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Ready mixed concrete: variability analysis of the compressive strength and physical properties along the unloading of the truck mixer

Concreto usinado: análise da variação da resistência à compressão e de propriedades físicas ao longo da descarga do caminhão betoneira

R. MASCOLO [a]
rafaelmascolo@yahoo.com.br

A. B. MASUERO [b]
angela.masuero@ufrgs.br

D. C. C. DAL MOLIN [c]
dmolin@ufrgs.br

Abstract

The common practice, in construction sites of the region of Porto Alegre, to collect samples for testing, of the first portion of the concrete discharged from the truck mixer, and the lack of standardization to measure the quality of the mixer and uniformity of mixing and the importance of quality control testing of concrete, this paper aims to examine the uniformity of ready mixed concrete. To achieve the aim was collected samples at five different points along the discharge of ready mixed concrete, for 13 lots of conventional concrete. There was not the formation of a representative profile of compressive resistance as the different collection point and there was not significant variation between the collection points.

Keywords: ready mixed concrete; truck mixer.

Resumo

Visto a prática comum nos canteiros de obra da região de Porto Alegre, de coleta de amostras, para fins de ensaio e moldagem dos corpos-de-prova, logo da primeira porção do concreto descarregado do caminhão betoneira, somada à inexistência de normatização para aferição da qualidade do misturador e uniformidade da mistura e a importância dos ensaios de controle de qualidade dos concretos. O presente trabalho tem como meta analisar a uniformidade de misturas de concreto em caminhão betoneira. A fim de atingir os objetivos realizaram-se coletas de amostras em cinco pontos distintos, ao longo da descarga do concreto do caminhão betoneira, para 13 lotes (amassadas) de concreto convencional. Não houve a formação de um perfil representativo das variações de resistência conforme o ponto de coleta e não foi constatada variação significativa entre pontos de coleta.

Palavras-chave: concreto usinado; caminhão betoneira

[a] *Universidade Federal do Rio Grande do Sul – Programa de pós-graduação em Engenharia Civil, rafaelmascolo@yahoo.com.br, Osvaldo Aranha, 99 – Prédio Castelinho, Porto Alegre/RS, Brasil;*
[b] *Universidade Federal do Rio Grande do Sul – Programa de pós-graduação em Engenharia Civil, angela.masuero@ufrgs.br, Osvaldo Aranha, 99 – Prédio Castelinho, Porto Alegre/RS, Brasil;*
[c] *Universidade Federal do Rio Grande do Sul – Programa de pós-graduação em Engenharia Civil, dmolin@ufrgs.br, Osvaldo Aranha, 99 – Prédio Castelinho, Porto Alegre/RS, Brasil.*

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1. Introduction

The concrete is considered one of the most important materials in modern construction, besides also is the material more produced in world in terms of volume. Such relevance achieved by this compound is, basically, due to excellent water resistance, ease of use with diversity of shapes and sizes, low cost, worldwide availability (MEHTA e MONTEIRO [1]), and their potential of use, which has been expanded over the years, with technological development.

Another factor that contributed to the increasing use of concrete in the world market, beyond technological development, was the rationalization of the production process, which created an industry with the concrete batching plants. From this industrialization may result reduced costs and increment of production capacity, while maintaining the performance and quality required of concrete. Today, in major cities worldwide, most of the concrete used is produced at concrete batching plants[1] and the trend is that this process becomes increasingly prevalent, especially in developing countries like Brazil, seen their advantages compared to the production at construction site.

The ready mix concrete can be mixed in the plant itself and transported with truck agitator or mixed during transport by truck mixer, being the latter predominant in the country (Brazil). Such choice is probably due to cost savings in the deployment of concrete batching plant, without stationary concrete mixer (fixed site), increase in term and distance of transport, and especially the type of taxation[2]. However, as Mehta and Monteiro [1], the quality control of concrete mixed in truck mixer is not as good as the one produced in stationary mixer.

The growing use of concrete, added with the pressure of civil construction market by reducing costs while maintaining the minimum requirements for project safety, increased the importance and necessity of technological control of the material. The parameter usually adopted as the standard for verifying compliance with the minimum requirements of the project is the compressive strength of concrete, since the property is easily to measure, it is able to expose the changes in the quality of the concrete and is related to several other properties of the material (NEVILLE [7]; HELENE e TERZIAN [8]).

