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Compressive strength values dispersion of side-mixed and ready-mixed concretes

Dispersão dos valores de resistência a compressão de concretos fabricados in situ e em central





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Abstract

Compressive strength testing method has been widely used as indirect way for evaluate the concrete quality, due to it simplest execution, reliability of the results achieved and low cost of execution. Independently, if the concrete was side or ready-mixed, it is necessary to achieve the compressive strength requirements stated during structure design, essentially because this parameter allows the obtainment of the average strength of the reinforced concrete structure analyzed. Following, as for ready-mixed, as for side-mixed concretes, it is need to ensure the correspondence between the concrete design parameters and the concrete mixed, namely these parameters are summarized in terms of the compressive strength and homogeneity in the different phases of the construction. This way, the present work aims to do the analysis of the dispersions of the compressive strength of concretes mixtures (corresponding to compressive strength classes of 20, 25, 30, 35 and 40 MPa), and identify some influence factors, in this case, the influence of the workers team variation. Two mixtures (35 MPa and 40 MPa) were ready-mixed, while five of the concrete mixtures were side-mixed, by five different worker's group with same time of experience on concrete's manufacture. The results demonstrate that the variation of the workers team presents a high influence for the homogeneity of the compressive strength of the concrete.

Keywords: compressive strength, quality of concrete, central concrete, concrete side-mixed.

Resumo

O ensaio de resistência a compressão tem sido largamente utilizado como forma indireta para avaliação da qualidade do concreto, devido a sua simplicidade na execução, fiabilidade dos resultados e baixo custo. Independentemente do concreto ser fabricado in situ ou em central, é imprescindível cumprir com os requisitos de resistência a compressão, especialmente porque este requisito permite a obtenção da capacidade resistente das estruturas de concreto armado. Neste seguimento, quer para concretos fabricados em central, quer para concretos fabricados in situ, há a necessidade de se garantir a adequada correspondência aos requisitos de projeto, nomeadamente resumidos em termos da resistência a compressão, e da homogeneidade entre os concretos utilizados nas diversas etapas da construção. Desse modo, este trabalho teve como objetivo analisar as dispersões dos resultados a compressão de sete misturas de concreto (correspondentes as classes de resistência de 20, 25, 30, 35 e 40 MPa), e identificar eventuais fatores de influência, como por exemplo o impacto na variação da equipe de execução. Duas misturas (35 MPa e 40 MPa) correspondem a concretos dosados em central, enquanto cinco das misturas de concreto foram produzidas in situ, por cinco grupos de trabalhadores diferentes com o mesmo tempo de experiência na fabricação do concreto. Os resultados mostraram que a variação dos grupos de trabalhadores apresenta uma elevada influencia para a homogeneidade dos resultados de resistência a compressão do concreto.

Palavras-chave: resistência à compressão, qualidade do concreto, concreto dosado em central, concreto *in situ*.

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1. Introduction

Concrete is the most employed building material applied throughout the infrastructure of a nation's construction, industry, transportation, defense, utility, and residential sectors[1], and as a widely used in the construction industry, concrete needs to keep its serviceability properties during the building service life. However, some external factors, as the environmental actions, and internal factors, as permeability, for instance, can reduced the concrete durability and consequently a reduction of the its service life [2]–[6].
Basically, concrete obtainment process starts with the material selection and the design method choice and it ends after the cure process. Nonetheless, between the material selection and the concrete cure, other factors also have influence on the concrete quality, for example the mixture process, that depending on the workers training level or automation level can present as results a concrete with high or low dispersion between the compressive strength of the structural elements. This way, homogeneity of the concrete has a direct influence with its quality properties up to the end of its service life, and can be affected not only by materials quality but mixture process, as well[7].
The concrete mixture needs to be systematically implemented in order of to avoid low durability or emergence of problematic issues after concreting. The general criteria for be considered in the mix design are: i) which aggregates are available; ii) which properties should concrete presents, and iii) what is the most economical way of providing these required properties[7]. In summary, the main goal of the concrete mix design is to select the appropriate components, considering the materials available and to determine the most economical way for to produce concrete with the desire characteristics [8]. In addition, the concrete mixture proportion is also an important component for the concrete structures strength and durability, extremely influenced by water/cement ratio (w/c) and type and cement content. Furthermore, binder type in a concrete mixture can influences the durability against a severe environment [9]. However, the use of materials with good quality and proper mixture proportioning will not ensure that the concrete will be durable[10], [11]. Good quality control and workmanship are also absolutely essential to the production of durable concrete[12], as well the attendance to the current codes[13].
Quality control can be understand as the analysis of the properties of concrete related with durability, since its process of obtainment [14]. This process covers the material selection, choice of the assessment methods, statistical analysis of the results and procedures of control. Nonetheless, when the concrete is side-mixed (produces in field), additional careful is needed due to its production in batches. In addition, the ready-mixed concrete also needs a good quality control, once variations can occur during transportation, placing, compacting, concreting and curing, as well. Variations in the final properties of the concrete may occur partly because of the quality of the materials and its proportion, and partly because of the differences methodologies used for concrete production [15], but the main aim of the quality control is to reduce those variations and to ensure the concrete produced achieves the properties requested by owners.
As advantages of the quality control it can be mentioned the reduction of the material costs, because quality control leads to a rational use of the available resources; time reduction, because to check every stage of the production of the concrete can avoid inspected problems or solve its in early time; and consequent, provide reduction of the maintenance costs[16].
Concrete properties must be analyzed either on fresh and hardened stage. The principal properties of the fresh concrete are: uniformity, stability, workability, pumpability, water demand and water/cement ratio, rate of change of workability, and finishing. For the hardened concrete, the main properties are connected to mechanical characteristics as strength and elasticity modulus, for instance[17]. It can also be mentioned the early-age properties of concrete are also important, as well the heat release, degree of hydration, mechanical short-term properties, viscoelastic behavior, thermal dilatation and autogenous shrinkage[18]. However, the durability characteristics of the concrete can be analyzed by the compressive strength of the concrete, since there is a good correlation between those two parameters[19].
In order to contribute for implementation of the state of knowledge on concrete quality control, the present work is focused on the assessment of the quality control of the ready-mixed and side-mixed concretes through analysis of the compressive strength (fck) dispersion values. In this study, seven concrete mixtures were performed for different levels of fck, namely 20, 25, 30, 35 and 40 MPa. Two mixtures (35 MPa and 40 MPa) were ready-mixed, while five concrete mixtures were side-mixed, by 5 different workers team with the same time of experience on concrete manufacture. The present work intents to answer the pertinent question if variations in the concrete mixture method can presents considerable influence on compressive strength of concrete. Once this study was done at North of Ceará State, it can be also understanding as a contribution to study of the methodologies of concrete production performed in North of Ceará.

