v. 3, n. 41, 2023

Journal of
Engineering
Research

# INFLUENCE OF THE MAXIMUM PASTE THICKNESS AND THE ADDITION OF SUPERPLASTICIZER ON CONCRETE FLOW UNDER VIBRATION

*Ana Flávia Baú Carneiro*
Academic Department of Civil Construction – UTFPR
Curitiba - Paraná
http://lattes.cnpq.br/2046448813378446

*Carlos Eduardo Costa Correia*
Academic Department of Civil Construction – UTFPR
Curitiba - Paraná

*Valéria Ramos Baltazar Quevedo*
Department of Civil Engineering - UFMS
Campo Grande - Mato Grosso do Sul
http://lattes.cnpq.br/7525169921357112

*José Alberto Cerri*
Academic Department of Civil Construction - UTFPR
Curitiba - Paraná
http://lattes.cnpq.br/5969194630840866

*Márcia Silva de Araújo*
Academic Department of Mechanics - UTFPR
Curitiba -Paraná
http://lattes.cnpq.br/5114251476191021

DOI 10.22533/at.ed.3173412307124

**Abstract:** The manufacture of large self-supporting tiles is carried out by a machine that contains a mobile feed box, which pours the concrete onto a long, open, W-shaped mold (track). As the concrete used does not flow under its own weight, they are hose vibrators are used to provide flowability. Aiming to simulate some conditions of the production process, an adaptation of the L-box test was made, in which a hose vibrator was inserted into the box's reservoir. The compositions used natural fine sand, artificial sand and gravel, in the proportions of 25%: 25%: 50% and 0%: 50%: 50%, by mass. The effects of the aggregate/cement ratio "m" and the addition of a 3rd generation superplasticizer additive based on polycarboxylate were studied. For each of these proportions, "m" values were defined equal to 4.0; 4.5 and 5.0, which reduces the amount of cement by up to 16%. To define the additive levels, the frustum slump test was carried out, which is the reference test in the industry for choosing composition in terms of flowability. The Maximum Paste Thickness (MPT) calculations resulted in negative values, indicating that the mixtures would lack paste between grains larger than 0.150 mm. The amount of superplasticizer required was more consistent with the solids fraction values found than with the cement concentration. The results showed that even the compositions with zero slump presented workability and flowed under vibration. The use of superplasticizer led to a significant decrease in flow time and an increase in mechanical resistance, especially for the lower cement concentration.

**Keyword:** concrete, MPT, superplasticizer, L-box.

## INTRODUCTION

### EXTRUSION OF SELF-SUPPORTING TILES

Self-supporting prestressed concrete tiles can cover spans of up to 25 meters, being widely used in covering warehouses and spaces that have large free spans. Furthermore, its use allows greater agility in the execution of work and organization on site, increasing quality, reducing costs and waste of materials (SILVA, 2011).

One of the methods used for the prefabrication of parts is through an extrusion machine, the process being relatively simple: the concrete is launched from the machine's nozzle, which flows under vibration over an open mold, with a previously determined shape according to with the product to be manufactured, in the case of self-supporting tiles it is in the shape of a W. The machine slides on rails depositing the material in the mold and thus shaping the tile (RICHARDSON, 2003).

For the extrusion process to be carried out properly, the concrete must have a viscosity low enough, under vibration, to facilitate flow, but high enough to maintain the shape of the tile after forming. Workability is also an essential characteristic in the extrusion process, encompassing two other factors of fresh concrete: fluidity and cohesion, described as the concrete's ease of mobility and resistance to exudation or segregation, respectively (GEYER, 2006).

Among the main problems in the extrusion process, segregation is what can most reduce the quality of the part. This phenomenon occurs mainly due to the difference in size and specific mass between the concrete particles (NEVILLE, 2015) which, when vibrated in excess or inadequately dosed, results in the separation between the cement paste and the coarse aggregates, allowing cracking and wear.