The control of mechanical properties is performed in a standard specimen, molded and cured according to standard prescriptions, and the strength testing realized, usually, at 28 days old of concrete. For purposes of acceptance, from as the result is verified compliance with the requirements of project resistance and safety of the structure built.

The specimens should be molded with concrete samples collected during discharge from truck mixer, according to the prescriptions of NBR 7212 [9] and NBR NM 33 [10], which recommend not using, for testing purposes, the 15 % initial and final from total volume of the concrete mixer. However, the current practice in most construction sites, the sample is collected immediately from the first portion of concrete discharged. Such procedure is due to the difficulty in collect the concrete during the discharge, often in areas of difficult access, and the ease and speed that you have to collect a single sample for slump test and molding of specimens for compressive strength test in an accessible place. The NBR 7212 [9] define a concrete batch of the same mixture as homogeneous for purposes of testing and control without, however, specifying parameters and tests to ensure the efficiency of the mixer as their primary function: produce a uniform mixture of concrete. Furthermore, it is known that concrete mixers have wear of its components, according to the use and therefore, may lose efficiency so as not satisfactorily perform its function. Countries like the U.S. and England have norms with guidelines for assessing the performance of mixers, such as ASTM C94/C94M [11] and BS 3963 [12], among others, which limits the variability of the mixture and ensures uniformity of concretes produced.

The NBR 12655 [13] recommends doing a uniformity test of mixtures in concrete mixers, when show up signs of heterogeneity of compositional or consistency during discharge, but does not provide more detailed information. Already ABECE [14] makes a recommendation a little more complete, indicating regular quality control of concrete mixers by comparing resistances between three different collection points: the first shortly after discharge 15% of the total volume, intermediate in the middle of the discharge, and the last one shortly after discharge 85% of the total volume. As control we have that the difference between the highest and lowest resistance of the first and last point should not differ more than 15% of the resistance of the intermediate point.

In the country there is not specific normalization for assess and control the quality of mixers, so there is not guarantee of representativeness of samples of concrete, even if collected between discharge 15% and 85% of total volume of batch, as recommended. This lack of guarantees for uniformity of ready mix concrete, and the common practice of collecting samples outside the recommended standards, can affect the credibility of quality control, creating uncertainties about tests of lots and up to the safety of structures.

Since the common practice of collecting samples differ from the norm, the lack of recommendations for measuring the quality of the mixer and the importance of quality control testing of concrete to certify the safety of structures, this study aims to analyze the uniformity of concrete mixtures in concrete mixer truck, during unloading the material, to determine if there is significant variation in

[1] At developed countries like USA and Japan, 75 and 71%, respectively, of the consumption of cement are used by ready mixed concrete, and in European countries like Germany, England and France this percentage is above 50% (NRMCA [2]; ERMCO [3]). At Brazil, the current consumption of cement is still sprayed with 55% of sales to small consumers and only 18% for the production of ready mixed concrete. However it is clear that cement consumption by concrete batching plants is growing in the country since 2006, when only 13% of cement consumption were intended for ready mixed concrete (SNIC, [4]).

[2] Mixing the constituents of concrete (cement, aggregates, water and eventually additives and additions) in truck mixer along the path between the plant and the local of service delivery (construction site), concreting companies are classified as service providers and thus subject only to the ISS (Service Tax), while the mixture in stationary mixer equipment at concrete batching plant, ie, off-site service delivery, the ready mix concrete shall be classified as a commodity and then there incidence ICMS (Tax on Circulation of Goods and Services). For companies concreting the ISS rate in the city of Porto Alegre is 4% of the value of the invoice, while the ICMS is 17% (state tax-rate basis for the Rio Grande do Sul), which explains the preference of concrete companies (BRASIL - Lei complementas n 116 [5]; SEFAZ-RS [6].

the compressive strength and physical properties. The topic of this research contributes to studies on quality control of concrete and shows the necessity for complementation in current normalization, in order to improve confidence about the quality and safety of concrete structures.