2. Theoretical background

The concrete mix design is related with achievement of the optimized proportion of the concrete components (cement, water, coarse and fine aggregates, and sometimes incorporation of chemical admixtures and mineral additions) necessary for to obtain a concrete with good quality. Generally, these conditions are determined by structural project and the conditions of the construction, and the guidelines considered, as for instance the Brazilian Standard ABNT NBR 12655: Portland cement concrete – Preparation, control and acceptance – Procedure[20]. This code states that the composition of each concrete with class of resistance above 20 MPa (C20), should be defined by mix design, and must be redefined each time there is a change in the component materials and in the construction conditions[20].
During the mixture design, the material proportioning is stated based on theoretical and experimental studies, that basically are performed in order of to define and to characterize the properties of the desired concrete, following some steps such as: characterization of the component of the concrete; first mix design; adjustment and verification of concrete mix and preparation of the concrete. Moreover, experimental tests should be done for evaluation of the concrete properties (strength, workability, i.e.) using concrete samples. The fresh and hardened properties of

Table 1
Standard deviation to be used depending on the concrete preparation condition [20]

Concrete preparation condition	Standard deviation (Sd)
A	4.0 MPa
B	5.5 MPa
C	7.0 MPa

the concrete properties are generally assessed following procedures as presented in [20], [21].

The obtainment of the mix design strength (fcj) considers the dominant variability conditions during construction, which leads to variability of the final properties of concrete, in the both fresh and hardened states. In general, the final variations are due to variability in the material components, equipment (mixing step) and the operation (transport, placing, compacting and curing). These conditions are measured by the standard deviation (Sd) that can be made smaller by making a good concrete quality control, since the variability of the concrete properties will be reduced.

The standard deviation, Sd , is a function of the concrete preparation condition and can be known or unknown. The Sd can be known when the concrete is always produced with the same materials, and similar equipment under equivalent conditions. So, the numerical value of Sd is set with a minimum of 20 consecutive samples results within 30 days and should never be lower than 2 MPa. When the Sd is unknown, it adopts the value according to Table 1, that consider the preparation conditions. The value must be kept constantly equal during all stages. The Equation 1 shows the relation between Sd and fcj , where fcj is the average compressive strength of concrete for the age of "j" days (MPa); fck is the real compressive strength of concrete (MPa) and Sd is the standard deviation of the mixture (MPa).

$$fcj = fck + 1.65\,Sd \tag{1}$$

Considering the Table 1, the condition A is applicable to classes of concrete from C10 to C100, where cement and aggregates are measured in mass, mixing water is measured by weight or by volume, using metering device. The amount of water is also a function of the humidity of the aggregates. Now, in the condition B, applicable to classes of concrete from C10 to C20, the cement is measured in mass, mixing water is measured in volume by metering device and the aggregates are measured in combined mass with volume, with humidity control and swelling whenever necessary; and also applicable to concrete class C10 to C15, where the cement and the mixing water is measured in similar form with the previous condition A, but the aggregates are measured by volume. The humidity of the fine aggregate is determined at least three times during the same turn of pour, and the volume of fine aggregate is fixed by swelling curve, established specifically for the material used. In the condition C, only for classes C10 and C15 of concrete, the cement is measured in mass, aggregates and mixing water are

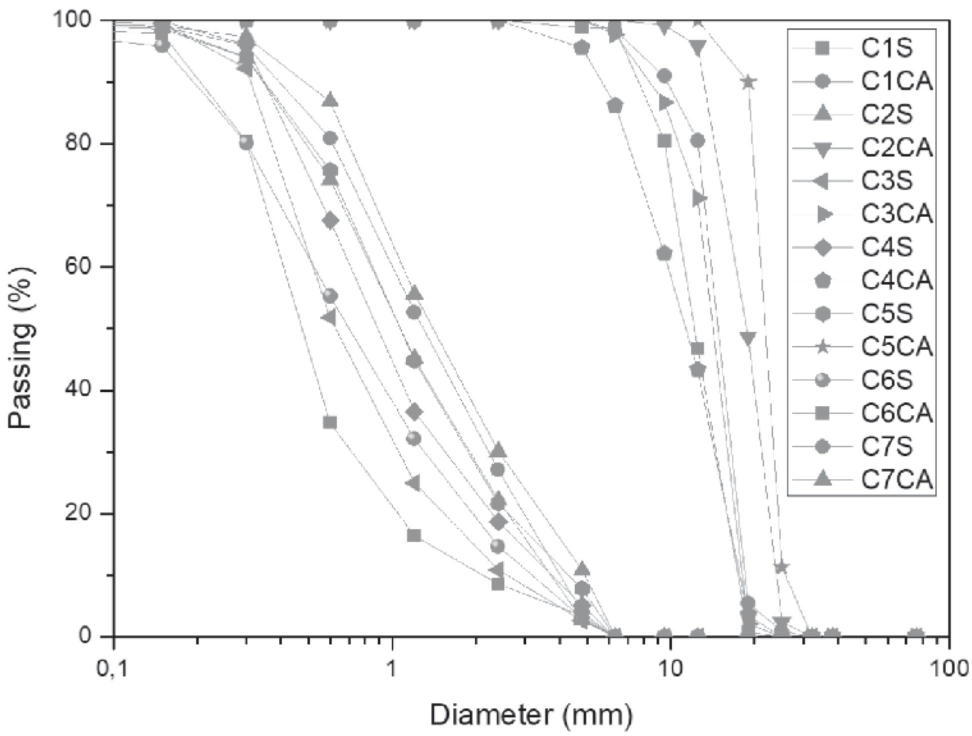

Figure 1
Particle size distribution of the aggregates employed in the concrete mixtures

measured in volume. The amount of water is also a function of the estimated humidity of the aggregates and determining the consistency of concrete, according to ABNT NBR NM 67 [22] or other standardized method. Also, for preparing in condition C, while the Sd is not known, it is required to C15 class a minimum cement consumption of 350 kg per one thousand liters of concrete.
Even with several concrete classes with different resistances, the ABNT NBR 6118 [23] states that for structural purposes the minimum resistance must be 20 MPa.

3. Experimental

3.1 Materials and concrete mixtures

For the concrete mixtures, were used sand from the Acaráu River (Sobral, Brazil), as fine aggregate and limestone aggregate as ground aggregate. The curves of the particle size distribution for both aggregates are showed by Figure 1, where C1, C2, C3, C4, C5, C6 and C7 represents the correspondent mixtures and the final abbreviations "S" and "CA" represents sand (fine aggregate) and coarse aggregate, respectively. Portland Cement type II was used as binder in the concrete mixtures, following the recommendation in ABNT NBR 11578 [24] and its chemical composition is presented by Table 2. The water used came from the water public service of Sobral city, in Brazil.
Seven concrete mixtures were performed and the details of each one of the seven composition can be seen by Table 3. Essentially, the ABCP (Cement Portland Brazilian Association) concrete mix design method was adopted and the concretes for strengths classes of 20 MPa (C4), 25 MPa (C2), 30 MPa (C3, C5 and C6), 35 MPa (C1) and 40 MPa (C7) were done. The Sd adopted for all mixtures was 4.0 MPa. The strength class of 30 MPa was studied for 3 different compositions due to the fact that it represents the compressive strength value most commonly adopted in Ceará State. The minimum mortar rate of the concrete mixtures was 45% while the maximum mortar rate was 60% and the water/cement ratio (w/c) used vary between 0.42 and 0.58.