Among the solutions to the problem are: optimizing the dosage of components, improving particle size distribution and reducing the volume of voids, taking precautions to maintain the cohesion of the mixture and enable the involvement of coarse aggregates by the cement paste. The amount of water must also be controlled, which can be done by replacing part of it with superplasticizing additives in the mixture, ensuring the fluidity of the mixture and avoiding excess water. In industry, cone slump is used to define the amount of superplasticizer, however, this test evaluates the workability of the concrete that will be used manually. In this article, these results will be compared to those of the modified L box, which uses a hose vibrator as in the extrusion process carried out in the industry.

## POLYCARBOXYLATE-BASED SUPERPLASTICIZERS

Superplasticizers based on polycarboxylates, also known as 3rd generation plasticizers, are macromolecules that act as dispersants, making it difficult for finer particles to reach the concrete. This way, it is possible to reduce the amount of water used and reduce the viscosity of the suspensions, improving workability and performance, without affecting consistency or mechanical resistance to compression (LYRA, 2010).

The polymers that make up this type of additive adsorb on the surface of the cement particles and, due to physical-chemical phenomena, promote the dispersion and separation of the particles. As a consequence, the hydration speed and setting times of the mixture are altered, that is, in excess they modify the reaction kinetics of the cement (LYRA, 2010 and LYRA et al., 2012). According to Kismi et al. (2011), for a certain water/cement ratio, the maximum dosage of superplasticizer (SP) is defined from the saturation point of the slump versus SP content graph, with no significant improvement in the flowability of the mixture after this point.

When incorporated into concrete in small quantities, even during mixing, superplasticizers modify the properties, both in the fresh and hardened state. According to Lyra (2010), additive levels between 0.05 and 1.5% result in a decrease in the yield stress and viscosity of the mixture, in addition to increasing the cement setting time.

According to Papayianni et al. (2004), the granulometry of the mixture also influences the performance of superplasticizers, especially the fines portion. Small aggregates, such as those from rivers, reduce the performance of dispersants, increasing the number of voids in the concrete.

The Excess Paste Theory establishes that workable concrete has a volume of paste greater than the volume of spaces in the compacted aggregate mixture. This excess paste, necessary to fill the spaces between the solid particles, depends on the consistency of the paste and the surface area of the aggregates. (KISMI *et al.*, 2011).

## ANDREASEN MODEL OF PARTICLE PACKING

The model proposed by Andreasen only considers the size of the largest particle and treats the distribution as continuous, including infinite small particles in the calculations (DINGER, 2001). Thus, the expression proposed by Andreasen for the distribution of particles is that presented in Equation 1.

$$\frac{CPFT}{100\%} = \left(\frac{D^n - D_S^n}{D_L^n - D_S^n}\right) \frac{CPFT\,\%}{100} = \left(\frac{D}{D_L}\right)^n \qquad \text{(Equation 1)}$$

CPFT being the accumulated percentage of particles finer than diameter D, which is the diameter of the particle in question; DL is the diameter of the largest particle and “n” is the modulus or distribution coefficient.

The value of the coefficient “n” that provides the greatest packing and reduces the amount of water necessary to maximize fluidity, according to studies by Andreasen is between 0.33 and 0.5, while for Funk and Dinger it is equal to 0.37 (OLIVEIRA et al., 2000). This coefficient can be obtained through the slope of the line that best describes the particle size distribution of a mixture, in a log-log graph of diameter in (ìm) versus CPFT (%). According to OLIVEIRA et al. (2000), the distribution can be divided in order to obtain two distinct coefficients: one for the fine region and another for the coarse region. The series of sieves to be used must have a ratio between sieves equal to the square root of 2 or fourth root of 2, the first reason being chosen for this work.

## CALCULATION OF MAXIMUM PASTE THICKNESS

The maximum paste thickness (MPT) is a parameter that expresses the separation distance between aggregates. This interparticle distance has a great influence on the rheological behavior of the composition, mainly on viscosity and fluidity. In concrete, the reduction in porosity with greater packing reduces the matrix volume, reducing flow due to the great interference between the aggregates (OLIVEIRA et al., 2000).

