ao tempo máximo de mistura e transporte especificado pela norma. Para tal, adotou-se como procedimento o restabelecimento do abatimento à condição inicial com aditivo superplastificante por um período de 6 horas. Os resultados mostram que não houve perda de resistência à compressão para esse tempo de mistura prolongada, nas condições dessa pesquisa.

Palavras-chave: mistura prolongada; concreto usinado; resistência à compressão; superplastificante.

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1. Introduction

Today, considerations of cost and ease of use as well as market requirements for improved proportioning, uniformity and homogeneity, much of the concrete used in Brazil is central-mixed. However, mixing plants pose problems of their own because they generate considerable amounts of waste and are therefore a cause for environmental concern. Most concrete waste is the result of leftover concrete that is rejected at site for failing to comply with the time limits for placement after load into mixer trucks specified by technical standards. Brazilian Standard NBR 7212 for ready-mixed concrete sets a limit of 90 minutes for transport between the mixing plant to the construction site and a limit of 150 minutes for concrete discharge. Some of the factors that may affect the time for concrete use include cement hydration reactions, the onset of setting and a reduction in workability observed in the first few hours, all of which may make placement and consolidation more difficult.

1.1 Bibliographical review

Ready-mixed concrete should be transported to the construction site in the shortest possible time to minimize hardening and loss of workability and allow appropriate consolidation and finishing operations after casting. Under normal circumstances, losses in workability in the first 30 minutes after the hydration of Portland cement are negligible. When concrete is kept at low mixing speeds or remixed periodically, some slump loss may be observed after some time, which usually poses no risk to the placement or compaction of fresh concrete in the first 90 minutes. Concrete workability determines the amount of effort required to handle a given amount of fresh concrete with a minimum loss of homogeneity. Handling refers to initial operations such as placement, compaction and finishing (MEHTA; MONTEIRO, 2008).
When subject to high temperatures, fresh concrete hardens faster when compared to concrete exposed to normal conditions. This faster setting time reduces workability during placement, compaction and finishing operations. In most situations, the interval between initial and final set is reduced as curing temperatures increase, a phenomenon related to the increase in cement hydration rates, particularly in the first few instants (HEIKAL et al., 2005). The major factors that influence concrete workability are evaporation, hydration, absorption and agitation. Environmental conditions may cause evaporation and hydration to accelerate over time. (DEWAR; ANDERSON, 1992). Slump loss in fresh concrete is a normal phenomenon and may be defined as a loss of flow characteristics over time. This property of concrete in particularly important for central-mixed concrete, because proportioning and initial mixing take place in the mixing plant, while placement and/or compaction will only take place minutes or even hours later, when the mixer truck arrives at the construction site (WEIDMANN et al., 2007). Prolonged mixing accelerates both hardening and the rate of slump loss, which is a problem in most situations, particularly when long transportation periods are involved, as is the case with ready-mixed concrete (ERDOĞDU, 2005).
Kirca et al. (2002) investigated concrete with strength values of 25.0 and 35.0 MPa and found significant slump losses when mixing periods increased, with greater losses reported for concrete compositions with higher cement consumption because of its hydration process. An increase in compressive strength was observed when mixing times were extended and no retempering was used. However, to make placement easier and allow suitable finishing operations, slump losses are often corrected by adding water. Teixeira and Pelisser (2007) carried out a study in a mixing plant using a concrete composition with a predefined strength of 20.0 MPa. They measured strength losses after retempering and found a reduction of 34% in strength after 2.5 hours and of 44% after 4 hours. Erdoğdu (2005) also observed this drop in compressive strength after retempering was used in concrete compositions that had been mixed for up to 150 minutes and in which water was added at 30-minute intervals to restore slump values. The drop is dramatic in the first 90 minutes of mixing, and then slows down afterwards. After 150 minutes of mixing, the loss of strength is greater than 40% when compared to initial values. The practice of retempering should be abandoned as superplasticizers provide a useful alternative that will not affect the other properties of concrete.
Admixtures generate chemical interactions with the binders in the concrete, thus affecting its performance both in the fresh and the hardened state. They may be used to improve the workability of the fresh mix or the strength and durability of hardened concrete. Superplasticizers are a more useful alternative to other chemical substances because of the range of improvements that can be achieved from their use (COLLERPADI, 2005).
Kirca et al. (2002) attempted to simulate the reality of a construction site, where ready-mixed concrete is used and transported in mixer trucks. Concrete mixes with two different compressive strength levels were prepared in a laboratory and kept under prolonged mixing for up to 4 hours, with samples analyzed every hour. The initial slump of 150 mm was restored at specific intervals by means of four different processes: adding water only, and adding water with three different superplasticizer concentrations (1.5%, 3.0% and 4.5% by weight of water). The addition of a superplasticizer meant that less amount of water was required to restore slump values. Therefore, the final w/c ratios of the mixes with the superplasticizer admixture are lower than when only water was used. Consequently, the reduction in compressive strength in concrete where slump was restored with the aid of a superplasticizer is smaller than the one observed when plain water is used. In fact, in some cases minor increases in compressive strength were observed in concrete adjusted with superplasticizer (particularly in concentrations of 4.5%).
Erdoğdu (2005) found an increase in compressive strength in concrete that was mixed for 150 minutes and whose slump was maintained with the addition of a superplasticizer at 30-minute intervals. An increase of 30% in compressive strength was observed after 90 minutes of mixing and of 10% when compared with the reference sample, which was mixed for 150 minutes.
Superplasticizers offer a good choice to improve concrete properties, particularly when slump values need to be maintained over time. They could be used alongside retempering, if necessary. In real life, situations arise when it is necessary to restore slump values. However, when water is used concrete properties are affected, as several studies attest. Therefore, the use of a superplasticizer is a sound alternative.