2. Materials and experimental program

To analyze the uniformity of ready-mix-concrete was defined the variables of response to the research as the compressive strength, slump test and coarse aggregate content. Was defined as controllable variable, five sampling points along the discharge from the concrete mixer truck, and was used conventional concrete to the research.

Due the proposed of research, which aims to analyze mixtures of ready-mix-concrete made in a mixer truck, the collection of samples was made outside the laboratory environment, with vehicles in normal service, so we did not have control over weather aspects, such as temperature and relative humidity, and about mixing time and speed of the mixer.

The concrete used in research was specified with resistance to 35MPa to 28 days, slump test of 120±20mm and coarse aggregate with D_{max}: 9.5mm. The concrete recipe provided by concrete batch plant on invoice to 8m³ was: CPV-ARI RS - 2600kg, POZZOLAN - 468kg, FINE SAND - 1472kg, MEDIUM SAND - 4552kg, COARSE AGGREGATE 0 - 8648kg, WATER - 1520l, ADDITIVE - 26kg. In unit proportion in order cement, sand, gravel and w / c ratio, the recipe is: 1:1.964:2.819:0.495.

Table 1 – Data of slump test, compressive strength and coarse aggregate content

Collection point	Sample	Slump (cm)	Coarse aggregate (%)	S1 (MPa)	S2 (MPa)	S3 (MPa)	Sample	Slump (cm)	Coarse aggregate (%)	S1 (MPa)	S2 (MPa)	S3 (MPa)
1-initial		14,5	50,4%	47,79	47,21	47,18		17,0	44,3%	45,27	44,8	44,12
2-initial third		14,0	47,9%	49,38	49,25	47,18		16,5	42,5%	44,89	44,78	43,25
3-middle third	A1	13,5	48,9%	47,94	47,82	47,79	A2	15,5	41,6%	44,25	43,73	42,17
4-final third		13,0	48,3%	49,37	48,28	47,29		16,5	43,7%	43,66	43,44	41,09
5-final		12,0	49,3%	48,06	47,91	46,58		16,5	40,7%	44,94	44,59	42,72
1-initial		13,0	36,6%	53,18	52,54	51,97		13,0	37,9%	49,35	47,43	45,56
2-initial third		13,5	39,5%	51,81	51,78	51,23		12,5	34,3%	51,74	51,14	49,56
3-middle third	A3	11,5	39,3%	53,38	52,43	51,91	A4	11,5	35,6%	50,64	49,15	43,67
4-final third		12,0	38,4%	52,91	52,43	51,49		11,5	35,5%	50,81	49,54	45,82
5-final		11,5	38,5%	53,23	53,16	52,9		10,0	38,2%	52,18	51,64	50,37
1-initial		12,5	43,7%	50,3	48,54	45,93		12,5	46,0%	48,802	46,905	44,835
2-initial third		9,5	40,8%	54,16	52,31	52,09		14,5	45,4%	48,56	46,02	45,71
3-middle third	A5	9,5	44,9%	54,36	53,60	47,00	A6	11,0	45,6%	47,57	47,32	46,51
4-final third		9,5	41,2%	54,67	54,56	53,23		9,5	44,9%	51,19	50,97	48,51
5-final		8,5	43,5%	52,23	50,86	50,34		10,5	42,0%	50,82	48,09	45,16
1-initial		8,5	45,3%	54,77	51,50	50,14		17,5	40,9%	49,36	46,29	45,81
2-initial third		8,5	43,2%	56,56	55,50	51,22		17,0	38,3%	49,74	49,59	48,66
3-middle third	A7	8,5	42,7%	55,61	54,76	54,57	A8	16,5	39,9%	47,71	47,64	47,47
4-final third		8,0	42,6%	53,24	53,09	50,97		15,5	40,5%	49,46	48,43	45,68
5-final		7,0	44,4%	56,28	53,98	51,07		13,5	44,0%	48,92	48,49	47,65
1-initial		11,0	43,3%	48,69	47,36	47,17		8,5	44,7%	39,12	38,75	38,33
2-initial third		12,5	41,6%	47,26	46,22	45,98		11,5	43,2%	35,49	35,35	35,26
3-middle third	A9	12,0	41,7%	46,54	44,99	44,51	A10	11,0	43,5%	35,73	35,14	33,03
4-final third		10,5	41,8%	46,46	45,02	44,83		11,0	43,8%	36,9	35,87	35,26
5-final		10,0	44,6%	47,47	46,97	46,64		8,5	45,6%	35,68	35,39	34,69
1-initial		15,5	38,7%	46,97	45,35	42,53		11,0	37,0%	53,35	51,67	50,23
2-initial third		15,0	37,8%	46,88	45,57	44,69		10,5	35,0%	53,65	52,44	50,17
3-middle third	A11	14,0	37,0%	47,81	45,96	45,40	A12	11,0	36,5%	52,36	51,32	51,32
4-final third		12,0	38,7%	48,50	48,21	47,72		12,0	34,2%	51,81	50,89	50,78
5-final		12,0	42,4%	48,04	47,09	46,84		12,0	37,4%	51,65	50,19	49,14
1-initial		13,0	45,2%	45,02	43,75	43,37						
2-initial third		13,0	44,2%	44,55	44,05	43,69						
3-middle third	A13	12,0	43,5%	43,95	43,74	42,7						
4-final third		12,0	40,6%	44,63	43,09	42,62						
5-final		9,5	43,0%	45,78	44,88	43,98						