Due to the presence of macroscopic particles in concrete, the “n” distribution modules must provide a high content of concrete matrix in order to increase the distance between the aggregates and increase fluidity values. Therefore, MPT values must be maximized in order to increase the fluidity of a concrete, minimizing contact between particles (OLIVEIRA et al., 2000).

The equation for calculating the MPT was developed from the IPS (interparticle separation distance) equation, used for suspensions, with some adaptations in order to encompass the macroparticles present in the concrete. According to OLIVEIRA et al. (2000), the fluidity of a concrete can be controlled based on the MPT of the coarse particles, which can be calculated according to Equation 2.

$$MPT\ [\mu m] = \frac{2}{VSA} \cdot \left[\frac{1}{Vs} - \left(\frac{1}{1-PFr}\right)\right] \cdot 10^4 \qquad \text{(Equation 2)}$$

VSA being the specific volumetric surface; Vs the volumetric fraction of solids of only the coarse particles and PFr is the expected fraction of pores in the mixture.

The calculation of the volumetric specific surface (VSA, Equation 3) was carried out based on the proportional sum of the contributions of the volumetric fractions ($x_i$) and the values of the sum of the specific surfaces (SSA, Equation 4) of each raw material (*i*) multiplied by the respective specific mass (ñ$_i$ in g/cm3). However, to determine the SSA it is necessary to add up the contribution of each class (*i*). The SSA, in turn, was obtained from the particle size distribution, assuming that they have spherical geometry and constant density between classes (HUNGER, 2008). From the geometric mean diameter (GMS, Equation 5), the specific surface (SA, Equation 6) and particle volume in class i (Vp, Equation 7) were calculated, with Vp being necessary to calculate the number of particles (NP, Equation 8) of each class. In the present work, the apparent volume of each class of sieve was also measured.

$$VSA\left[\frac{m^2}{cm^3}\right] = \sum_i^n \ xi.\rho_i.SSA_i \qquad \text{(Equation 3)}$$

$$SSA\left[\frac{m^2}{g}\right] = \frac{1}{massa\ de\ 1\ m^3}\sum_i^n SA_{classe\ i} \,.\, NP_{classe\ i} \qquad \text{(Equation 4)}$$

$$GMS_{classe\ i}\ [\mu m] = \sqrt{(D_{superior} \,.\, D_{inferior})} \qquad \text{(Equation 5)}$$

$$SA_{classe\ i}\ [(\mu m)^2] = \pi.GMS^2 \qquad \text{(Equation 6)}$$

$$V_p\ [(\mu m)^3] = \frac{\pi.GMS^3}{6} \qquad \text{(Equation 7)}$$

$$Número\ de\ Partículas\ (para\ 1cm^3) = \left(\frac{\frac{\%\ retida_{volume}}{100}}{V_{partícula}}\right).$$

$$(10^{12})NP_{classe\ i}\ [partículas\ em\ 1m^3] = \left(\frac{fração\ volumétrica\ retida\ na\ classe\ i\ .\ 1m^3}{V_{p\ classe\ i}}\right).10^{18} \qquad \text{(Equation 8)}$$

The calculation of the solid volumetric fraction (Vs) consists of the ratio between the volume of the fraction with a diameter greater than 0.150 mm, considered the coarse fraction, and the total volume of the concrete, calculated based on the sum of the volumes of the materials. The expected pore fraction (PFr) was obtained using relationships used by DINGER (2001). The author establishes through Equations 9 and 10 the relationships between the maximum apparent volume (Va), the expected pore fraction (PFr) and the packing factor (PF).

$$V_a = \frac{1}{PF} \qquad \text{(Equation 9)}$$

$$PFr = 1 - PF \qquad \text{(Equation 10)}$$

$$V_{a\,n} = \sum_{j=1}^{n-1} x_j + a_n x_n \qquad \text{(Equation 11)}$$

The maximum apparent volume is the largest value calculated among the sieve classes using Equation 11, "n" corresponds to the sieve to be calculated, $V_{an}$ is the apparent volume calculated for the nth class (sieve), $x_j$ and $x_n$ are the volumetric fractions of classes "j" and "n", respectively and, $a_n$ is the apparent volume of a monodispersion of the nth class, defined by Equation 12.

$$a_n = \frac{1}{1-\left(\frac{1}{CSR}\right)^{0,37}} \qquad \text{(Equation 12)}$$

CSR is the class of sieves used. According to DINGER (2001), for a CSR of √2, the number is equal to 8.3090.

