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Lightweight cementitious composites reinforced with *Pinus* spp. sawdust

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ABSTRACT

Aggregates play an important role in concretes and mortars, as besides reducing production costs, they have a beneficial influence on the material characteristics and on its final application. This work reports experimental investigations on the use of *Pinus* spp. sawdust as aggregate to mortars and concretes for the production of cementitious composites. Tests for sawdust characterization were performed according to standards for aggregates used in mortars and concretes. The percentages of sawdust added in mortar and concrete varied by 10, 15, and 20%. Composites were characterized according to described mortar and concrete standards. Results obtained in the granulometry test classified the sawdust as a thick and continuous aggregate, which makes it possible to use sawdust as an aggregate in concretes. In the consistency tests, the higher is the sawdust percentage, the greater is the water demand to reach the adequate workability in mortars. For water absorption test, the addition of larger amounts of sawdust resulted in higher absorption. The addition of 15% sawdust showed better results in both the compressive strength and the consistency index.

Index terms: aggregate, construction, forest residue, light constructions.

Ideias centrais

- Emprego de serragem *Pinus* spp. como agregado em materiais cimentícios.
- Propriedades no estado fresco e endurecido de sistemas cimentícios reforçados com serragem *Pinus* spp.
- Aproveitamento de resíduos florestais para o setor da construção civil.

Compósitos cimentícios leves reforçados com serragem de *Pinus* spp.

RESUMO

Os agregados desempenham um papel importante em concretos e argamassas, pois, além de reduzir os custos de produção, apresentam influência benéfica sobre as características do material e sua aplicação final. Este trabalho relata investigações experimentais sobre o uso da serragem de *Pinus* spp. como agregado em argamassas e concretos para a produção de compósitos cimentícios. Os ensaios para a caracterização da serragem foram

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realizados de acordo com as normas para agregados empregados em argamassas e concretos. A percentagem de serragem adicionada a argamassas e concretos variou em 10, 15 e 20%. Os compósitos foram caracterizados segundo as normas descritas para argamassas e concretos. Os resultados obtidos no ensaio de granulometria classificaram a serragem como agregado grosso e contínuo, o que torna possível empregá-la como agregado em concretos. Nos ensaios de consistência, quanto maior é o percentual de serragem, maior é a demanda de água para alcançar a trabalhabilidade adequada em argamassas. Para o ensaio de absorção de água, a adição de maior quantidade de serragem resultou em maior absorção. A adição de 15% de serragem obteve melhores resultados tanto na resistência à compressão quanto no índice de consistência.

Termos para indexação: agregado, construção, construção leve, resíduos florestais.

INTRODUCTION

Concretes and mortars are widely used materials in the civil construction industry because of their capacity of compressive strength and ability to shape in various geometric configurations (Neno et al., 2014). Concrete and mortar uses are only feasible when using aggregates, since they offer characteristics such as shrinkage reduction of concrete and mortar, and strength increase, which makes the final product cheaper. However, aggregates have been used intensively, which in a way generates innumerable environmental impacts due to their extraction. Thus, within the construction sector, solutions have been sought to offer a sustainable model, in order to minimize negative effects of its activity of production and extraction of raw material, besides proposing the appropriate waste management, assessment, reuse, and recycling (Argiz et al., 2014; Saiz-Martínez et al., 2015). The use of industrial waste as substitutes for virgin raw material in the construction results in the reduction of the environmental impact of both industries (Mehta & Monteiro, 2008).

Lightweight composites generally comprise two components: a reinforcing material and a binder (usually called as matrix). The lightweight construction shows prospective material for the composite industry reinforced with lignocellulosic materials. Using lightweight concrete and mortars is an alternative to minimize the environmental impacts of construction, as they show various advantages for their use in several applications, allowing of the reduction of costs by employing wasted or low-cost materials in the manufacturing process, and they can show high resistance, durability, lightweight, and low maintenance requirements (Corinaldesi, 2012; Stevulova et al., 2013).

Sawdust generated by timber industries is a residue that has potential to be used as an aggregate (Gil et al., 2017). For this purpose, it is necessary to carry out a detailed study on the characteristics of wood residue to be used, as well as the effects on concretes and mortars after incorporation (Hiramatsu et al., 2002; Osei & Jackson, 2016).