To each of 5 sampling points per batch were performed: (1) slump test according to the specifications of NBR NM 67 [15], (2) compression test-axial of specimens, following the requirements of NBR 5738 [16] and NBR 5739 [17] and (3) determine the coarse aggregate content as recommended by the ASTM C94/C94M [11].
Whereas the main goal of the research is to check the variability of the compressive strength and physical properties of ready-mix-concrete within the same batch, has been in the collection of samples from several batches one of the fundamental stage for the development of research. In research, each batch is defined as the volume of concrete of the same mixture, so each lots has between 7 and 8 m³, which is the maximum capacity of the truck mixers used in the region.
For the tests were taken five samples of fresh concrete in each of the thirteen lots: one at the beginning of unloading (point 1), another during the initial third (point 2), the third in the middle third (point 3), the penultimate in the final third (point 4) and the last one near the end of the discharge (point 5). In percentage terms, the sampling points described above were collected, approximately, after unload of 5%, 25%, 50%, 75% and 95% of the total volume of the truck mixer.
During discharge of the concrete had not precisely the real volume unloaded, then the points were determined from the experience of the person responsible for the operation of sampling, so the actual collection points vary around the percentages cited before.
The sample collection of concrete was made at construction site, directly at the point of discharge into 20l pails, without interrupting the flow of material discharge. A shovel was used to assist in the collection due to the impossibility of moving the chute of discharge. As soon as the end of the sampling collection, samples, properly stored, covered and identified, were sent to the test site, molding and preparation of the samples, inside the construction site. Initially, in the first portion collected from the point in question, was realized slump test, casting the specimens and preparation of samples for subsequent wash off the construction site. The same procedures occurred for the portions of the following points, obeying the order of collection. Thus, the starting point was tested first, followed by the second, third, fourth, and last one, which consequently remained a longer stored.
Each sample of a representative point consisted of three specimens, i.e. one more than recommended by the NBR 12655 [13], and usually performed in quality control. This choice of the number of specimens was adopted to obtain greater security for the results and to evaluate the uniformity and efficiency of operations and test control.
To determine coarse aggregate content, was separated a sample by point, with volume around 2l, from the main sample of 20l, which was added concrete retarder in order that the mixture keep fresh state for a long period until transportation to the laboratory.
The wash of fresh concrete samples, to determine the coarse aggregate content was performed at laboratory because of the need of precision balance, usually not available in a site construction. For determination of coarse aggregate content, the sample was weighed and then forwarded to wash with water under 4.8 mm mesh sieve. After the material retained in the sieve remained until losing all excess water and subsequently was weighted, as recommended by ASTM C94/C94M [11].
The casting of the cylindrical specimens was performed using manual density with a metal rod, as recommended by the NBR 5738 [16]. The specimens remained for a period of 24 hours on construction site, protected from direct exposure to sunlight, and then were transported to the laboratory, where they were demolded and identified. After these steps the specimens were sent to submerge curing in water saturated with lime, in a wet room with a temperature of 23 ± 2 ° C.
One day prior of rupture, the specimens were removed from the cure for base preparation previous the compression test. The specimens from the same batch were always demolded, placed and removed from curing, prepared for testing of compressive strength, and tested in short periods of time to reduce any possible influence of other factors.