## MATERIALS AND METHODS

To carry out the tests, high initial strength Portland cement CP V ARI, fine natural sand (quartzite), artificial sand (granite) and crushed stone 0 (granite) were used. From raw material characterization tests and compaction tests, two ratios were determined, by mass, for the study of natural sand, artificial sand and crushed stone 0 (4.8 to 9.5) mm: 25%: 25%: 50% (C1) and 0%: 50%: 50% (C2). For each relationship, 3 "m" values were assigned: 4.0; 4.5 and 5.0, with "m" being the mass ratio between dry aggregates and cement and the water/cement factor (w/c) equal to 0.45, which according to NBR 6118 /2014 is the maximum value for concrete to be classified as aggressiveness class IV. The super plasticizing additive used was MC-Power Flow 1102, a 3rd generation synthetic additive based on polycarboxylates. The quantities of deflocculant for each mix were defined by the result of 80 mm obtained in the cone slump tests, standardized by NBR NM 67 - Concrete (ABNT, 1998). Table 1 indicates the compositions studied.

| Sample | C1 m 4 | | C1 m 4,5 | | C1 m 5 | | C2 m 4 | |
|---|---|---|---|---|---|---|---|---|
| "m" | 4 | | 4,5 | | 5 | | 4 | |
| Cement Consumption (kg/m3) | 436 | | 398 | | 370 | | 433 | |
| Deflocculant (%) | 0 | 0,15 | 0 | 0,2 | 0 | 0,3 | 0 | 0,2 |

Table 1 – Compositions Studied – w/c = 0.45

## SPECIFIC MASS

The specific masses of each composition were obtained from the mass ratio between the specific masses of each material, obtained as specified in NBR NM 52 (ABNT, 2009).

### APPARENT VOLUME

The volume of 500 g of raw materials and the C1 and C2 composition of the aggregates were compacted and measured in a beaker. The total masses were measured, as well as those retained on the sieve with an opening of 0.150 mm.

### ADAPTED L-BOX TEST

Standardized by NBR 15823-4, the L-box test aims to determine and evaluate the passage of self-compacting concrete (SCC), in the fresh state, between the reinforcement openings (ABNT, 2010). The test also makes it possible to observe the fluidity and segregation tendency of the mixture, essential properties for the application of not only fluid concretes such as SCC, but also viscous and cohesive ones that present fluidity at the time of application, such as extruded concrete, by vibration.

The adapted L-box has the same dimensions as the conventional one, with the only difference being the insertion of a hose vibrator in the reservoir, since the compositions studied result in non-self-compacting concrete, with vibration being essential for flow to occur.

Thus, the adapted L-box test allows testing cohesive compositions with low workability, as the vibrator inserted at the time of the test favors the fluidity of the mixture.

During the test, the vibrator was kept centralized and the concrete level in the reservoir was monitored.

The test followed the following procedures:

1) After previously mixing the materials in a concrete mixer with an inclined axis, 13 kg of concrete were added, with the gate closed, into the vertical reservoir of box L;

2) The initial height (H0) of the concrete inside the reservoir was measured;

3) Pre-vibration was applied to the concrete, even with the gate closed, to eliminate voids. Then, the height H0 was measured again after vibration;

4) With the vibrator turned off, the gate was opened and the behavior of the concrete was checked, which did not move;

5) The vibrator was turned on for 5 seconds and the flow was observed. The distance traveled was measured, as well as the heights H0, H1 and H2, when possible (Figure 1);

6) The vibrator was turned on for approximately 1 more minute and, immediately after the end of time, the total distance traveled and the heights $H_0$, $H_1$ and $H_2$ were measured.