For each new raw material used in the production of cementitious composites, there is a need for studies of the variables that can influence the properties in the fresh and hardened state of the final product, such as chemical composition, particle size distribution, moisture content, water absorption, and properties related to the incorporation of these materials, such as workability, mechanical strength, durability, aggregate quantity, and distribution (Santana et al., 2018; Silva et al., 2018).

For mortar, one of the most important properties is its workability in fresh state. Once this is not workable, water is added, so that the mortar is easily spread over the coating (Bastani & Kansal, 2015). However, this increase of water content can cause segregation and exudation in fresh state and, consequently, the reduction of strength in the hardened state (Angelin et al., 2018). In this situation, additions, aggregates, and residues act because the granulometric composition of the used material and its physical and chemical characteristics influence the final product; this is also an efficient way of diversifying mortars rheological properties (Stolz & Masuero, 2015).

Concretes are materials of great importance for civil construction are widely used in structural and non-structural elements. Required concrete characteristics in the fresh state, such as workability, – and, in the hardened state, such as compressive strength, are met through structural performance and safety requirements imposed by current standards (Ribeiro et al., 2016).

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Many factors can influence concrete durability whose properties are directly associated with dosage, type of the material used, and production process. The choice of concrete components is the principle of searching for concretes with specific characteristics that result in the desired performance (Ribeiro et al., 2016). To ensure sustainability and reduce concrete costs, the use of residue as aggregates is desirable (Acheampong et al., 2013; Onuaguluchi & Banthia, 2016).

The objective of this work was to evaluate the potential of *Pinus* spp. sawdust as aggregate to reinforce composites for concretes and mortars, through tests of sawdust granulometry and consistency index, water absorption, and compressive strength of cementitious composites.

MATERIALS AND METHODS

Wood sawdust of *Pinus* spp. came from the Santa Maria Company of Paper and Pulp located in the municipality of Guarapuava, PR, Brazil. The cement used was the CP II Z 32, Itambé Brand.

Sawdust characterization

Sawdust was characterized according to its granulometry and humidity. For the particle size test, the samples were dried in an oven at 105 ± 5º C, for 24 hours, to remove the sawdust moisture, as this influence on particle size. Sharp analysis of *Pinus* spp. sawdust was determined from four samples which were sieved according to the ABNT/NBR NM-248/2003 standard (ABNT, 2003).

The determination of fineness modulus was performed according to the ABNT/NBR-7217/1987 standard (ABNT, 1987), by the following equation:

$$MF = \frac{\sum \% \text{ retained}_{\text{accumulated}}}{100}$$

in which: MF is the modulus of fineness; and $\sum$% retainet$_{\text{accumulated}}$ represents the sum of percentages of retained and accumulated samples.

The maximum characteristic size of sawdust was calculated according to the ABNT/NBR-7211/2009 standard (ABNT, 2009), which corresponds to the retained percentage accumulated equal to or less than 5% by mass.

In order to classify sawdust in usable zones and in small or large aggregates, the ABNT/NBR-7211/2009 (ABNT, 2009) was also used, within the ranges for recommended granulometric distribution that vary according to the size of the sand particles (very fine, fine, medium, and thick).

As to the fineness modulus (MF) of sand, intervals for sand classification are: fine sand, MF <2.0 ; medium sand, $2.0 \leq MF \leq 3.0$; and coarse sand, MF> 3.0.

Moisture content determination was performed according to the ABNT/NBR-14929/2017 standard (ABNT, 2017).

Production of cementitious composites

Specimen preparation for the consistency index tests

Cement was made using sawdust and cementitious, with 0.4 fixed water / cement ratio (a/c). Sawdust was added by 10, 15, and 20% percentages and used as cement additive.

To evaluate the consistency index, composites were based on traditional methods for making concrete and mortar in a manual and mechanized way. These analyses were performed in four replicates, according to the variations of sawdust percentages.

Mortar was used for the cement composites produced with the mechanical mixer. The mixing procedure is below described:

- Initially, the entire amount of water and cement was added, mixing both at low speed for 30 s.
- Without paralyzing the blending operation, sawing was added during 30 s.
- Immediately after finishing sawdust placement, speed was increased to high for 30 s.
- Finally, the mixer was turned off for 1 min and 30 s, and reconnected for another 1 min, totaling a mixing time of 4 min.