Table 2
Particle size distribution of the aggregates employed in the concrete mixtures

Cement chemical analyses	%
Silicon dioxide (SiO_2)	20.6
Aluminum oxide (Al_2O_3)	5.2
Ferric oxide (Fe_2O_3)	3.5
Calcium oxide (CaO)	65.0
Magnesium oxide(MgO)	2.74
Sodium oxide (Na_2O)	–
Potassium oxide (K_2O)	–
Equivalent alkali	1
Phosphorous oxide (P_2O_5)	–
Titanium oxide (TiO_2)	–
Sulfur trioxide (SO_3)	2.93
Loss in ignition	5.85

Bogue potential compound composition	%
Tricalcium silicate (C_3S)	67.0
Dicalcium silicate (C_2S)	7.8
Tricalcium aluminate (C_3A)	7.8
Tetra calcium aluminoferrite (C_4AF)	10.5

While C1 and C7 concrete mixtures correspond to ready-mixtures by mechanical automation, the compositions C2 until C6 represents the side-mixture concretes. For the side-mixture concrete, were selected workers with correspondent experience time, namely between 5 and 10 years of experience on concrete mixtures performance. For each one of the concrete mixtures a different worker group was selected. In order to make clear the difference between the production process of ready-mixed concrete and the side-mixed, a flowchart is presented in Figure 2.

Table 3
Concrete compositions)

Mixtures	Proportion (binder, fine aggregate, coarse aggregate)	fck	Cement consumption	Mortar rate	water / cement ratio (w/c)
C1*	1.00 : 1.41 : 2.14	35 MPa	482.28 Kg/m³	53%	0.42
C2	1.00 : 1.94 : 2.71	25 MPa	382.71 Kg/m³	48%	0.53
C3	1.00 : 1.71 : 1.93	30 MPa	424.96 Kg/m³	46%	0.44
C4	1.00 : 2.60 : 2.59	20 MPa	318.88 Kg/m³	48%	0.58
C5	1.00 : 1.74 : 2.53	30 MPa	410.81 Kg/m³	52%	0.47
C6	1.00 : 1.66 : 2.45	30 MPa	431.61 Kg/m³	60%	0.47
C7*	1.00 : 1.40 : 2.22	40 MPa	465.40 Kg/m³	52%	0.47

(*) Ready-mixture concretes.

3.2 Specimens preparation

The number of specimens necessary for each mixture was stated based on ABNT NBR 12655 [20] recommendations, taking into account the quantity of concrete. This way, 343 specimens were produced to C1, 106 specimens to C2, 74 specimens to C3, 124 specimens to C4, 62 specimens to C5, 128 specimens to C6, and 284 specimens to C7. The specimens were produced according to ABNT NBR 5738 [25] and after 24 hours, the cylindrical samples (10 cm x 20 cm) were submitted to water immersion for concrete cure process, during 28 days.

3.3 Compressive strength testing

The compressive strength test was performed through the centralization of a cylindrical concrete specimen between a rigid plate and a load cell. The correct positioning is fundamental for make the specimen axis coincides with the axis of the testing machine, making the resultant of the forces passes through the center of the sample. The apparatus applies load until the failure of the sample, which is then removed. The compressive strength value of the samples was obtained according to ABNT NBR 5739 [26]. For this procedure, an electrical Contenco® loading machine was used. It has a load range of 100.000 Kgf with subdivision of 10 Kgf.

4. Results

The graphs of the Figure 3 and 4 shown the frequency distribution of the axial compressive strength test results of the ready-mixed and side-mixed concretes, respectively. In addition, it also can be observed the normal distribution curve, fck values, mean and standard deviation (Sd) of the samples.
Preliminarily, it can be seen by Figure 3 that the average of the

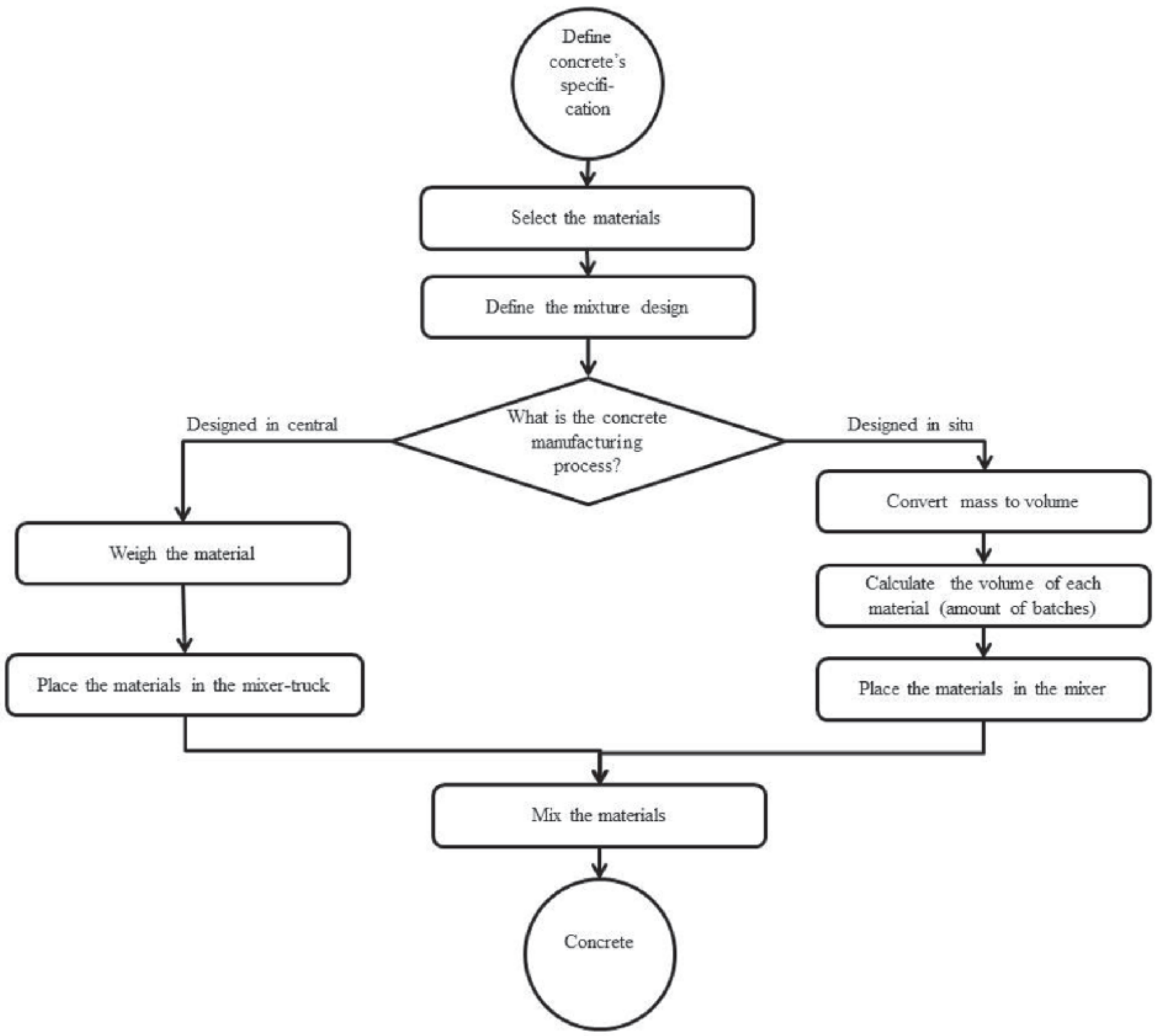

Figure 2
Flowchart of production process of the ready-mixed and side-mixed concrete

results is higher than the fck (the fck for C1 was 35 MPa, and the mean obtained was 38.7 MPa; for C7, the fck obtained was 40 MPa, and the mean obtained was of 42 MPa). Furthermore, for the side-mixed concretes (Figure 4) it can be observed that 3 of the 5 concretes have not reached the fck. C3, C5 and C6, has fck of 30 MPa, but they only reached the mean of 21.9 MPa, 26.1 MPa and 27.4 MPa, respectively. However, the discussion of these values is not the focus of this study.