3. Results and discussions

Table 1 shows the slump test results, compressive strength and coarse aggregate content for each of the five points analyzed in each of the thirteen batches of ready mixed concreto. Figure 1 shows the variation of the compressive strength, where each row of dots represents the results of the three specimens that compose the five samples from each batch, being the upper and lower ends, higher and lower resistance, respectively, and at the midpoint the intermediate value of three brothers specimens. The batch lowest average value got 36.7 MPa, while the higher 55.3 MPa, which represents an amplitude of 18.6 MPa, a value of the same order of size as found in other studies of the kind such as Borges [18], wherein the resistance variation for a 30 MPa concrete, mixed in a mixer truck, was 19.2 MPa.
To facilitate understanding of data, is showed the figures 2 to 4, with the results of compressive strength, slump test and coarse aggregate content, for each of five sampling points of the batches tested.
In Figures 2-4, the results of slump test are presented in unit of “cm”, and their possible variation, as the limits of the slump test, from 0 to 30cm. About the results of the compressive strength, was used the highest value among the three specimens that composing each sample, i.e. each point is represented by resistance potential. For data compression strength and coarse aggregate content is adopted, for each batch, the third sampling point collected from the

Figure 1 – Compressive strength of specimens

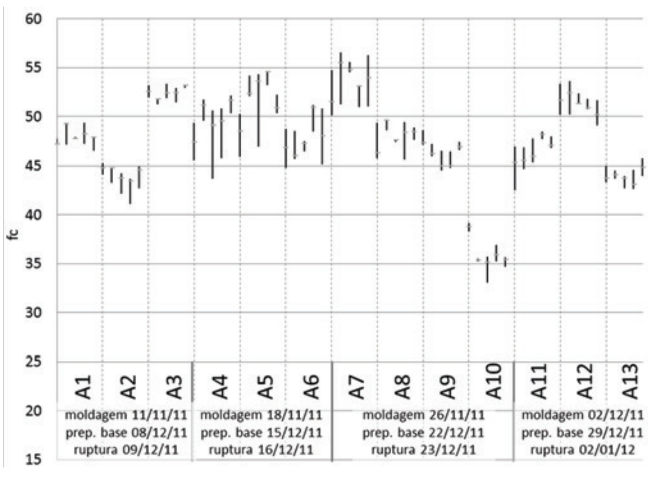
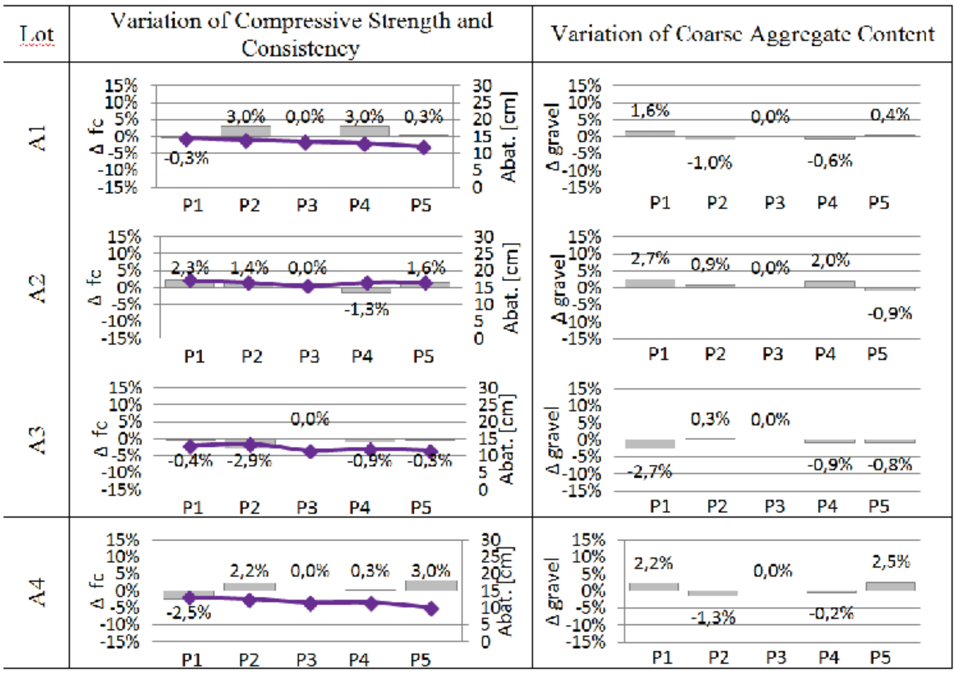
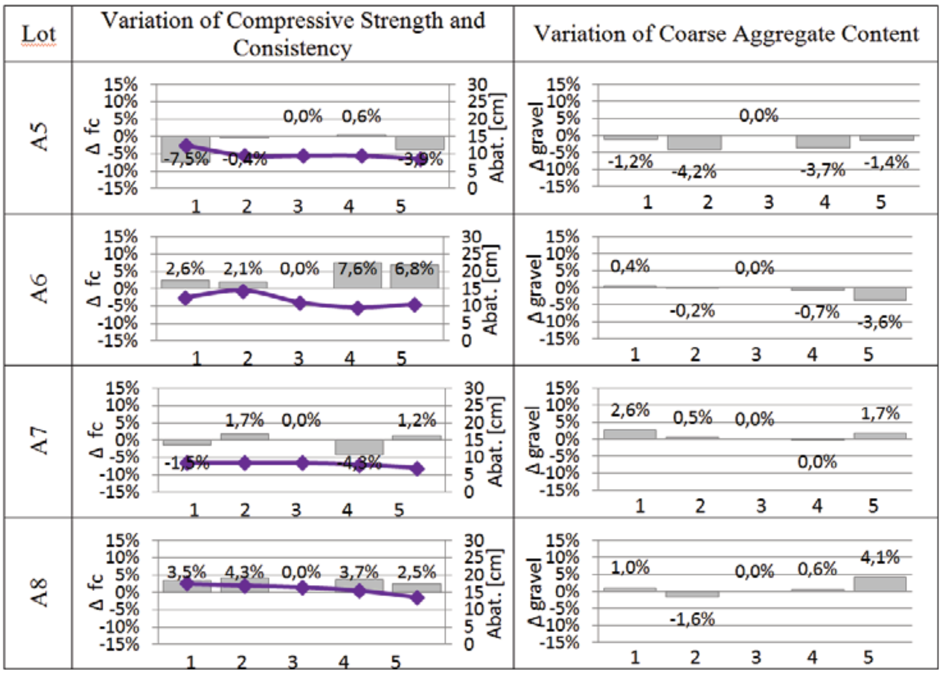