The mixing procedure adopted for cement composites, reinforced with *Pinus* spp. sawdust produced by manual mixing, had a total duration of 6 min and followed the sequence below:

- Sawdust distributed all over the surface, with approximately 15 cm layer.
- Addition of cement, and mixing of both materials until obtaining a homogeneous mixture.
- Next, a conical structure with a hole in the center was mounted, where water has been added carefully and gradually.
- Finally, the entire mass was mixed until a homogeneous composite was obtained.

For water absorption and compressive strength tests, composites were made using a mechanized method.

Specimen preparation for the absorption and compression tests

After the mixing of components, specimens were molded according to the ABNT/NBR-5738/2015 standard (ABNT, 2015). After the molding of the composites, the samples were subjected to a simple curing process at ambient temperature and humidity for the period 28 days.

Cementitious composites characterization

Consistency index of cementitious composites reinforced with sawdust

For the analysis of composite consistency, the spreading test was applied through the flow table, according to the ABNT/NBR-13276/2016 standard (ABNT, 2016). Test pieces were shaped like conical trunks. Samples were produced in three layers of same height and, with a normal socket, 15, 10, and 5 strokes were uniformly distributed, applied in the first, second, and third layers, respectively, scraping the surface after blows were finished. The mold was carefully removed, lifting it vertically. Crank was moved from the apparatus to measure consistency, causing the table to fall 30 times in about 30 s. After abatement, a pachymeter was used to measure the scattering by orthogonal diameters average (in millimeters). This test was repeated four times for each sawing dosage.

Absorption assay of cementitious composites reinforced with sawdust

The absorption test of the composites was performed according to the ABNT/NBR-9778/2005 standard (ABNT, 2005), and six samples were determined for each percentage of sawdust variation. Initially, the composites were dried in a greenhouse (105 ± 5ºC) of the material and, then, the specimens were weighed. Subsequently, specimens were immersed in water at ambient temperature. With this procedure, the water absorption percentage in the composites was calculated through the following equation.

$$A = \frac{m_{sat} - m_s}{100}$$

in which: msat is the saturated mass; and ms is the dry mass.

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Compression assay of cementitious composites reinforced with sawdust

Mechanical characteristics, including the tests to determine resistance to compression at 28 days (RC 28d) were performed according to the ABNT/NBR-5739/2007 standard (ABNT, 2007). In order to avoid irregular influences on specimens' tops, and to guarantee rupture by simple compression, a grinding was used. The equipment used was a universal test machine Emic, model DL 30000, with computerized data acquisition. Four samples were tested for each percentage variation of sawdust.

Statistical analysis

A statistical analysis was performed for the tests of compressive strength and absorption of test specimens, using the analysis of variance and the Tukey´s test, with 95% confidence, to evaluate the influence of factors and difference between means.

RESULTS AND DISCUSSION

Sawdust granulometry

The material under study shows a continuous granulometry, since sawing occurs in all grades, according to the granulometric curve of *Pinus* spp. (Figure 1).

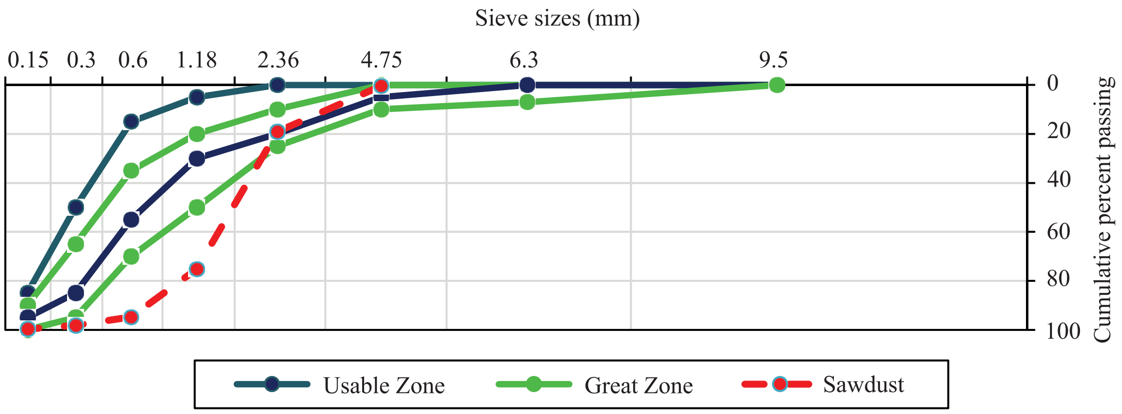

Figure 1. Granulometric curve of *Pinus* spp.