As previously mentioned, a Sd of 4 MPa was used for the ready-mixed concretes. Since the average Sd for the 7 samples was 4.1 MPa, the value of 4 MPa is presented as a sensible value for an initial guess. However, it was noted in Figure 3 that the Sd of C1 (3.1 MPa) is smaller 23.75% than the value stablished and, in a critical situation, the C7 surpasses the value of 4 MPa in 32%, showing a Sd value of 5.3 MPa. Similarly, it can be observed in Figure 4 that the Sd of the values of C2 and C3 was 3.2 MPa and 3.9 MPa, respectively. Therefore, they are smaller in 20% and 4.25%. But, still in the Figure 4, it can be observed that C4 and C6 exceed this value, with a Sd of 4.8 MPa and 4.3 MPa, respectively. It can be said that only the concrete C5 obtained the Sd according with established.

For obtainment of a most suitable Sd value in the concrete mix design, it must be used a Sd value of twenty sequential measurements (Sd20). In order to examine the reliability of these results, the individual results of all Sd20 and the compressive strength average of 20 sequential measurements (AS20) of all sets were plotted in the Figure 5 and Figure 6. Also, the compressive strength values of each measurement, the Sd of the total population (SdTotal) and the total average strength (ASTotal) are there indicated.

Figure 5.a shown C1 compressive strength results, where can be noted that the SdTotal is 3.1 MPa, and the Sd20 vary over this value, with the minimum value of 1.1 MPa and a peak of 4.4 MPa. Considering the total population of 343 samples, were formed 324 sets of 20 samples. Firstly, it was observed that AS20 is moving on the value of the total mean of 39 MPa for all samples. Additionally, was noted peaks and valleys along the entire sample, with the highest peak at 42.0 MPa, and the lowest valley at 35.2 MPa, which provide maximum amplitude of 6.8 MPa and the maximum difference between the total mean value and the further AS20 value of 3.8 MPa. This may indicate that the preparation conditions were homogeneous throughout over 2720m³ of concrete in this construction.

Figure 5.b presents the results of samples relating to C2, with an average value of 3.4 MPa (SD20 oscillates about this value with a maximum and minimum value of 4.5 MPa and 1.7 MPa). C2 had 87 sets, with the mean 26 MPa and AS20 varies about this value. The curve for these values had a peak between two valleys (28.9 MPa and 22.5 MPa) for one and for the other a value of 23.7 MPa, and a maximum amplitude of 6.4 MPa and a maximum difference from the mean of 3.5 MPa. Note that the curve of AS20 and Sd20 presents a biased cyclical, also indicating similar preparation conditions throughout the work.

Similarly, to what occurs in C1 and C2 (Figure 5.a and b), the sensitivity analysis shows us reasonably homogeneous preparation conditions C3 (Figure 5.c), C4 (Figure 5.d), C5 (Figure 6.a) and C6 (Figure 6.b), where it was observed behaviors that tend to periodicity. Moreover, they had maximum amplitudes of 4.1 MPa, 6.9 MPa, 5.3 MPa and 7.5 MPa, respectively, and the greatest difference in the total mean and AS20 was of 2.4 MPa, 4.7 MPa, 2.8 MPa and 4.8 MPa respectively. These data indicate a homogeneous preparation conditions along the concrete production.

In the sample C7 (Figure 6.c), the Sd20 curve had abrupt slope at several points together with a no behavior basis. This curve had a maximum peak of 7.1 MPa and a lower minimum value of 1.1 MPa. Moreover, the maximum peak and the valley were 49.7 MPa and 36.5 MPa, respectively, which generates high amplitude, with the maximum of 13.2 MPa, and the major difference between the mean of 42.0 MPa, with a sample average value of 7.7 MPa. This curve was not considered for further analysis in this work because the results indicated that some change had occurred in the

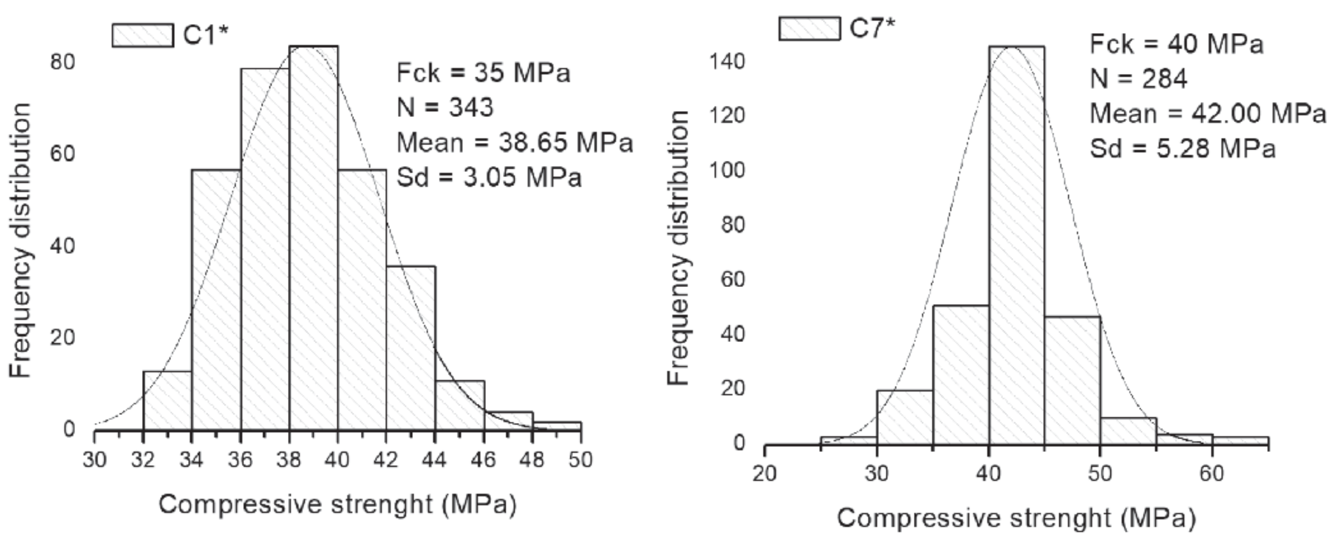

Figure 3
Normal distribution of the compressive strength values of the ready-mixture concretes

