Determination of Shrinkage and Compressive Strength of Concrete with Construction and Demolition Wastes

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Abstract — Civil construction in Brazil has undergone steady growth and this has led to a rise in demand for construction materials and more efficient techniques and practices. In this context, reinforced concrete construction stands out, especially in association with other elements, such as steel, creating high performance mixed structures. These elements should work together so that the loads and deformations are equal, thus avoiding premature rupture. Therefore, the aim of this study is to develop two devices which allow evaluation of temperature variation and plastic shrinkage in drying of a concrete with aggregate of construction and demolition wastes (CDW). For purposes of this study, the materials were characterized and a concrete mixture ratio was defined in the proportion of 1.000:1.830:0.849:1.981:0.657 (cement: sand from CDW: gravel 0 from CDW: gravel 1 from CDW: water) in weight, with Slump Test in the value of 30 mm. Set up of the device for temperature measurement and shrinkage was immediately after molding of the test specimen, and remained for 7 days. During the concrete curing process, temperatures and displacements were registered, which allows understanding of existing events.

Index Term — Concrete; construction and demolition wastes (CDW); shrinkage; ultrasound.

I. INTRODUCTION

The strength of hardened concrete, just as other properties, is a result of the composition of the matrix, paste and air mixture, and by ratios such as cement and water content. Ratios between voids and the cement may be expressed. The voids are occupied in the first place by water; this therefore allows the ratio to be established in terms of the water/cement factor. Part of the water, 23 to 25% of the weight of the cement, is hydrated and the rest is eliminated during curing through evaporation.

According to [1], the presence of fine inert powders in the mixture, which is common in construction and demolition wastes (CDW), may require more water for wetting and may thus increase the initial hydration rate of the Portland cement, which results in multiplication of sites where hydrates may grow and thus increase the heat of hydration rate, thus promoting cracking by shrinkage, which leads to reduction in compressive strength and durability of the concrete[16 and 17]. When the powders are active, such as elements with hydraulic charges and/or pozzolanic activity, heterogeneous nucleation of hydrates is produced. For example, for a mixture with active silicon, the pozzolanic reaction is added to the nucleation process and thus reduces the hydration speed in early age, which reduces the quantity of heat generated, and thus the volumetric variation also reduces. As the strength of the concrete is a function of the hydration process of the cement, which is relatively slow, and when due care is not taken, there is the rise of cracks in the concrete due to shrinkage. [2]. According to [3], this trend toward cracking is one of the most serious disadvantages of the use of concrete in construction projects.

In regard to the incorporation of waste products in production of materials, [4 and 6] affirm that it is a possibility for reducing energy consumption in the production of a given product using residues and, depending on where the residue and its consumer market is located, it may reduce transport distances and thus contribute to reducing cost. Authors [7, 8,18 and 19] highlight that the insertion of CDW as aggregate in the concrete leads to surprising results in regard to compressive strength, tensile strength and elasticity modulus over time.

It should be noted that concrete prepared with recycled aggregate, which contains varied materials, such as ceramic, gravel, mortar, among other materials, may exhibit unsatisfactory compressive strength, especially when many particles of this aggregate are ruptured, thus observing that the strength of the aggregate would be less than the nominal compressive strength of the mixture, [9, 21,22 and 23]. Another important factor, commented on by [10,19 and 20], is particle size composition, which alters the ductility and mechanical resistance of concretes. This may lead to the
existence of voids among the particles, increasing cement and water consumption, which is a result of the quantity of fine inert materials of the CDW, thus producing compounds with high porosity.

Thus, understanding the mechanical behavior of construction materials, as in the case of construction and demolition wastes (CDW), is fundamental for successfully placing them on the market and, above all, being able to evaluate the properties of these materials with simple and easily acquired devices, which makes the process less costly for the contractor and for the researcher.

In light of the above, the aim of this article is to evaluate the physical behavior of a mix ratio of conventional concrete of Portland Cement with the use of aggregate of CDW through experimental trials that allow determination of plastic and drying shrinkage, as well as temperature variation over the curing period.