It is known that a suitable aggregate for civil construction should fills well the vacuums of mortars and concretes (Gopinath et al., 2017). This way, sawing can be used in the production of mortars and concretes, since it is a material with continuous granulometric variation.

Aggregates with a continuous granular distribution show the highest compressive strength in concretes (Meddah et al., 2010). In addition, aggregates with continuous granulometry increase the compressive strength, besides showing a workability improvement (Bastani & Kansal, 2015; Tapkire et al., 2017).

Particle packing was studied in order to obtain more economical, sustainable, and resistant concretes, and the authors concluded that aggregate particles should have several sizes, expanding their range to improve the performance of concretes (Mohammed et al., 2012; Wong et al., 2013).

Stolz & Masuero (2015) varied the granulometric fractions of each sieve, relating it to the packing factor; these authors concluded that samples with the highest uniformity index were more continuous and showed higher packaging, better mechanical properties, and lower porosity.

The limits of usable zone for concrete production, recommended by the ABNT/NBR-7211 (ABNT, 2009), can also be observed (Figure 1). It can also be noted that the curves obtained for sawdust are outside the standard range, and it does not meet the specified limits of the usable zone (Figure 1).

Fineness module and maximum feature size

The fineness modulus found for *Pinus* spp. sawdust is of 4.88 and, according to the ABNT/NBR-7211 (ABNT, 2009) standard, sawdust is classified as thick, since it has MF> 3.0. The maximum characteristic size for *Pinus* spp. sawdust is of 4.8 mm, which classifies the sawdust as kidnapped, according to the ABNT/NBR-7211 (ABNT, 2009) standard.

For concrete, sawdust could be better employed, since coarse-grained aggregates are efficiently added, reducing the cement consumption and providing greater savings (Gopinath et al., 2017). However, thicker aggregates make concrete rougher, reducing the workability, making it more difficult to perform densification (Yurugi et al., 1993). For Meddah et al. (2010), aggregates with coarse grain size are more important in normal compression strength than fine grain aggregates. Zarauskas et al. (2017) found that the increase of volumetric concentration of coarse aggregates has a negative effect on resistance to concrete freezing/thawing. According to Haach et al. (2011), the coarse fraction aggregates exhibited a more ductile behavior and lower modulus of elasticity in the mortars.

Argiz et al. (2014) studied the relation between the granulometric bands with the air permeability of the concrete, and found that aggregates of thick granulometry showed better results than aggregates of fine granulometric bands.

The coarse fraction aggregates are generally more studied because of the extreme porosity they show in mortars used in wall coverings (Neno et al., 2014). Mortars prepared with fine aggregates require more water than coarse aggregate mixture, which reduces their compressive strength (Bastani & Kansal, 2015; Tapkire et al., 2017). In the present study, sawdust can be used in concretes, but it is not indicated for use in mortars.

Moisture Content

Pinus spp. sawdust showed 8.45% average moisture content. The knowledge of moisture content is important when materials such as sand or even sawdust are applied as aggregates in mortars or concretes due to their influence on the water/cement factor (Domagala et al., 2015). Water / cement factor is also directly related to adequate resistance of concrete or mortar (Haach et al., 2011) A critical moisture content of fine aggregate (sand) of 5% was reported by Lima & Iwakiri (2014), which is a value below that found for *Pinus* spp. Sawdust, and it could suffer changes in the amount of water to be used in mortar or concrete.

Consistency index of cementitious composites reinforced with sawdust

Firstly, procedures of blends of reinforced cementitious composites with *Pinus* spp. sawdust and later the results of the consistency assay through the flow table.

Mixing Procedures for Composites

For composites produced manually and mechanically, it was verified that higher the percentage of sawdust, less fluid became the composite, reducing the ease of execution and handling of samples. The inclusion of sawdust in cementitious pulp considerably reduces the workability.

Memon et al. (2017) studied sawdust for use in light concrete, since Raheem et al. (2012) and Dhull (2017) verified sawdust powder. All these authors obtained the same conclusion: that the increasing the incorporation of sawdust also increases the water demand, so that it reaches the desired workability; this means that the sawdust increase causes the workability decrease of cement-based components. Therefore, it is important to standardize the maximum possible variable, using mechanized procedures instead of manuals (Stolz & Masuero, 2015).