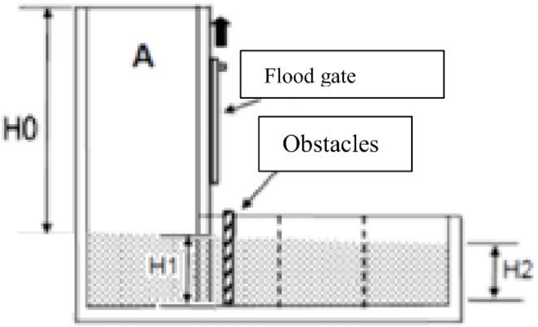

Figure 1 - Location of measurements in box L.

Source: Nepomuceno, 2005 (adapted).

Throughout the test, items such as ease of molding, appearance, cohesion, presence of exudation or segregation, fluidity (with the gate open and later with vibration) and whether the concrete returned to rest after the vibration ceased were observed.

## RESULTS AND DISCUSSION

The specific mass and apparent volume values of the compositions are indicated in Table 2. Compositions C1 and C2 have approximately the same packing density.

| Characteristics of the Compositions | C1 | C2 |
|---|---|---|
| **Specific mass (kg/m3)** | 2615 | 2590 |
| **Total Apparent Volume (mL)** | 600 | 600 |
| **Apparent Vol. Above 0.150 mm (mL)** | 500 | 500 |
| **Total Packing Density** | 0,637 | 0,644 |
| **Packing Density Above 0.150mm** | 0,692 | 0,717 |

Table 2 - Specific Mass and Apparent Volume for 1kg of composition material

To obtain the distribution coefficients for the fine and coarse fraction of each composition, the graphs of % CPFT versus Sieve Opening (µm) were plotted on a log-log scale (Figure 2). Andreasen's theoretical curve, with n = 0.37, was also plotted, along with the trend lines corresponding to each fraction.

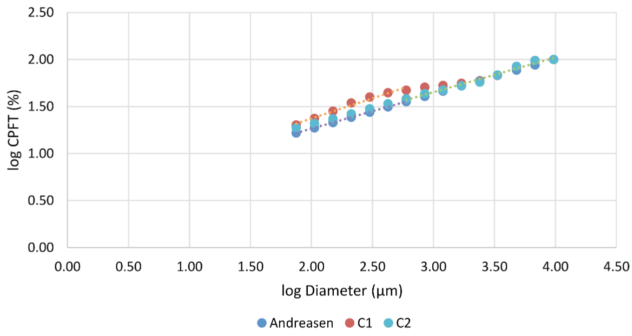

Figure 2 - Log-log graph of CPFT (%) versus Sieve Opening (ìm)

The angular coefficients obtained from the linear regression for the coarse fraction common to Compositions 1 and 2, the fine fraction of Composition 1 and the fine fraction of Composition 2 in the graph in Figure 2 were 0.3693, 0.4290 and 0. 37, respectively, indicating that composition 2 is better packed, overlapping Andreasen's maximum packing curve. The R2 values obtained from the trend lines were 0.982 for the coarse ones, 0.979 for the fine ones in C1 and equal to 1 for the fine ones in C2.

## MAXIMUM PASTE THICKNESS

The results of the calculations carried out to obtain the Maximum Paste Thickness (MPT) value for the compositions studied are presented in Tables 3 and 4. Composition C1 has more fines than C2, which reflects in the higher values of SSA and VSA, as well as the lower PFr value, as C2 is more compacted. The negative MPT values found indicate a lack of material between coarse particles larger than 0.150 mm, typical of material with zero slump. The higher the value of m, that is, the smaller the amount of cement, the lower the MPT value, which is consistent with the greater need for deflocculant to achieve the same slump. The volumetric solids concentration (VS) of C1m4.5 is close to that of C2m4, which would explain the need for a larger volume of superplasticizer in relation to the C1m4 composition. As the C2m4 composition has fewer fines, they do not occupy the spaces between the coarse particles, reducing the MPT value in relation to C1.