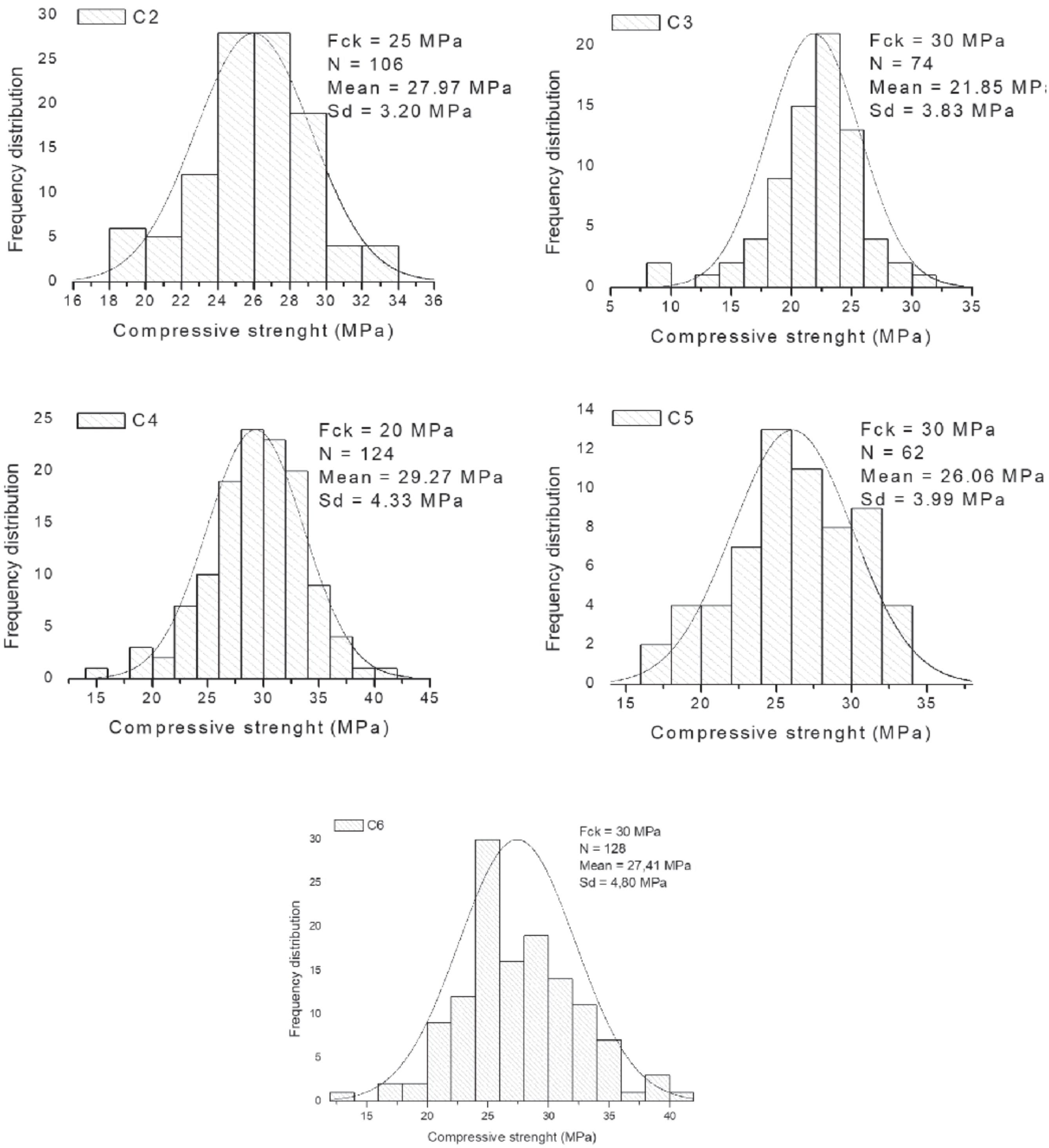

Figure 4
Normal distribution of the compressive strenght values of the concretes side-mixed

preparation process, and it was not homogeneous throughout the analyzed period.

It can be observed in Figure 4 that some Sd20 values presented lower values than the SdTotal, however, the Brazilian Standard recommends that the value adopted from Sd must be multiplied by 1.65 (see Equation 1). The ratio between each Sd20 and SdTotal were calculated, which generated the a correction factors for each set. The standard also specifies that in no case can adopt a Sd lower than 2.0 MPa, consequently, in this analysis, all Sd below this value were replaced by 2.0 MPa.

Figure 7, 8 and Figure *9* shows the cumulative Gaussian distribution curves and its complement together with the frequency distribution for the correction factors of the 7 samples.

Figure 7.a and b refer to concrete C1. It could be inferred by a Gaussian curve that the probability of a value of the correction factor be greater than 1.65 is equal to 3.6% and the actual frequency at which the correction factor is higher than 1.65 is equal to 0. Additionally, the Figure 7.c and d are the C7 values, but those values were not considered for this study because, as previously mentioned, these samples are not adequate for the analyses performed in this study.

Figure 8.a and b refer to concrete C3 and Figure 8.c and d to concrete C4. It can be seen in the Gaussian curve that the probability of a correction factor to provide greater than 1.65 for C3 is 30% and that the actual frequency of these values is 31.7%. In addition, the probability of occurring a correction factor larger than 1.65 in C4 is 12.5% and that the actual frequency of these values is 16.3%.

Figure 9 refers to concretes C2, C5 and C6. Through Gaussian curves is observed that the probability of occurrence of a correction factor greater than 1.65 is 10.3% for C2, 0.5% for C5 and 1.8% for C6 and the frequency of these values for C2, C5 and C6 is 18.4%, 2.4 % and 4.7%, respectively.

In order to compare the ready-mixed and side-mixed concretes, all validated data were grouped and they are shown in the Figure 10. The probability of obtaining a correction factor equal to or less than 1.65 for the ready-mixed concrete was of 3.6%, while the probability of getting the same factor for the side-mixed concrete was of 9.6%. To achieve the same probability of 3.6% the correction factor of the side-mixed concrete should be 1.82.