Figure 2 – Profile of variations in compressive strength, consistency and coarse aggregate content – lots 1 to 4



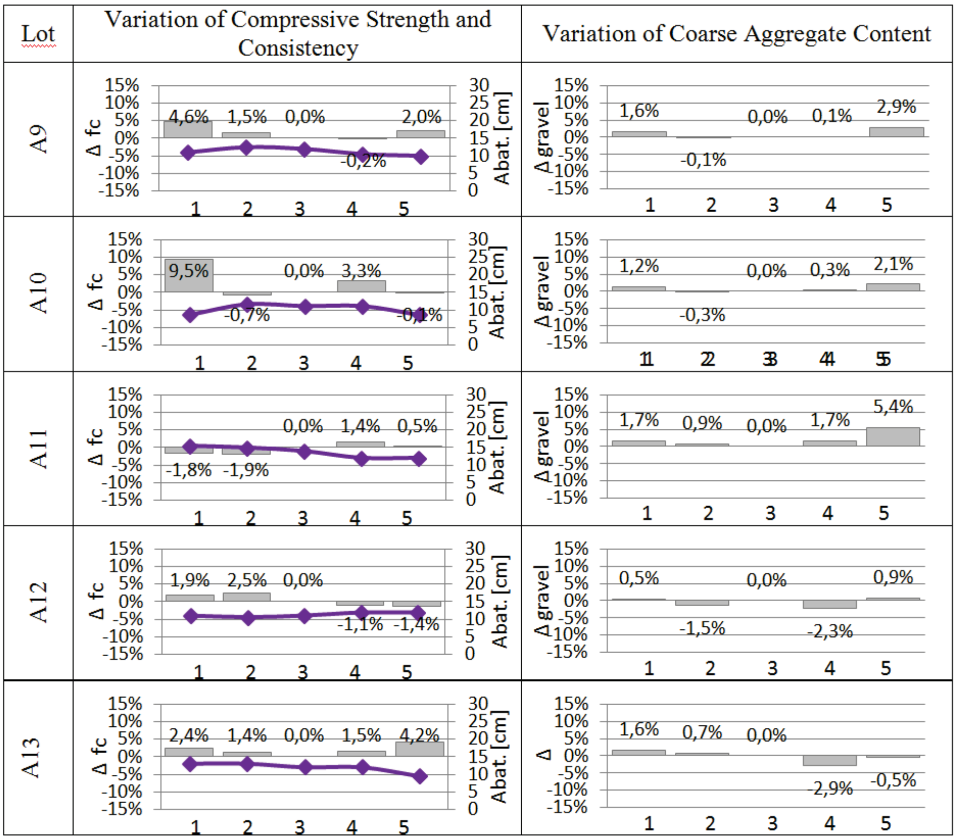
* P1 to P5 correspond to collection points within each batch
* The percent variation of compression strength are given from potential resistance of each sampling point relative to the central point (P3), taking as the reference.