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Consistency test

From composites produced mechanically, it can be verified that the sample produced with 10% was very fluid, which made it difficult to perform the consistency test with samples spread by test table in 16 strokes. Samples that had 15% sawdust did not segregate and also did not spread by the table, which allowed of the test execution with 30 strokes, according to the standard. However, in composites with 20% cannot guarantee the homogeneity of the mixture. In addition, it was observed that some grains of the cement were not hydrated and showed segregation during the test. The 20% sample segregated with 10 strokes. Trait with sawdust content of 20% showed a “crumb” aspect.

Among manually produced composites, the sample with 10% sawdust showed superior diameters in comparison with mechanically produced composites, which indicates that the manually produced sample is more fluid and less homogeneous than the mechanized one. There was no homogeneity in the sample, and it showed exudation at the end of the test. The sample with 15% sawdust produced by hand showed a different aspect from that of the mortar, as homogeneity could not be attained in the mixture; therefore, this sample resulted in a greater segregation than that produced in the mortar, at the same percentage. This sample had already shown a “crumb” aspect. Samples with 20% sawdust showed segregation, as well as the same percentages produced mechanically.

The average spreading results of cementitious composites – mixed both manually and mechanically – are presented through the consistency test across the flow table (Figure 2).

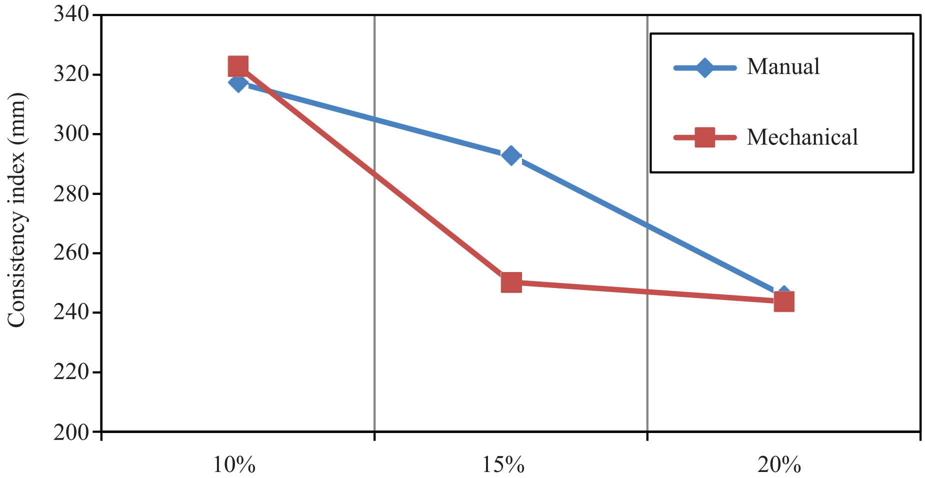

Figure 2. Samples spreading -manual and mechanical production.

The spreading diameter varies according to the sawing percentage in the samples; we can observe that the smaller is the percentage of sawdust, the greater (that is, more fluid) is its scattering diameter.

Composites with the addition of 15% sawdust showed a better workability during the test, and no exudation was observed; when mechanically produced, these composites showed no segregation. The 20% addition of sawdust resulted in difficulty for the mortar opening and in low workability. Thus, due to material characteristics, a small variation of the percentage of addition can have a major impact on the mortar performance.

Good workability and adhesion were reported for mortars with the addition of 0.5 and “1.0% wood sawdust, which ensured a good dispersion of mortars (Gil et al., 2017). The workability of mortars directly influences the hardened behavior, as well as the granulometric composition and aggregate theories, and it is an efficient way to diversify mortar rheological properties (Stolz & Masuero, 2015).

Absorption assay of cementitious composites reinforced with sawdust

Water absorption results by immersion in the reinforced sawdust composites (Figure 3).