1.2 Research significance

Brazilian standard NBR 7212 specifies a total time limit for mixing, transporting and unloading concrete. In practice, it is often the case that mixer trucks may have to hold their concrete load for 4 or 5 hours because of delays in transportation or unloading, which means that the time limits specified by the standard are exceeded. In such cases, two situations arise:

a) The concrete is accepted by the site engineer for the simple reason that no changes in concrete temperature are noticed, in which case it is likely that slump values will be corrected by adding water. This, in turn, will affect w/c ratios and the mechanical properties and durability of concrete, rendering this approach unacceptable;
b) The concrete is returned to the mixing plant, which must find a destination for this rejected concrete. This creates other problems given that this concrete reject poses an environmental hazard. The problem is compounded by the large volumes involved and the financial losses incurred.

Faced with these choices, users need to decide whether to use concrete in these conditions. This is a serious issue as there is no conventional wisdom regarding the final properties of concrete that is placed after the time limit specified by the standard. For this reason, and also because of the lack of data and studies that analyze the time limit for mixing and transporting concrete, it is imperative to advance and further expand scientific knowledge on the impact of mixing times on the properties of concrete mixes that are used when the time specified by the standard is exceeded.

This aim of this study was to assess the compressive strength properties of concrete that is used when the time limit of 150 minutes for mixing and transporting after the first contact of cement with water, as specified in Brazilian Standard NBR 7212, is exceeded and concrete slump is maintained by adding a polycarboxylate-based superplasticizer.

2. Materials and test program

The selection and choice of the materials used in the research took into account the reality of concrete mixing plants in the city of Porto Alegre and surrounding areas area. All materials were assayed in the laboratories of the Science and Technology Foundation of Rio Grande do Sul (CIENTEC).

2.1 Materials

2.1.1 Cement

This study used blended Portland cement (CP II Z 32). Its properties are shown in Table 1.

2.1.2 Fine aggregate

Quartz sand was used a fine aggregate, quarried from a local river with specific mass of 2.62 kg/dm³ according to Brazilian Standard NBR NM 45 (2006), maximum nominal size of 4.75 mm and fineness modulus of 2.54 according to Brazilian Standard NBR NM 248 (2003).

2.1.3 Coarse aggregate

Two types of coarse aggregates of basaltic origin were used, identified as crushed aggregate #1 and crushed aggregate #0, with maximum nominal size of 19mm and 9.5mm and fineness modulus of 6.82 and 5.70, respectively, according to Brazilian Standard NBR NM 248 (2003). Specific masses were determined according to Brazilian Standard NBR NM 45 (2006), with 2.80 kg/dm³ for crushed aggregate #1 and 2.82 kg/dm³ for crushed aggregate #0.

2.1.4 Water and admixture

Mains water from the city of Porto Alegre was used. The admixtures used in this research were a standard plasticizer, designed for concrete production, with mean density of 1.05 g/cm³ (manufacturer's data) and a polycarboxylate-based superplasticizer used to correct slump, with mean density of 1.08 g/cm³, both with normal setting times.