It is emphasized that this work was comprised one single concrete mix with CDW, evaluated both dispositive (shrinkage and temperature) on a single test piece of 15 cm diameter and 30 cm in height. This was due to the limited availability of space and equipment in the Structures Laboratory, such as data acquisition system and thermocouples.

II. MATERIALS AND METHODS

A. Basic concepts

Concretes currently produced with CDW often do not exhibit satisfactory mechanical resistance and/or physical properties to fully serve projects with high loads and with adverse environmental conditions. Some properties have a greater or lesser influence on these characteristics.

Shrinkage. This is a phenomenon which occurs in the concrete and is characterized by reduction in volume due to water loss through suction of the forms, through evaporation or through chemical reaction of the components of the cement and water. Cracks through plastic shrinkage may appear after finishing of the concrete and may be mapped, visibly or in microcracks, and may or may not affect the entire thickness of the concrete. Their dimensions, opening and width are greater on the surface, decreasing rapidly with depth. The cracks from shrinkage allow water percolation through the already hardened concrete, compromising its imperviousness and, consequently, its useful life. Shrinkage may be classified as plastic, which is characterized by water loss before setting of the cement, when the solid fraction of the mixture has mobility of particles in relation to each other. Reduction in volume of the system corresponds to the volume of water lost. The greater the heat of hydration, the greater this effect will be. The higher the heat of hydration of the cement greater this effect. In the hardened state, this effect occurs after setting of the cement and is known as drying shrinkage. This depends on the size and type of void that loses water and the way the water is bonded to the solid surfaces of the hardened paste. It may be free, if adsorbed in the internal walls of its structure, between the layers of the calcium silicate hydrate (C-S-H) or chemically combined. It is considered that the magnitude of total shrinkage of the hardened paste depends directly on the degree of difficulty found for removal of the water and on the mechanical properties of the CDW concrete. Author [11] mentions that in addition to water loss, shrinkage may have other causes, such as thermal shrinkage (through carbonatation or through hydration of the cement) and autogenous shrinkage, which may occur at the same time or in different phases of the useful life of the concrete. Water loss is one of the main causes of shrinkage in cement-based composites, occurring in the saturated state after mixture, when these materials normally are exposed to environments with relative humidity below 100%.

Heat of hydration. According to [2], the heat of hydration, or temperature variation during curing, occurs because of variation of the external temperature. Simply the day and night cycle may cause it, and it is mainly due to exogenous chemical reactions between the cement and the water during hydration of the cementitious composites. Heat of hydration may occur over months, in accordance with cement consumption and/or volume of the cementitious composites. The temperature depends, above all, on the characteristics of the cement, such as chemical composition, quantity and type of additions and fineness, on their content in the concrete mix and on the quantity of water. Reference [11] adds even more factors that affect shrinkage, such as temperature of the mixture and of the environment, incidence of solar radiation, relative air humidity, and wind speed, among others. In some situations, the heat of hydration may be a problem, as for example in structures with a high volume of concrete (dams), and in concretes with very large exposed areas, which generates cracks due to accelerated shrinkage. Moreover, it may cause problems in mixed structures like concrete pillars and beams encapsulated in steel, causing detachment of these elements, which reduces their constructive efficiency. In other situations, temperature variation or heat of hydration may have a positive effect, as in the case of services with these composites during the winter when the environmental temperature is very low, and it may be necessary to provide energy for activation of the hydration reactions, [3].

B. Influence of the properties of the concrete on temperature and on shrinkage

Consistency is the property in which the concrete, in the fresh state, tends to resist deformations, where the quantity of water in it is one of the main factors which affects the concrete in the curing process. It is associated with the workability of the concrete during its application. Authors [12] affirm that consistency and workability are very important in the fresh state since they recommend or restrict utilization of the concrete.