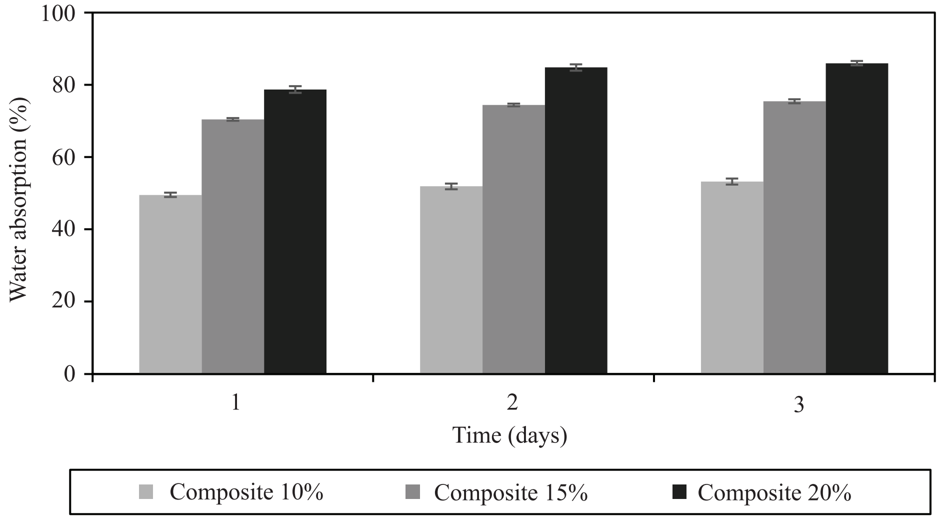

Figure 3. Water absorption by composites immersion.

Composites with 10% sawdust showed the lowest absorption results by immersion; the addition of larger amounts of sawdust resulted in higher absorptions. Bilcati et al. (2018) found that the increasing of lignocellulosic materials caused the increment of water absorption, and it was difficult to attain the homogeneity of cement and wood panels due to the lignocellulosic materials hygroscopicity. Gil et al. (2017) observed that the increase of absorption magnitude due to the presence of sawdust caused a poor adhesion at cement / sawing interface.

The statistical analysis showed that there is a significant difference between the results obtained for most samples, except among constants (Figure 4). Therefore, the percentage of sawdust is an important factor for water absorption by cement composites. In the present work, after 48 hours of testing, the specimen reached its saturation completely, with no difference for all percentages.

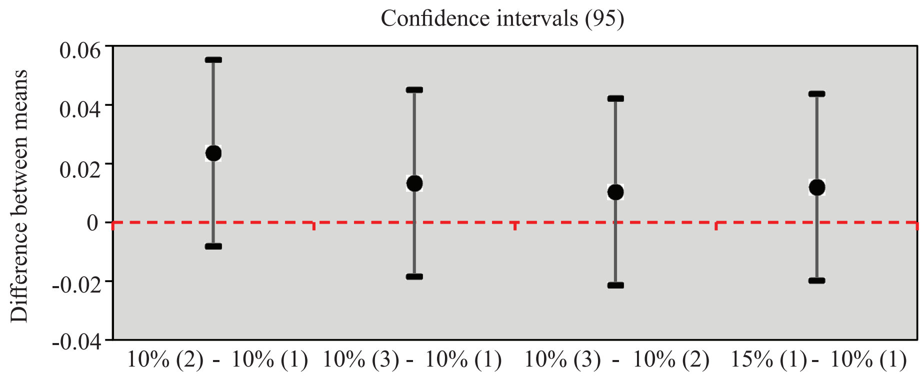

Figure 4. Difference between nonsignificant means: 10-10% (2 -1 day), 10-10%, 15-15%, 20-20% (3-2 days).

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Compression assay of cementitious composites reinforced with sawdust

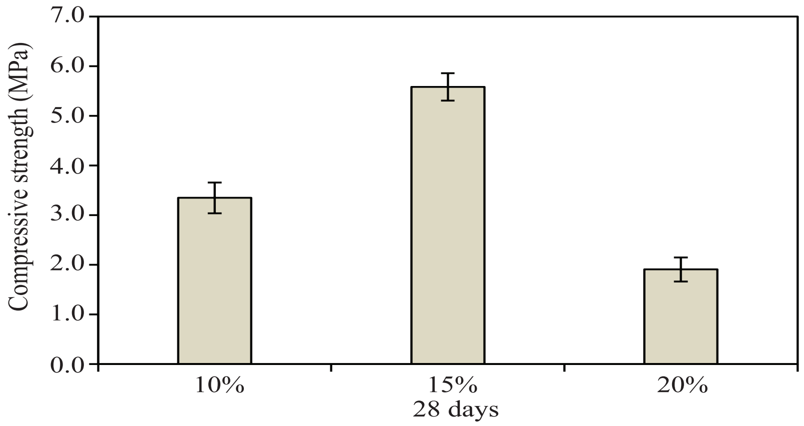

Figure 5. Compressive strength of composites.