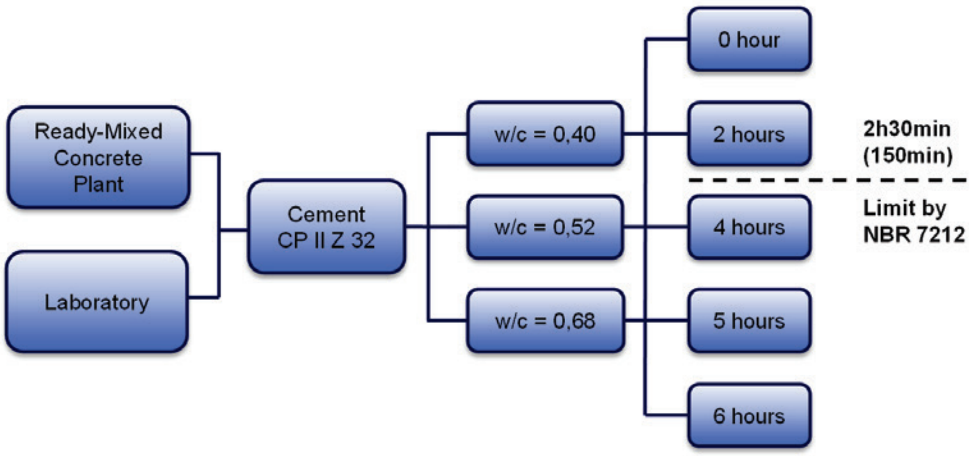
2.2 Test Program

Three w/c ratios and five mixing periods were used as control variables in this study. Concrete mixes were prepared in a laboratory

Table 1 – Characteristics of Portland cement compost used

Characteristics and properties	Manufacturer information	Values obtained	Specifications by NBR 11578 (ABNT, 1991)
CaO	1,44	–	–
MgO	6,01	–	≤ 6,5
SO_3	2,90	–	≤ 4,0
Loss on ignition	4,98	–	≤ 6,5
Specific surface - blaine (cm^2/g)	4763	4310	≥ 2600
Specific mass (kg/dm^3)	3,02	2,96	–
Fineness on sieve nº 200	0,9%	0,4%	≤ 12,0
Initial setting time (min)	184	185	≥ 60
Final setting time (min)	262	235	≤ 600
Compressive strength (MPa) 3 days	27,6	27,2	≥ 10,0
Compressive strength (MPa) 7 days	33,2	31,0	≥ 20,0
Compressive strength (MPa) 28 days	41,1	43,6	≥ 32,0