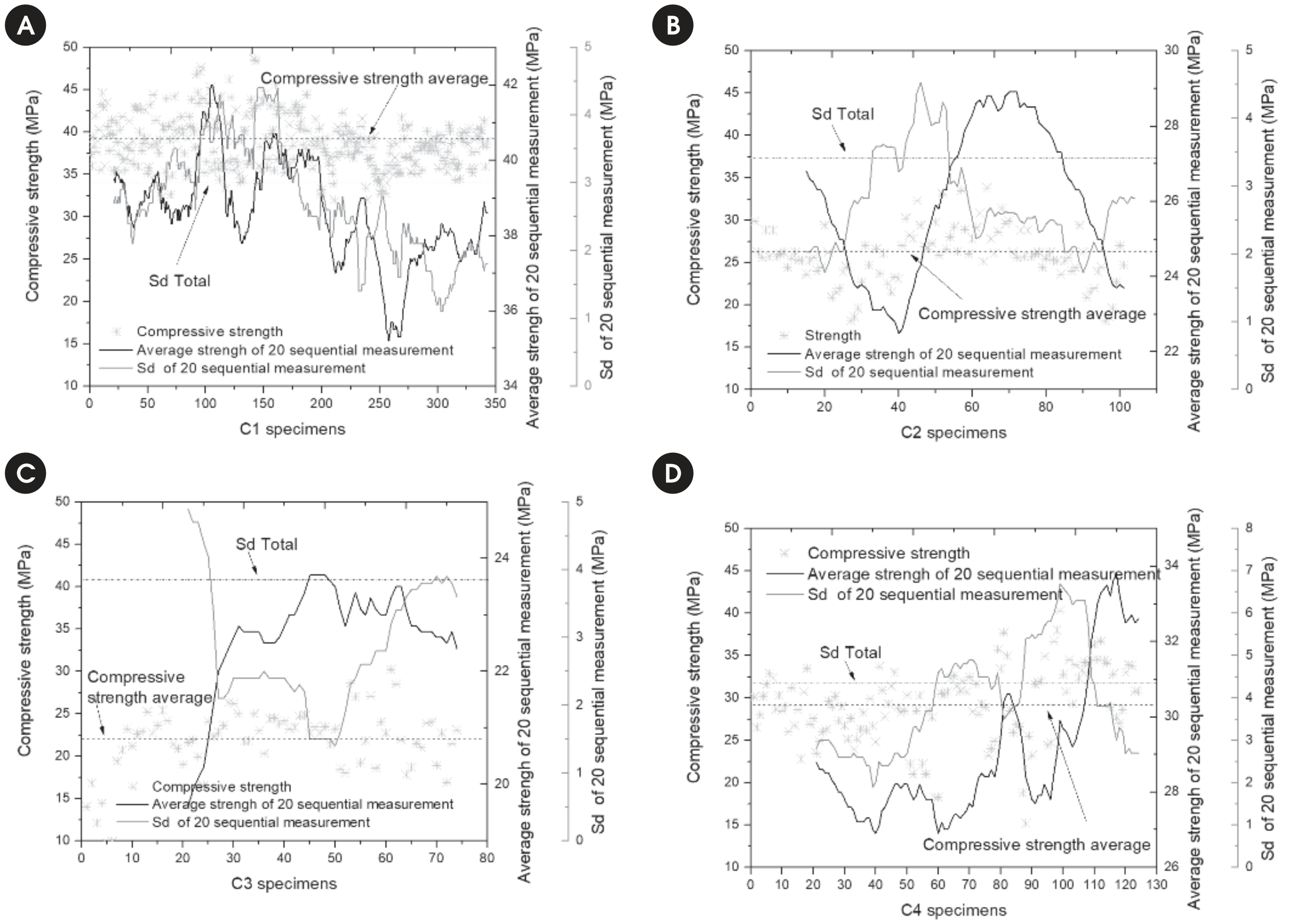

Figure 5
Compressive strength results of C1, C2, C3 and C4 mixtures

5. Conclusions

The results for the seven concrete mixtures analyzed showed that only in one mixture was obtained the standard deviation (Sd) established previously, considering the average of all values. Also, the found results can be not directly related with the standard deviations and the compressive strength values obtained, because some concrete samples presented standard deviation values higher than that stated, but compressive strength values lower than the fck.

By the individual analysis of Sd and compressive strength for every mixture, only C7 mixture possibly does not kept homogeneity during the production of the ready-mixed concrete. The remaining mixtures indicate a existence of a linearity in the quality of concrete, regardless of production location.

The side-mixed concretes can have quality equivalent to the concrete produced in central when it is only analyzed the resistance capacity of the material. In general, in order to obtain a concrete side-mixed with the same quality of concrete ready-mixed, some steps must be performed: good material selection, mass measurement of the material and standardization of the manufacturing process of the concrete side-mixed. As well, in order of to achieve better standardization of side-mixed concrete it is necessary to define which workers will be responsible for concrete manufacturing, and it is recommended to keep the same team as long than possible.

Finally, this work also demonstrates that worker's variation can present significant influence on the concrete properties, and that is a topic that need more attention by técno-scientific field, in order of to provide new methodologies for side-mixed concrete production.

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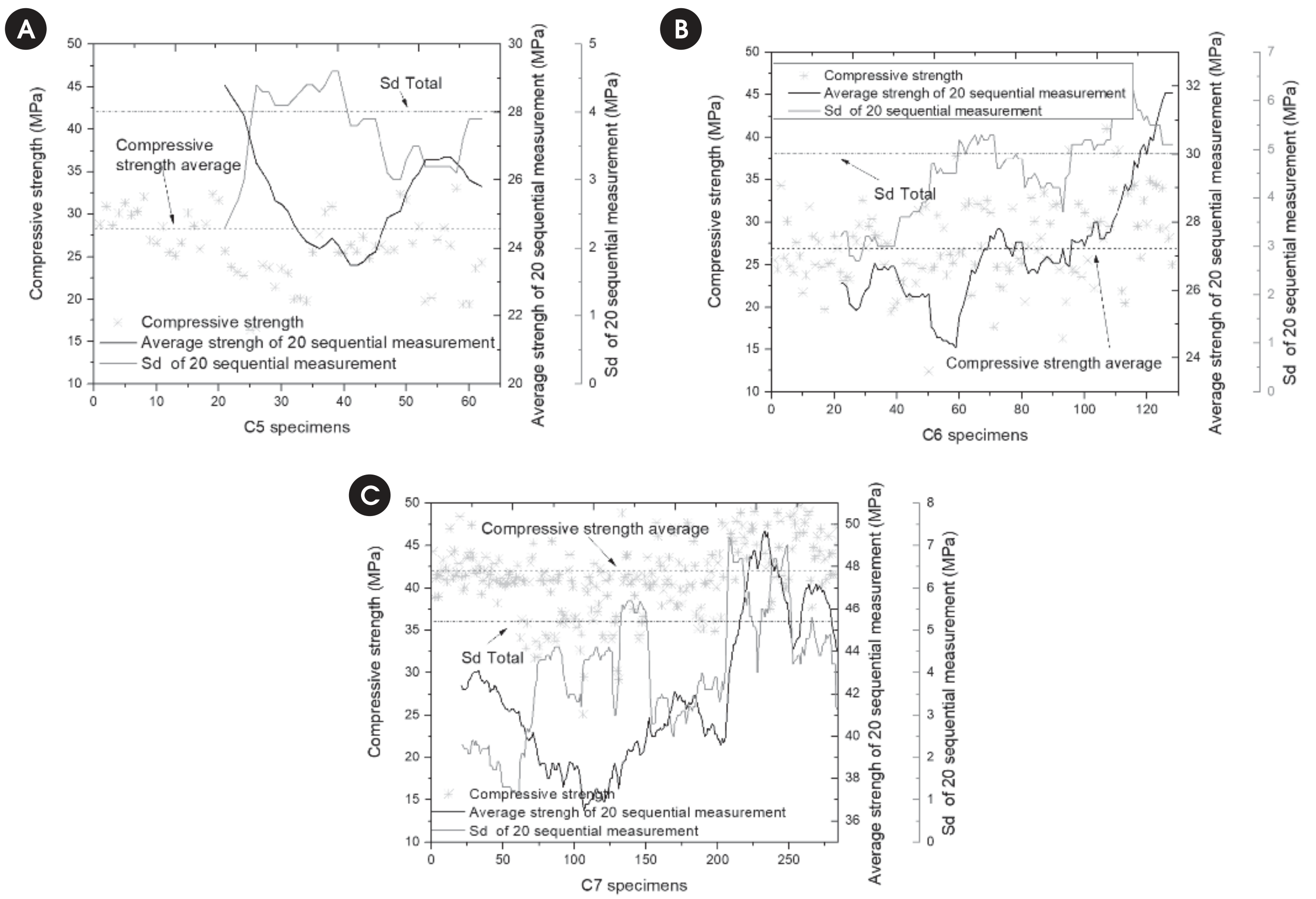