The best results for compressive strength were obtained in composites with the addition of 15% sawdust, reaching 5.6 MPa; however, a low resistance was observed for use in structural concretes. This result was also found by Dhull (2017), who verified that the concrete structure becomes less viable as the percentage of sawing increases, due to the low compressive strength, and it justifies the fact that reinforced sawdust composites demand more water. For Osei & Jackson (2016), sawdust can be potentially used as an aggregate in nonstructural concrete production.

The recommended strength in mortars for use in masonry is 5.3 MPa, according to Sasah & Kankam (2017). Therefore, cementitious composites with 15% sawdust could be used in mortars for laying and coating on internal walls of buildings, where absorption of water by the mortar would be reduced.

Corinaldesi (2012) and Claudiu (2014) found that the optimum content found in sawdust composites was 5% sawdust, and they verified a drastic reduction of compressive strength in composites with a higher proportion. Sasah & Kankam (2017) reported better results of compressive strength in composites with proportion of sawing between 8% and 13%. Authors as Corinaldesi (2012), Osei & Jackson (2016) and Gil et al. (2017) verified that high contents, above 15% sawdust, reduce the compressive strength of the composites.

The analysis of variance and the Tukey´s test showed significant differences between the results for all samples by (Figure 6). The addition of 15% sawdust was a categorical point, since it had better results for compressive strength and consistency index of mortar. The issue related to water absorption is particular to the material and occurs due to its hygroscopic characteristic. Thus, although the addition of 15% sawdust has a higher water absorption than that of 10% sawdust, it was able to achieve higher compressive strength values, and it set an optimum content.

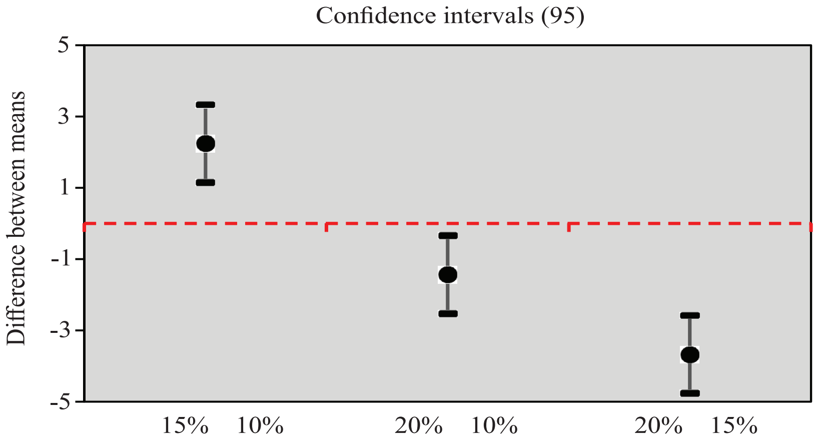

Figure 6. Difference between sample means by the Tukey’s test.

CONCLUSIONS

- The studied sawdust is classified as aggregate for use in mortars and concretes as continuous and coarse, classification which can be used as aggregate in civil construction.
- Cementitious composites with 15% sawdust showed better workability than the additions of 10% sawdust (very fluid), and 20% sawdust (that show a “crumb” appearance).
- The larger is the percentage of sawdust incorporated, the smaller is its scattering diameter, and that the smaller the percentage of sawdust, the greater its scattering diameter (that is, more fluid it is).
- Composites with 10% sawdust show the lowest absorption results by immersion, and the addition of larger amounts of sawdust results in higher absorptions.
- Best results for compressive strength (5.6 MPa) are found in composites with the addition of 15% sawdust; however, these composites show a low resistance for their use in structural concretes.
- Subsequent studies on mortar and concrete applications for nonstructural purposes are necessary to understand the behavior of this material before its set and requests; and a preliminary study of sawdust and cementitious composite characteristics is important to determine the feasibility of its use, and it is necessary to impose some limitations only for the effectiveness of the material for its intended purpose.

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