| Composition | SSA ($m^2/g$) | VSA ($m^2/cm^3$) | PFr |
|---|---|---|---|
| **C1** | 3030,7 | 7931,6 | 0,457 |
| **C2** | 2090,7 | 5346,7 | 0,498 |

Table 3 - Calculation results based on the composition of aggregates with particle sizes above 150 mm

| Sample | C1 m 4 | | C1 m 4,5 | | C1 m 5 | | C2 m 4 | |
|---|---|---|---|---|---|---|---|---|
| **Defloccu-lant (%)** | **0** | **0,15** | **0** | **0,2** | **0** | **0,3** | **0** | **0,2** |
| **VS** | 0,5979 | | 0,6213 | | 0,6418 | | 0,6158 | |
| **MPT (µm)** | $-4{,}298 \times 10^{-1}$ | | $-5{,}888 \times 10^{-1}$ | | $-7{,}181 \times 10^{-1}$ | | $-9{,}311 \times 10^{-1}$ | |

Table 4 - VS and MPT calculation results

## ADAPTED L BOX

The tests were carried out for the 8 chosen compositions, evaluating aspects of appearance, behavior and flow profile. Previous vibration with the gate still closed was used in order to eliminate the influence of voids created when placing the material in the reservoir, in addition to facilitating the placement of the vibrator. The flow profile of the compositions is shown in Figure 3.

It is noted that compositions with additives make the curve smoother, indicating that the flow is more uniform and the mixture is distributed more linearly in the box than those without additives. The only composition that showed uniform flow without additive was the composition C2 m4.0%.

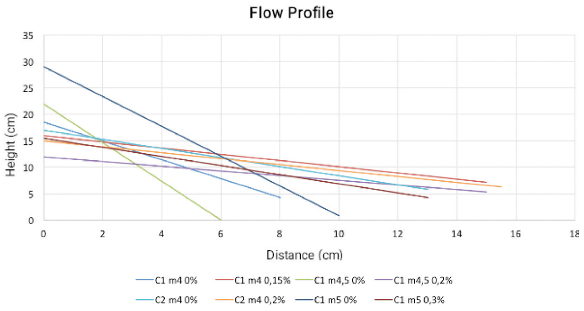

Figure 3 - Composition Flow Profile

Furthermore, mixtures with superplasticizers reached greater distances for the same time interval, as shown in Figures 4 to 7.