Cohesiveness, according to [13], may be understood as coalescence. This property is directly connected with finer
constituents, i.e. with the greater specific area of the solids, with the paste and the part of the fine elements being responsible for the cohesion of the concretes. Thus, it may be said that cohesion in the fresh state of the concrete will be reflected in the hardened state, more specifically in tensile strength, which may be evaluated through the pure tensile stress test.

In the case of exsudation, there is a phenomenon of separation of part of mixing water of fresh concrete maintained at rest without any type of vibration or shock, which thus constitutes a form of segregation in which the solids tend to settle under the force of gravity and the components of the concrete do not retain the water of the mixture in a dispersed state while the solids are setting, [14]. When exsudation occurs, a different process of hydration will develop in the layers of the concrete, which may cause spalling and variation in strength in the hardened state.

According to [15], the rheological behavior of cement-based materials is complex, due to the different types (concretes, mortars, fiber cement), to the mixing conditions (speed, time, confinement) and applications (extrusion, self-compacting, pumping, etc.), in addition to the reactive nature of the cement. This variety of materials and applications requires different rheological characteristics that may or may not accelerate the hydration processes and consequently increase the heat generated, causing shrinkage. For [13], rheological behavior is affected by diverse factors, such as volumetric concentration of solids, characteristics of the liquid medium, temperature, time elapsed since the beginning of mixing, physical characteristics of the particles (particle size distribution, density, morphology, surface area and roughness) and type of particle interaction in the medium (state of dispersion).

C. Material

The materials used were high initial strength Portland Cement – CP V-AR1, which generates high heat of hydration already in the early ages of curing, fine and coarse aggregates obtained from construction and demolition wastes from the recycling plant of the Belo Horizonte, Brazil city government, the characteristics of which are shown in Table 1, and potable water from the distribution network.

After characterizing the materials, a concrete mix ratio was defined in the proportion of 1.000:1.830:0.849:1.981:0.657 (cement: sand from CDW: gravel 0 from CDW: gravel 1 from CDW: water) by weight, with Slump Test at the value of 30 mm. With this mix ratio, a test specimen (TS) was fashioned on which a device was set up to determine temperature and the plastic shrinkage and drying shrinkage of the concrete with CDW. Test specimens (TSs) were also fashioned for their characterization. The choice of the mix ratio is based on the study of [16].

### Table 1: Physical Characteristics of the Aggregate of CDW

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Sand</th>
<th>Gravel 0</th>
<th>Gravel 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum diameter (mm)</td>
<td>4.8</td>
<td>9.6</td>
<td>19.0</td>
</tr>
<tr>
<td>Fineness modulus</td>
<td>2.65</td>
<td>5.48</td>
<td>6.83</td>
</tr>
<tr>
<td>Real specific mass (g/cm³)</td>
<td>2.64</td>
<td>2.64</td>
<td>2.64</td>
</tr>
<tr>
<td>Unit specific mass (g/cm³)</td>
<td>1.44</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td>Clay content</td>
<td>Exempt</td>
<td>Exempt</td>
<td>Exempt</td>
</tr>
<tr>
<td>Powder material content (%)</td>
<td>4.00</td>
<td>0.70</td>
<td>0.50</td>
</tr>
<tr>
<td>Organic impurity (p.p.m.)</td>
<td>&lt;300</td>
<td>&lt;300</td>
<td>&lt;300</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>10.47</td>
<td>5.06</td>
<td>4.34</td>
</tr>
<tr>
<td>Shape of particles</td>
<td>Angular</td>
<td>Angular</td>
<td>Angular</td>
</tr>
</tbody>
</table>

D. Determination of shrinkage and temperature

Shrinkage (S) is calculated by S=ΔL/L (%) where ΔL is the contraction and L the length of the TS. In the TSs, it was observed that the temperature increases, causing dilation of the TS, generating errors in measurement of shrinkage. To avoid these errors, the external temperature must be controlled, placing all the TSs in the same environment with equal temperature, wind and sun, and measuring ΔL until its stabilization, in a more accentuated way during curing and less during drying. Figure 1 illustrates possible variations during curing. Shrinkage is an event that occurs in three dimensions; however, at this time it is only possible to evaluate the upper surface of the TSs and, as of the correlations, the volumetric shrinkage of the concrete is determined.