Figure 6
Compressive strength results of C5, C6 and C7 mixtures

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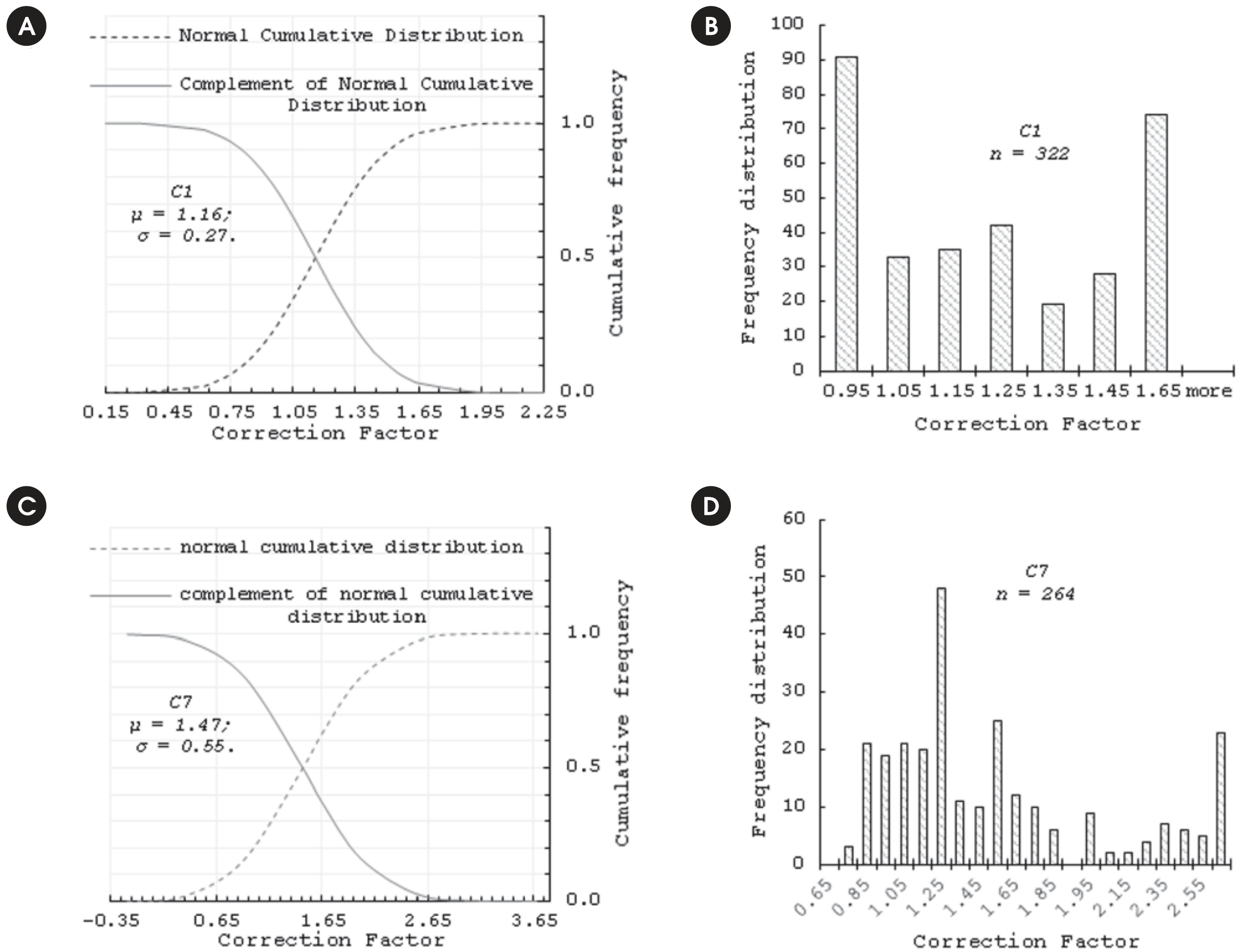

Figure 7
Cumulative Gaussian distribution curve and frequency distribution for the correction factors of concretes C1 and C7

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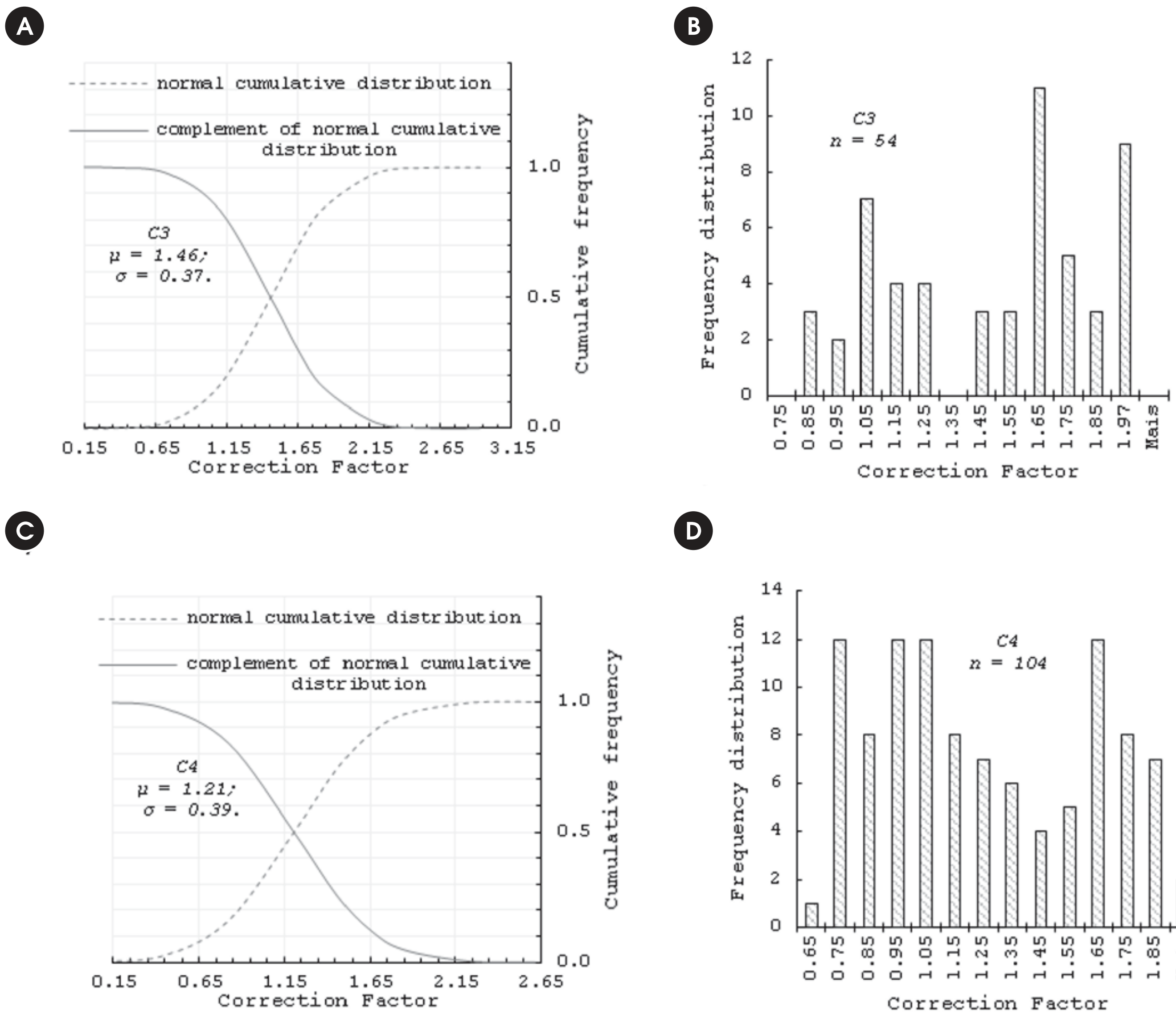