Figure 1 – Combinations between the controllable variables of research

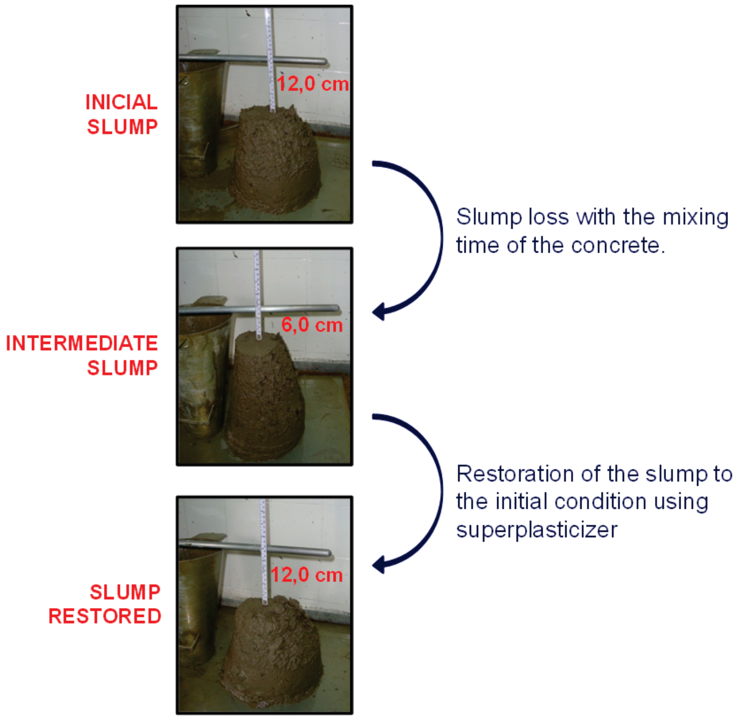


and in real life conditions in a ready-mixed concrete plant for all control variables selected, resulting in a total of 30 compositions, as shown in figure 1.
The cement type used is readily available from mixing plants in the city of Porto Alegre and surrounding areas, which includes the plant in which the laboratory tests were reproduced in real life production. The three w/c ratios used were selected because they correspond to different cement consumption thresholds and therefore provide a better assessment of compressive strength behavior in three different levels. As it was necessary reproduce the test results in real life conditions, the concentrations used followed the patterns used at the mixing plant (table 2), characterized by the amounts of cement, natural sand, crushed aggregate #0, crushed aggregate #1, water and superplasticizer admixture. The coarse aggregate consists of 85% crushed aggregate 19mm and 15% crushed aggregate 9.5mm. The concentration of superplasticizer was 0.6% by weight of cement and slump was set at 120±20mm.
Tests were carried out in freshly mixed concrete, after 6 hours of mixing and at intervals in between these limits to provide a better picture of concrete strength behavior. Two-hour intervals were used. The test program allowed a fifth sample to be tested so an interval of 5 hours of mixing was used (instead of 3 hours, which was another possible sampling interval) as it was felt that longer mixing times might result in more dramatic changes in concrete properties.
Concrete slump was measured according to Brazilian standard NBR NM 67 (1998) to determine fresh concrete workability. The test program attempted to maintain the workability of concrete by adding a polycarboxylate superplasticizer at specific intervals along a period of 6 hours after concrete mixing started, which is when cement particles first come into contact with water.
In laboratory conditions, the materials were mixed for five minutes to ensure materials were thoroughly mixed before measuring concrete workability. Slump was then measured at the intervals of 120 min (2h), 180 min (3h), 240 min (4h), 300 min (5h) and 360 min (6h) along rest (15 minutes) and agitation cycles (5 minutes). After each measurement, the superplasticizer was added to restore slump to its original value (120±20 mm) and test specimens (TS) were cast for each time interval. It should be noted that the time intervals for the slump test checks in the mixer trucks are slightly different from the intervals used in the laboratory mixer. This was necessary because the drums in mixer trucks must be kept revolving. In order to simulate real life construction site conditions, the drum was kept at 2 rpm during the rest intervals. Just before measuring slump, drum speed was increased to 16 rpm. The process of restoring slump can be seen in figure 2.

Table 2 – Dosages of the concretes used in this study

Mix proportion 1 : m	Unit mix proportion, in mass	Amount of materials per m^3(kg)				Mortar level (%)	w/c ratio
		Cement	Fine aggregate	Coarse aggregate	Water		
1 : 3,2	1 : 1,28 : 1,95	514	660	1000	206	54	0,40
1 : 4,5	1 : 1,97 : 2,53	395	776	997	205	54	0,52
1 : 6,2	1 : 2,90 : 3,32	300	869	996	204	54	0,68

Figure 2 – Checking the slump and restoration to the initial condition (120±20mm) by incorporating superplasticizer to the mixture during a period of 6 hours



After casting, TS were stored and sheltered with a plastic liner for the first 24 hours to prevent water loss by evaporation. They were then removed from the molds and labeled. After labeling they were placed in a tank with saturated lime water at 23±2ºC and cured in a controlled temperature chamber at the NORIE/UFRGS laboratory until the test age, 28 days, was reached, as specified by Brazilian Standard NBR 5738 (2003).

Compressive strength, the most important property of concrete, was measured at 28 days, according to Brazilian Standard NBR 5739 (2007). A total of 15 TS were cast for each composition (three TS for each mixing interval). The surface of the TS is ground one day before the compressive strength test to ensure the planeness and perpendicularity of test surfaces. Compressive strength tests were performed in a servo controlled Shimadzu press of 2.000 kN at a compressive speed of 0.45 MPa/s, which was kept constant through the test.

Figure 3 – Average results of compressive strength at 28 days of concrete produced in laboratory

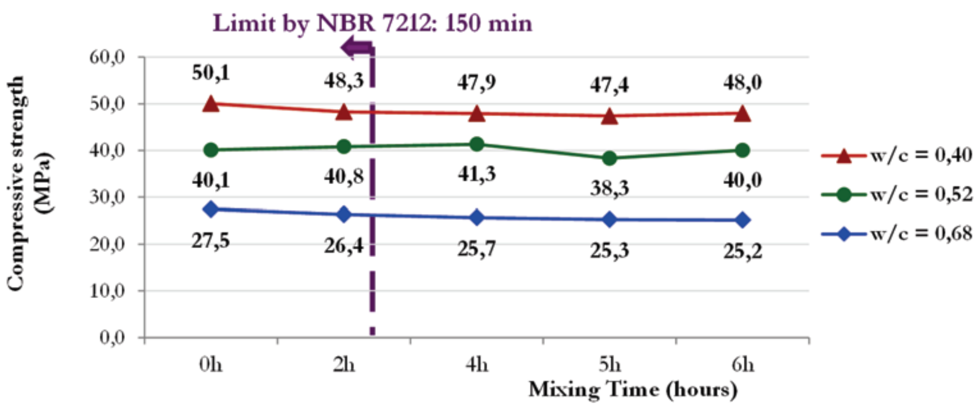
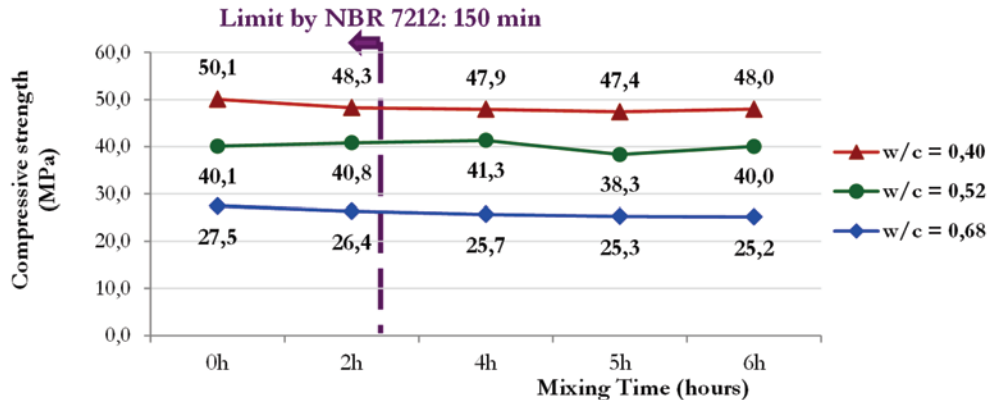