Figure 3 – Profile of variations in compressive strength, consistency and coarse aggregate content - lots 5 to 8



* P1 to P5 correspond to collection points within each batch
* The percent variation of compression strength are given from potential resistance of each sampling point relative to the central point (P3), taking as the reference.

Figure 4 – Profile of variations in compressive strength, consistency and coarse aggregate content - lots 9 to 13



* P1 to P5 correspond to collection points within each batch
* The percent variation of compression strength are given from potential resistance of each sampling point relative to the central point (P3), taking as the reference.

central portion of the discharge (midpoint), according standards recommendations, as reference for representing the variation between the collection points of every batch. Thus there has been shown the percentage differences of points 1, 2, 4 and 5 in relation to the center point.
From the comparative shown in Figures 2 to 4 it is observed the absence of a specific profile that can represent the variation of the compressive strength along the discharge of ready mix concrete. There are profiles constants, with less than 2% difference between the points, and other profiles with high percentages of variation of approximately 10% along the five sampled points.
In table 2 is showed a summary, with the percentage of occurrences of variation of compressive strength of each point relative to midpoint, where it can be seen that over 85% of cases are concentrated in the zone of ± 5% from the central point. It is also possible to note that there is a tendency of values greater than the resistance to P3.
Based on these results of compressive strength is not possible to affirm that the samples collected as recommended by NBR 7212 [9] and NM33 NBR [10], which exclude 15% initial and final of the total volume of concrete-mixer for testing purposes, have the best representation of the concrete, since this points do not always present the greatest resistance of batch.
Considering the recommendation of ABECE [14] where the resistance variation should not differ more than 15% compared to the central point, the lots analyzed fully satisfy this criterion.
It is possible see in Figures 2-4 that there is a tendency to reduce the consistency along the 5 points for each batch of samples, which is more explicit when viewing the summary of variations in the consistency of each point relative to the central, as shown in table 3.
From the data of Table 3 is perceived that the variations in consistency between points are more concentrated in the region

Table 2 – Summary of percentage of occurrence of the compressive strength of each point relative to point P3

Zone	P1	P2	P3	P4	P5
<-10%	0%	0%	-	0%	0%
-5-10%	8%	0%	-	0%	0%
até -5%	38%	31%	-	38%	31%
até 5%	46%	69%	-	54%	62%
5 a 10%	8%	0%	-	8%	8%
>10%	0%	0%	-	0%	0%

Table 3 – Summary of percentage of occurrence of the consistency of each point relative to point P3

Zone	P1	P2	P3	P4	P5
<-4cm	0%	0%	0%	0%	0%
-2-4cm	8%	0%	0%	0%	23%
até -2cm	8%	8%	0%	46%	54%
0	15%	15%	0%	31%	8%
até 2cm	62%	69%	0%	23%	15%
2 a 4cm	8%	8%	0%	0%	0%
>4cm	0%	0%	0%	0%	0%