Figure 8
Cumulative Gaussian distribution curve and frequency distribution for the correction factors of concretes C3 and C4

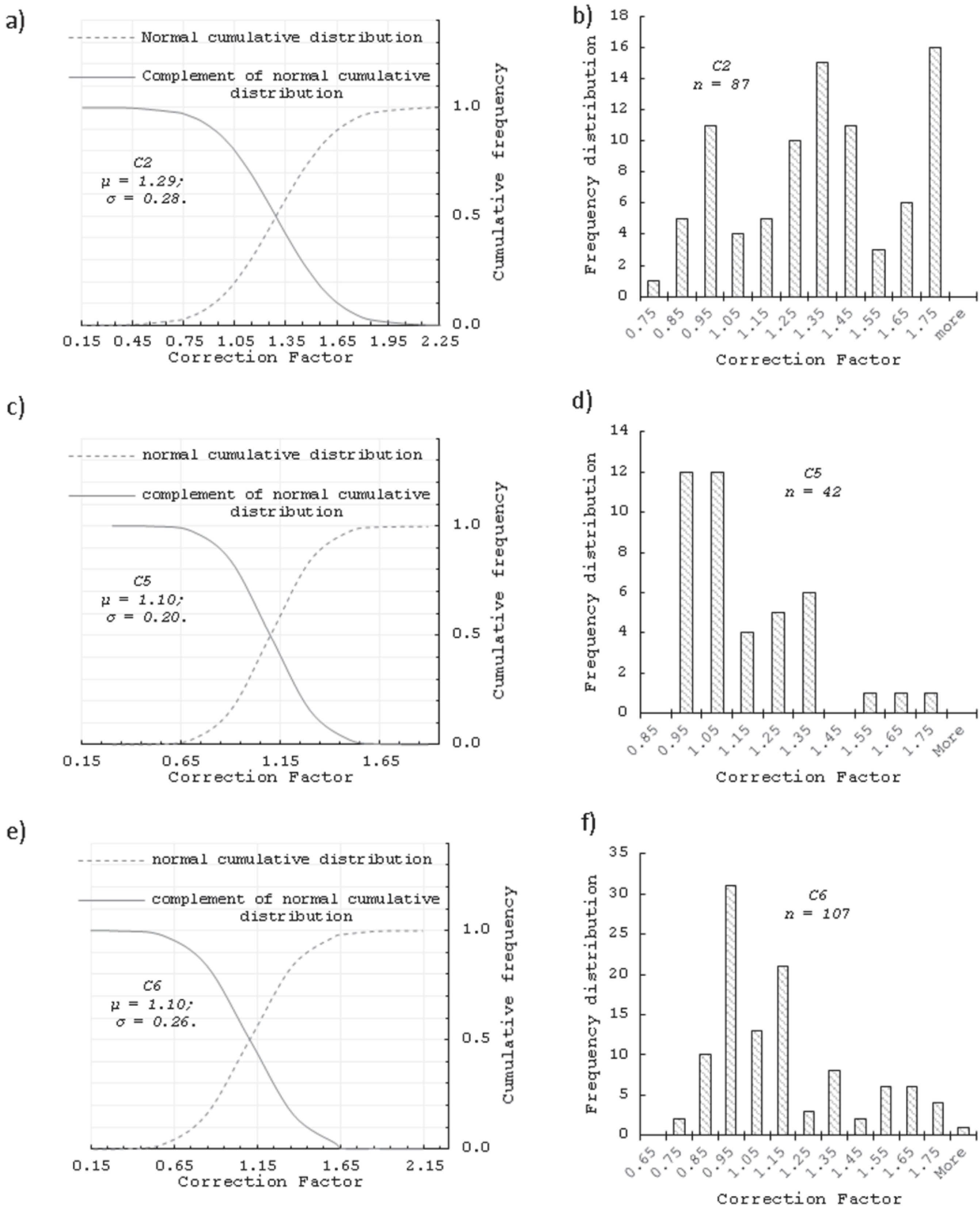

Figure 9
Cumulative Gaussian distribution curve and frequency distribution for the correction factors of concretes C2, C5 and C6

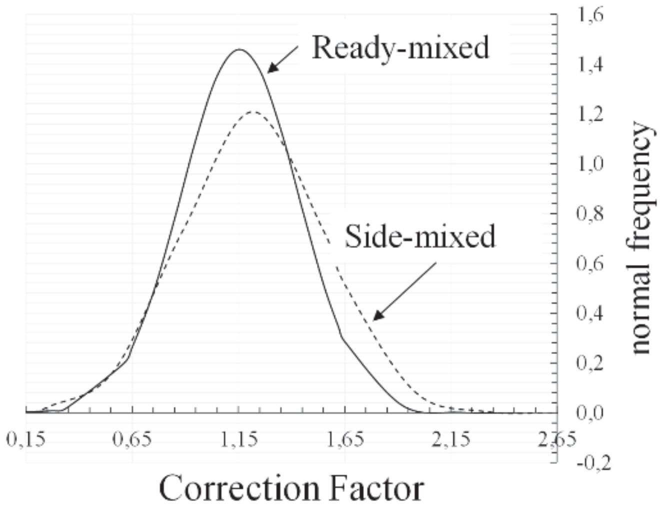

Figure 10
Frequency distribution for the correction factors of all ready-mixed and side-mixed concretes

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