Figure 4 – Average results of compressive strength at 28 days of concrete produced in ready-mixed concrete plant



3. Results and discussion

3.1 Compressive strength

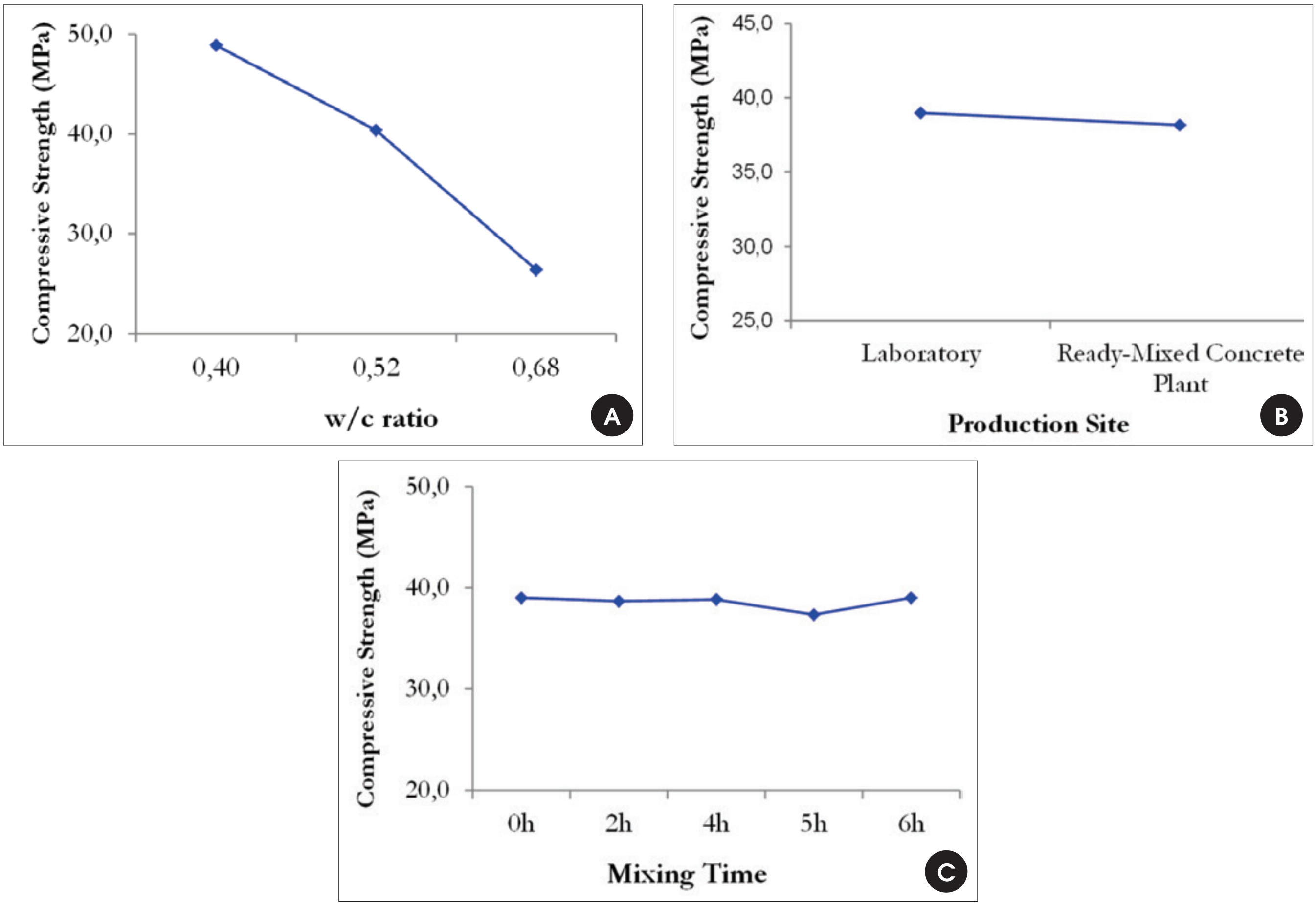
Polesello (2012) recorded all individual results for compressive strength as well as standard deviation values and their corresponding coefficients of variance. Figures 3 and 4 illustrate the mean values of compressive strength for concrete sampled in the laboratory and in the mixing plant, respectively.
Results show that even when a concrete sample is mixed for a period of up to 6 hours, using a superplasticizer as described in this study, its mean compressive strength value at 28 days is maintained. To check for the influence of w/c ratios, production site and mixing periods, as well as for interactions of these variables on the results, individual values were checked using analysis of variance (ANOVA). The results of this analysis are shown in table 3.
ANOVA results show a statistically significant influence for the three control variables (w/c ratio, production site and mixing time) on compressive strength at 28 days. The isolated behavior of each of these variables is shown in figure 5.
Figure 5a presents the effect of the w/c ratio in isolation. It shows that compressive strength values decrease as the w/c ratios increase, a confirmation of conventional wisdom in the technical field. Mixing times display a significant effect as illustrated in figure 5c. The mean results in the 5-hour interval show a slight drop in compressive strength followed by an increase. After 6 hours, compressive strength was identical to the one in freshly mixed concrete. With reference to the statistical significance of the production site factor, this could be explained by the fact that the volume of concrete mixed in real-life conditions is much larger than in a laboratory, which results in differences in evaporation and mixing processes.
The fact that the mean compressive strength at 28 days was maintained in concrete mixed for a period of 6 hours could be explained by the loss of water to the environment, which would cause w/c ratios in the mixture to drop. Kirca et al (2002) recorded this loss of water in their study, and found an increase in compressive strength in two concrete compositions of different classes, C25 and C35,