The chemical reactions that will occur in the concrete will promote an expansion process, especially in the beginning, which may falsify the result of the shrinkage. Because of that, the temperature will also be measured. As the temperature varies according to curing time and shrinkage, i.e., temperature variation will occur due to the chemical reactions in the Portland Cement concrete, a thermocouple inside the TS will be used. Some of these chemical reactions are: i) tricalcium aluminate (C₃A–3CaO.Al₂O₃) reacts instantly with the water with high release of heat of hydration and, thus, the addition of sulfate (gypsum) is necessary for generation of insoluble products in the water; ii) tetracalcium aluminate iron (C₄AF–4CaO.Al₂O₃.Fe₂O₃) exhibits very fast setting; iii) others, such as free calcium oxide (CaO), periclase (MgO), alkalis (Na₂O, K₂O); iv) other compounds such as calcium silicates [t(C₂S, C₂S)₂,C₃S+6 H₂O → C-S-H + 3 Ca(OH)₂, and 2 C₂S + 4 H₂O → C-S-H + Ca(OH)₂], which have C-S-H–3CaO.2SiO₂.3H₂O as their main component, which is known as calcium silicate hydrate (tobermorite gel).
To characterize the shrinkage phenomenon, a device was created composed of 5 potentiometric transducers, with sensitivity of 0.01 mm, and two type T thermocouples, Figure 1. These sensors were connected to a data acquisition system (DAS) controlled by a computer. This system allowed measurement of the variation of surface displacement of the concrete brought about by plastic shrinkage and then by drying and, along with that, it registered temperature variation, especially during the curing process.

A cylindrical TS of 15 cm diameter and 30 cm height was prepared in which potentiometric transducers were placed, and two thermocouples were inserted at a depth of 10 cm, Figure 2. Furthermore, 3 TSs of 10 cm diameter and 20 cm height were prepared for the ages of 1, 2, 3, 7, 14, and 28 days, for the purpose of determining the dynamic elasticity modulus through ultrasound waves, and of determining compressive strength. Figure 2-b shows the wide variety of materials in the composition of the concrete of CDW, ceramic pieces, gravel and mortar. Some of these materials have high porosity and low mechanical resistance, thus affecting the properties of the concrete, like the ceramic elements.

III. RESULTS AND DISCUSSION

Figures 3, 4 and 5 show the results of testing and the correlations as a function of time, together with the results found by [16].

![Fig. 1. Schematic of the physical event of shrinkage that occurs during curing and drying](image)

![Fig. 2. (a) Test specimen of CDW and instrumentation, (b) component materials of the TS of CDW before rupture through axial compression](image)

![Fig. 3. Axial compressive strength ($f_c$) x time.](image)
The propagation speed of the ultrasound pulse and the dynamic elasticity modulus ($E_{dim}$) are shown in Figures 6 and 7 as a function of compressive strength ($f_c$), together with the results of [16].

Upon analyzing Figure 3, an accelerated gain in strength is perceived in the early ages, 7 days, showing that the greater fineness of the CPV-ARI cement increased its exposure area, accelerating curing. In addition, an increase in the ultrasound pulse speed in the early days is observed, Figure 4, which shows that the hydration process promotes filling of the voids with the hydrated cement crystals. The $E_{dim}$ also shows a gain in the early days, which may be explained by the presence of water in the pores of the concrete, above all in the early ages, which allows passage of the ultrasound wave with greater speed, Figure 5.

The regression curves of $f_c$, $V$ and $E_{dim}$, Figures 3 to 5, exhibit the same mathematical model, with logarithmic expressions with a high $R^2$ drawing near to them. In the last two Figures, 6 and 7, the linear nature of the dependence of the $V$ and $E_{dim}$ properties in relation to $f_c$ is observed, which shows that there was greater filling of the concrete pores by the hydrated cement crystals, which promotes an increase in $f_c$, ensuring greater durability to the structure.