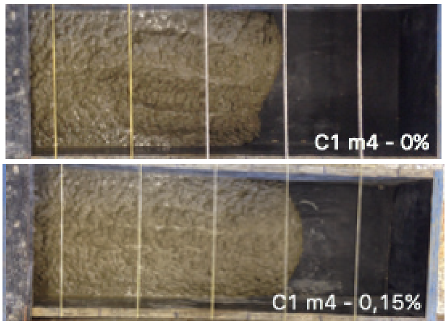

Figure 4 - Flow of Composition C1 m4 0% and 0.15%

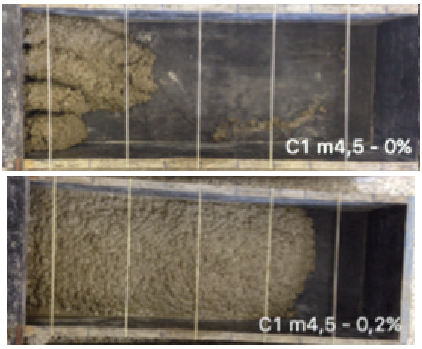

Figure 5 - Flow of Composition C1 m4.5 0% and 0.2%

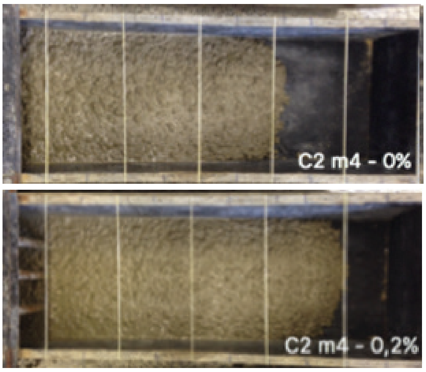

Figure 6 - Flow of Composition C2 m4 0% and 0.2%

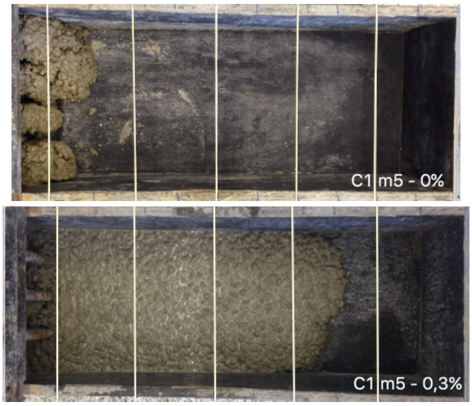

Figure 7 - Flow of Composition C1 m5 0% and 0.3%

The greatest distances for the same time interval (60 seconds) were obtained by the compositions C1 m4.5 - 0.2% (52 cm), C2 m4 - 0.2% (57 cm) and C1 m5 – 0.3% (57 cm), indicating that the presence of additives in the mixture directly influences the flowability of concrete under vibration.

During the tests, it was observed that no mixture moved under its own weight, only under vibration. In general, the compositions with additives had a wetter appearance and were more easily moldable and fluid when vibrated.

The flow rate (in kg/s) of each of the compositions was also calculated. The results are presented in figure 8.

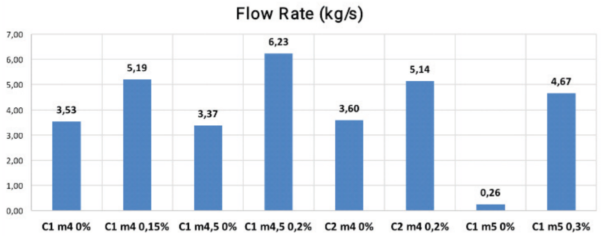

Figure 8 - Flow Chart

The compositions with additive had higher flow rates than those without additive, maintaining close values, between 5.14 kg/s and 6.23 kg/s. It is noted that the composition C1 m5 - 0% presented the lowest flow rate, and the composition C1 m 4.5 0.2%, the highest.

## MECHANICAL RESISTANCE TO AXIAL COMPRESSION

Figure 9 illustrates the compressive strength results for the 8 compositions analyzed. It was found that the lowest resistances were obtained for the compositions C2 m4 - 0% and C1 m5 - 0% and 0.3%, drier mixtures that are difficult to mold. This indicates that the amounts of cement and additive influence the average resistance after 7 days.

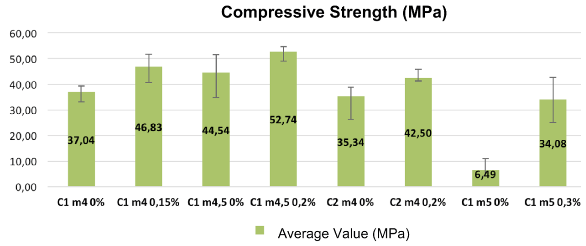

Figure 9 - Compressive Strength Graph after 7 days

## CONCLUSIONS

Through adapted L-box tests, it was observed that even concretes without additives and with lower workability, when subjected to vibration, have a homogenized surface and flow, changing their initial appearance from dry to more fluid.

The Maximum Paste Thickness (MPT) calculations resulted in negative values, indicating that the mixtures would lack paste between grains larger than 0.150 mm. The amount of superplasticizer, necessary to achieve a slump of 80 mm, was more consistent with the VS value than with the amount of cement for different aggregate compositions, however there was no significant difference in the flow rate between compositions C1m4 and C2m4 without superplasticizer.