Table 3 – ANOVA results for compressive strength at 28 days

Font	SQ	GDL	MQ	Test F	Prob.	Significance
A: w/c ratio	7745,70	2	3872,85	1333,10	0,00%	S
B: production site	15,08	1	15,08	5,19	2,51%	S
C: mixing time	36,01	4	9,00	3,10	1,95%	S
AB	1,34	2	0,67	0,23	79,41%	NS
AC	29,29	8	3,66	1,26	27,45%	NS
BC	21,60	4	5,40	1,86	12,48%	NS
ABC	8,76	8	1,10	0,38	93,03%	NS
Error	174,31	60	2,91	–	–	–
Total	**8032,08**	**89**	–	–	–	–

SQ - sum square; GDL - degree of freedom; MQ - averae square; Test F - calculated value of F.; Prob. - significance level associated with the calculated value of F.; S - significant; NS - not significant.

Figure 5 – Behavior of concrete produced with CPII on the compressive strength at 28 days due: (a) w / c ratio, (b) production site, (c) mixing time

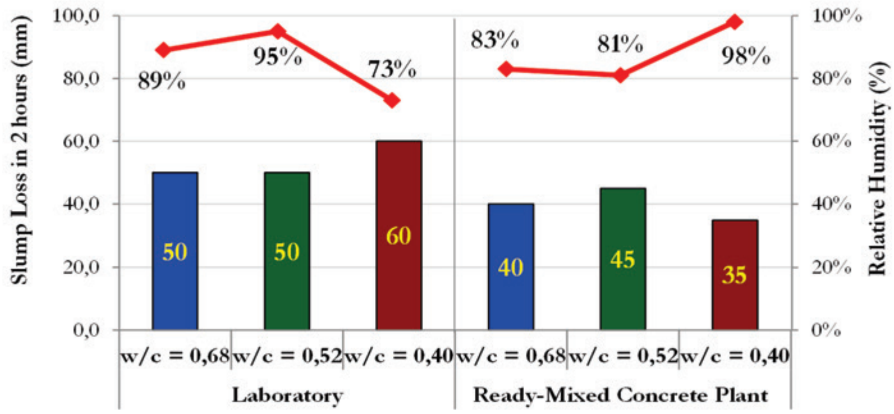


when kept in prolonged mixing for 4 hours. According to these researchers strength at 28 days increased by 15% and 27%, respectively. Alhozaimy (2007) investigated real- life conditions in the delivery of ready-mixed concrete and also observed that the fall in slump values observed between the arrival of the mixer truck at the construction site and midway through the unloading operation was accompanied by a small increase in strength when no retempering was used. In the studies of Erdoğdu,(2005), there was an increase in compressive strength of 15% at 28 days for concrete mixed for 150 minutes with no retempering. When a superplasticizer was used to correct slump values, according to the methodology used in the present study but for shorter intervals, of up to 150 minutes, increases in compressive strength slightly greater than 10% at 90 minutes and approximately 8% at the end of 150 minutes were