Table 4 – Summary of percentage of occurrence of coarse aggregate content of each point relative to point P3

Zone	P1	P2	P3	P4	P5
<-10%	0%	0%	-	0%	0%
-5-10%	0%	0%	-	0%	0%
até -5%	15%	62%	-	62%	38%
até 5%	85%	38%	-	38%	54%
5 a 10%	0%	0%	-	0%	8%
>10%	0%	0%	-	0%	0%

of ± 2 cm, with some exceptions, and in addition there is a greater number of occurrence of points P1 and P2 with greater consistency than P3 and the converse for the points P4 and P5, which typically have a consistency smaller than the midpoint. This is due, probably, to the time of testing of each point collected, seeing that, as previously mentioned, the samples were used in the same order of collection (point 1 to 5), so the starting point was tested first, followed by second, third, fourth, and last, which remained a longer time stored and had greater mixing time.

Table 4 shows a summary of the variations in coarse aggregate content of each point relative to the midpoint. Analyzing the percentage of occurrences for each zone, is verified that for the points P1 and P5 there is a higher concentration of coarse aggregate that the midpoint, centered in the range of up to +5%. The higher coarse aggregate content at the starting point corroborates the statements of HELENE [19] and RECENA [20] that there is a concentration of coarse aggregate in the beginning of the discharge.

From the results of the compressive strength of the specimens and the coarse aggregate content were realized statical analyses to determine the statistical significance of variations between lots of the same dosage and the influence of the different sampling points on the compressive strength of the concrete. In table 5 and 6 shows the analysis of variance for the compressive strength, considering three results each point, and the coarse aggregate content, respectively.

Based on analysis of variance of the compressive strength, was found a significant difference between batches and not significant between points, to a confidence level of 95%, i.e., there is variation in compressive strength according to the batch analyzed, while to the collection point there isn't interference if the point is taken at the beginning, middle or end of the discharge. For the content of coarse aggregate was found that there is significant difference between the lots and the points.

4. Conclusions

The dispersions of compressive strength within the batches, usually were concentrated in zone ± 5%, in relation to the reference point (central, P3). Seeing the occurrence of many profiles varia-

Table 5 – Variance analysis for compressive strength

Source of variation	SQ	GL	MQ	Fcalc.	Ftab.	PROB.	SIGN.
Lot	3848,873	12	320,739	155,210	1,827	0,00%	S
Collection Point	16,929	4	4,232	2,048	2,441	9,14%	NS
Interactions	217,931	48	4,540	2,197	1,455	0,02%	S
Error	268,644	130	2,066				
Total	**4352,376**	**194**					

Table 6 – Variance analysis for coarse aggregate

Source of variation	SQ	GL	MQ	Fcalc.	Ftab.	PROB.	SIGN.
Lot	0,079	12	0,007	34,599	1,960	0,00%	S
Collection Point	0,003	4	0,001	4,093	2,565	0,62%	S
Error	0,009	48	0,000				
Total	**0,091**	**64**					

tions between individual points. It was not possible to identify a profile to represent the variation of the compressive strength along the discharge.

From statistical analysis, there was no significant variation between the points of one same batch based on the criteria of ABECE [14], wherein the acceptable difference between the points is 15%, there was also no difference between collection points for compressive strength.

Based on these results we cannot say that the samples taken from the middle portion, as prescribed by the NBR NM 33 [10] and NBR 7212 [9], have better representation of the batch with respect to compressive strength.

For coarse aggregate content is viewed a higher concentration of gravel in extreme points, initial and final, and percentage variations are typically within the range of ± 5% from the central point P3. There is significant difference (statistically) of coarse aggregate content to different collection points and between batches.

In assessing the consistency of ready mix concrete over the five sampling points during discharge from mixer truck can observe a linear reduction of the slump from the starting point to the end point, which indicates a probable influence of rehearsal time on the result, since the samples were assayed in same order of collection and there is a difference of at least 30 minutes between the use of the first sample point for the last. The amplitudes of variations in the consistency of the lots were consistent with the limits permitted by NBR 7212 [9].

Due the absence of a clear profile for the behavior of compressive strength as variation of collection points, as occurs for the coarse aggregate content and slump test, it was not possible to identify a correlation between the results of such properties.

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