When compared to the results of [16], lower axial compressive strength is perceived, around 28 days of age, 13% of which may have occurred through increase of the w/c factor. Nevertheless, visual analysis of the ruptured TSs shows that the coarse aggregates coming from clayey materials exhibited rupture, showing that they reached their maximum stress, consequently leading to rupture of the concrete.

Another factor to be considered is the compaction process. The mix ratio with CDW had low workability, slump of 30 mm, requiring the use of a vibrator, whereas in the mix ratio created by [16], manual compaction was used. The use of a vibrator may have reduced the porosity of the concrete and increased its strength and the speed of the ultrasound pulse.

In comparison of the results of $E_{dim}$ with the values found by [16], a more abrupt fall is noted for 28 days, Figure 5 (31%), this fact being explained by the high porosity of the material studied, above all of the ceramic materials, which impedes the passage of the ultrasound wave, reducing its value and consequently that of the $E_{dim}$. It is important to emphasize that this reduction leaves the material more deformable, which may
restrict its use in some structural elements.

The result of shrinkage of concrete with CDW throughout the curing time is shown in Figure 8. The temperature results during the curing of concrete with CDW were disturbed by the high variation of environmental temperature and the low isolation of the TS.

Furthermore, in Figure 8, accentuated shrinkage is observed at the beginning of the process, especially in the first hour, which must have occurred in large part due to evaporation of the water from kneading. Thus, it is evident that shrinkage of the concrete is high at first, more than half of the 1.2% shrinkage after molding. Carrying out the “curing process” is indispensable to prevent this phenomenon from occurring in an accelerated manner and causing reduction in its strength and durability. Another important factor to observe is that shrinkage tends to stabilize over time; for the cement used, this may be some days or even hours, depending on the climatic conditions, or otherwise extend for days in the case of cements with low heat of hydration, such as those that have hydraulic and pozzolanic additions.

It may also be perceived that there is a small variation of deformation near the surface of the TS form and in the more internal points, which shows the existence of lateral friction of the concrete of the TS with the form, which may mask the results. However, that did not impede carrying out the test since the measurement in the center of the TS is reliable for the property under analysis.

In light of the results found, it can be seen that the devices proposed proved to be efficient, with small adjustments necessary for the results to be more precise. Thus, we propose the substitution of the TS of 15 cm diameter and 30 cm height by 5 TSs of 10 cm diameter and 20 cm height, increase of the support bracket of the potentiometers from 2x2 cm to 5x5 cm, to reduce the effect of the force of spring application, and in the set-up of the TSs of 10x20 cm, one be isolated from another with a fiberglass or rockwool cover so as to impede premature heat loss from the TSs.

IV. CONCLUSIONS

The phenomenon of shrinkage is measurable and may reach high amounts and, depending on the structural elements involved, it may cause serious damages, compromising the safety and durability of construction projects, as in the case of concretes with CDW. Reduction in the quantity of water helps in the process of decreasing shrinkage; nevertheless, it is a phenomenon that needs to be studied more so as to be sure of the percentages of variation at each moment in the curing process. Therefore, we propose that isolated forms be made to measure shrinkage in five TSs with a diameter and height proportion of 1:2, for example, 10 cm x 20 cm. We believe that this procedure will permit good verification of the shrinkage values.

In regard to temperature, we propose the use of similar TSs; however, attention should be paid to totally covering them with thermal insulation so as to avoid heat loss to the external medium. This will thus allow accurate measurement of temperature variation as a function of curing time.

In general, the procedures proved to be efficient; nevertheless, some adjustments are needed so that the measurements obtained are more precise and better characterize the phenomena which have occurred in the shrinkage of concretes with CDW.

For future studies are proposed the evaluation of plastic and drying shrinkage and temperature variation in concrete with other types of aggregate, admixtures, and cement additives. It also proposes a comparative assessment with existing normative procedures for shrinkage drying for scouting and conformation of this device for the evaluation of these properties effectively.

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LITERATURE REFERENCES

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