Table 4 – Slumps, environmental conditions and slump loss during 2h

Production site	w/c	Slump (mm)		Temp. (°C)	Relative humidity (%)	Loss (mm)
		Initial	Final			
Laboratory	w/c = 0,68	120	70	18,0	89%	50
	w/c = 0,52	140	90	18,3	95%	50
	w/c = 0,40	130	70	17,9	73%	60
Ready-mixed concrete plant	w/c = 0,68	120	80	13,7	83%	40
	w/c = 0,52	125	80	15,8	81%	45
	w/c = 0,40	120	85	14,6	98%	35

Figure 6 – Slump loss in 2 hours with the registry of relative humidity



recorded. A possible reason for this behavior (i.e. maintenance or increase in compressive strength) may be the continuous agitation of concrete during the hydration phase, which may cause the initial hydration products (larger and more fragile) to break down.

3.2 Slump loss and superplasticizer consumption

Slump loss in concrete occurs at a specific rate that is affected mainly by time, temperature, concrete composition and the type of additions used (MEHTA; MONTEIRO, 2008). Table 4 lists initial slump values and their respective decrease over a period of 2 hours, when no superplasticizer was added, alongside concrete production conditions. The loss recorded in the first two hours can be better seen in figure 6.

As expected, for lower w/c ratios and therefore greater cement consumption, a greater decrease in slump is observed. In situations when this decrease was the same or smaller, for different w/c ratios, the influence of relative humidity on slump loss is noticeable, as shown in figure 6.

After 2 hours of mixing, the superplasticizer was added to the mix at the intervals specified above to restore slump to its initial value. The slump measured at each time as well as increases resulting from the addition of the superplasticizer for the laboratory samples and the mixing plant can be seen in figures 7 and 8, respectively.

Slump behavior along the mixing interval was similar at both production sites. However, in laboratory conditions, final slump values show smaller differences, because it is easier to visualize the concrete in the mixer at the moment of adding the superplasticizer. It is also noticeable that slump losses tend to increase as longer mixing periods are used. This happens because at the end of the test, slump is more affected by the addition and less by the water content.

The concentrations of superplasticizer used (by weight of cement) to correct slump values along the test period of 6 hours are shown in figures 9 and 10. It should be remembered that the use of additions such as plasticizers or superplasticizers can affect setting times.

More superplasticizer was needed to restore slump to its initial val-

Figure 7 – Slump and increase in slump by the addition of the superplasticizer for concrete produced in the laboratory, during the 6 hours of mixing

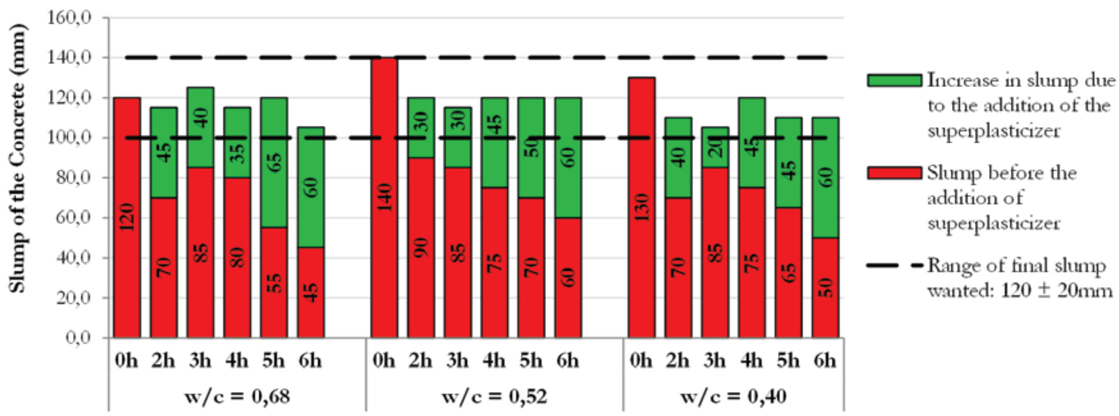
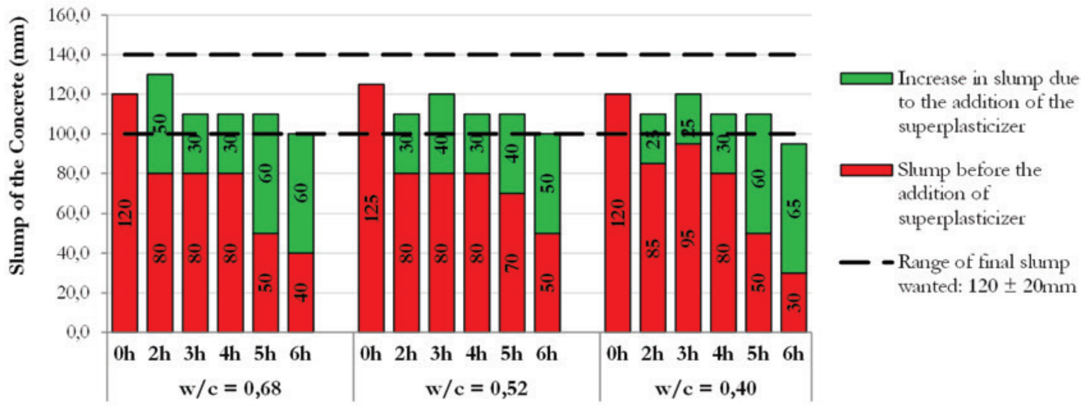