Practically all compositions showed average resistance at 7 days well above the reference value used in the industry, with the exception of the composition C1 m5.0 - 0% and 0.3%. The low values obtained for these compositions are mainly due to the difficulty in molding the test specimens, as the compositions resulted in dry mixtures. In the case of composition C1m5, the addition of superplasticizer significantly improved resistance due to improved moldability.

## THANKS

Thanks to ``Cimento Itambé`` and ``Cassol Pré-fabricados``.

# REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 6118: Projeto de estruturas de concreto - procedimentos.** Rio de Janeiro, 2014.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 9062: Projeto e execução de estruturas de concreto pré-moldado.** Rio de Janeiro, 2006.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **ABNT NBR 15823-4 - Determinação da habilidade passante - Método da caixa-L.** Rio de Janeiro, 2010. 4p.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR NM 45**: **agregados - Determinação da massa unitária e do volume de vazios.** Rio de Janeiro, 2006.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NM 67: Concreto - Determinação da consistência pelo abatimento do tronco de cone.** Rio de Janeiro, 1998.

DINGER, D. R. **Particle Calculations for Ceramists.** D.R. Dinger Publishing, Clemson, SC, 2001.

GEYER, A. L. B.; SÁ, R. R. **Importância do Controle de Qualidade do Concreto no Estado Fresco.** Realmix - InformativoTécnico. A. 2. V. 2. 2006.

HOORNAHAD, H., KOENDERS, E. A. B. **A performance-based method for granular-paste mix design.** 9th International Masonry Conference in Guimarães, 2014.

HUNGER, M.; BROUWERS, F.H.F. Flow analysis of water-powder mixtures: application to specific surface area and shape factor. **Cement and Concrete Composite**, 31, 2009.

KISMI M., SAINT-ARROMAN, J., MOUNANGA, P. Minimizing water dosage of superplsticized mortars and concretes for a given consistency. Université de Nantes – IUT Saint-Nazaire, Nantes, France, 2011.

LYRA, J. S. **Estudo da influência de policarboxilato comercial na hidratação, reologia e físico-químida de superfície do cimento.** Diss. Mestrado, Escola Politécnica da Universidade de S. Paulo, S. Paulo, SP, 2010.

LYRA, J. S.; ROMANO, R. C.O.; PILEGGI, R. G.; GOUVÊA, D. **Consolidação de pastas cimentícias contendo policarboxilatos um estudo calorimétrico e reológico.** Escola Politécnica da Universidade de S. Paulo, S. Paulo, SP, 2012.

MELO, K. A.; MARTINS, V. C.; REOETTE, W. L. **Estudo de compatibilidade entre cimento e aditivo redutor de água.** Ambiente Construído, V. 9. N. 1. P. 45- 56. 2009.

NEPOMUCENO, A. A. **Mecanismos de Transporte de Fluidos no Concreto**. Concreto: Ensino, Pesquisa e Realizações. São Paulo: IBRACON, 2005.

NEVILLE, Adam M. **Propriedades do Concreto.** 5ª ed. São Paulo: Bookman, 2015. 912 p.

QUEVEDO, Valéria R. B. **Estudo de Composição de Concreto Extrudável para Pré Fabricados.** Dissertação de Mestrado, Universidade Tecnológica Federal do Paraná, Curitiba, 2013.

OLIVEIRA, C. O. **Análise das Propriedades Reológicas de Materiais Cimentícios Associando o Conceito de Empacotamento de Partícula.** 2013. 142p. Dissertação de Mestrado, Faculdade de Engenharia, UNESP. Ilha Solteira, 2013.

OLIVEIRA, I. R.; STUDART, A. R.; PILEGGI, R. G.; PANDOLFELLI, V. C..**Dispersão e empacotamento de partículas - princípios e aplicações em processamento cerâmico**. Fazendo Arte Editorial, 2000. 195 p.

PAPAYIANNI, I.; TSOHOS, G.; OIKONOMOU, N.; MAVRIA, P. **Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures.** Aristole University of Thessaloniki, Thessaloniki, Greece, 2004.

RICHARDSON, J. **Advanced Concrete Tehnology 3: Processes.** Butterworth-Heinemann, 2003.