Figure 8 – Slump and increase in slump by the addition of the superplasticizer for concrete produced in the ready-mixed concrete plant, during the 6 hours of mixing



ue in the concrete prepared in the mixing plant, which also tends to require higher concentrations of admixture as mixing times increased. The total concentration of superplasticizer used until the time limit of 6 hours in both test settings fell within the limits specified by the manufacturer for this addition (between 0.2% to 1.0%).

4. Conclusions

The results for the tests with ready-mixed concrete and in laboratory conditions indicate that, for the methods and materials in this test, it is possible to use concrete that has been mixed for periods that

Figure 9 – Percentages of admixtures used in concrete produced in the laboratory

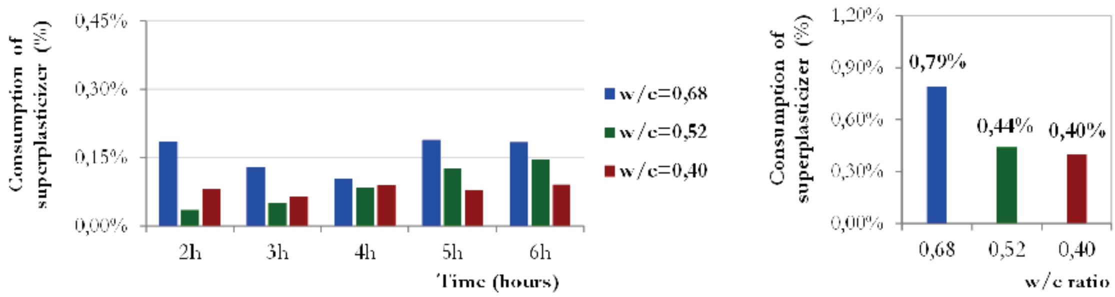
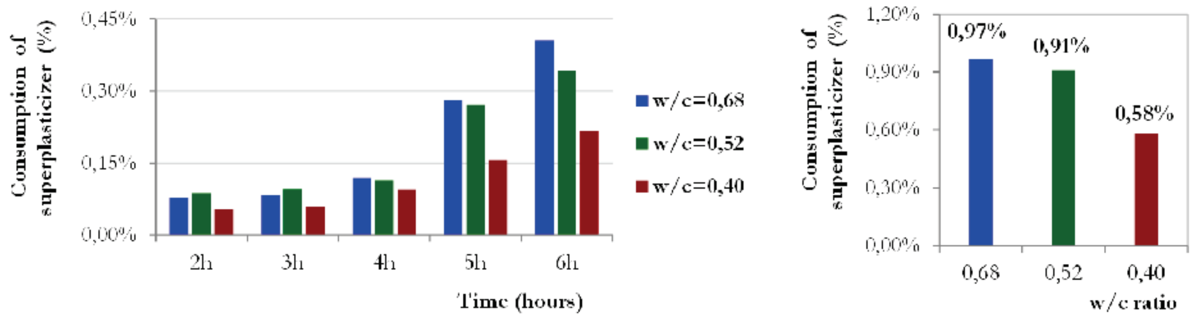


Figure 10 – Percentages of admixtures used in concrete produced in the ready-mixed concrete plant



exceed the time limits specified by Brazilian Standard NBR 7212, as long as that the concrete workability is maintained by adding a superplasticizer under constant agitation and no water is added until concrete placement. Further studies with other concrete types and mixing temperatures, among other variables, can be performed to consolidate the procedures used in this test and contribute significantly with decisions made in real life conditions regarding the possibility of accepting or rejecting concrete shipments when mixing and transportation periods do not comply with the standard.

5. Acknowledgements

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