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Use of wood ash as a substitute for fine aggregate in the production of lightweight concrete

Uso de ceniza de madera como sustituto del agregado fino para elaborar hormigón liviano

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Abstract

The present study proposes the use of wood ash as a partial substitute for fine aggregate, for which a base concrete of 180 kg/cm² and concretes with 30, 50 and 70% replacement were proposed. Laboratory tests were carried out on all concrete components such as: granulometry, real and apparent density, absorption capacity with a sample of 36 cylindrical specimens evaluated at 7, 14 and 28 days. Subsequently, an analysis was made of the real hardened density and compressive strength, the results of which showed the influence of wood ash on these properties. The densities of 2233.75 kg/m³, 2210.38 kg/m³ and 2176.96 kg/m³ that decrease progressively according to the replacement percentages do not allow a classification within the light concretes because the considered limit of 2000 kg/m³ is exceeded. With respect to the compressive strength,

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which shows a decrease, it was determined that in order to comply with the design, the replacement will not exceed 30%. In short, this concrete could be used in the construction of sidewalks and curbs, prefabricated masonry constructions used in the division of environments and for cyclopean concrete.
Keywords: Lightweight concrete, Fine aggregate, Wood ash, Construction.

Resumen

El presente estudio plantea el uso de ceniza de madera como sustituto parcial del agregado fino, para lo cual se planteó un hormigón base de 180 kg/cm² y hormigones con 30, 50 y 70% de reemplazo. Se efectuaron ensayos de laboratorio de todos los componentes del hormigón como: granulometría, densidad real y aparente, capacidad de absorción con una muestra de 36 probetas cilíndricas evaluadas a los 7, 14 y 28 días. Posteriormente se hizo un análisis de la densidad real endurecida y la resistencia a compresión, cuyos resultados evidenciaron la influencia de la ceniza de madera en dichas propiedades. Las densidades de 2233.75 kg/m³, 2210.38 kg/m³ y 2176.96 kg/m³ que disminuyen progresivamente de acuerdo con los porcentajes de reemplazo no permiten una clasificación dentro de los hormigones livianos pues se sobrepasa el límite considerado de 2000 kg/m³. Con respecto a la resistencia a compresión que presenta una disminución se determinó que para cumplir con el diseño el reemplazo no excederá el 30%. En definitiva, este hormigón podría ser empleado en la construcción de aceras y bordillos, construcciones de mampostería prefabricadas usadas en la división de ambientes y para hormigón ciclópeo.
Palabras clave: Hormigón liviano, Agregado fino, Ceniza de madera, Construcción.

Introduction

Throughout the ages, research has sought to achieve truly novel qualities in the production of concrete that require and allow changes to take advantage of its full potential.

Thus, lightweight concretes have been used since ancient times, for example; the Romans used it in the 2nd century to build the dome of the Pantheon in Rome using a concrete with pumice stone as aggregate (Weigler & Sieghart, 1985). (Weigler & Sieghart, 1985)..

The Park Plaza Hotel in St. Louis, the Southwestern Bell Telephone building in Kansas City, and the upper roadway of the San Francisco Oakland Bay Suspension Bridge are examples of early uses of reinforced lightweight concrete in the 1920s and 1930s (Weigler & Sieghart, 1985). (Weigler & Sieghart, 1985)..

The diffusion of this type of concrete, made with different materials and the existence of buildings constructed with it, does not mean that the possibilities for its innovation have ceased.

A study establishes that in the elaboration of low density concrete with pumice as coarse aggregate, dosages for compressive strength of 60 kg/cm2 and 45 kg/cm2 were sought. (Medina & Fonseca, 2015)..

For the 60 kg/cm2 concrete, the uncured cylindrical samples reached a compressive strength equal to 62.94 kg/cm² and the cured cylindrical samples obtained a compressive strength of 63.66 kg/cm²; in both cases at 28 days of age. For the 45 kg/cm2 concrete, the uncured cylindrical samples reached a compressive strength equal to 45.18 kg/cm² and the cured cylindrical samples obtained a compressive strength of 47.48 kg/cm² for both states at 28 days of age. This indicates the importance of curing the concrete specimens, since this directly influences the compressive strength.

Concrete made in materials testing laboratories for a strength of f'c = 60 kg/cm² has an average density of 1649.50 kg/m³; which is within the limits and is called a lightweight concrete.

Concrete produced in materials testing laboratories for a strength f'c = 45 kg/cm² has an average density of 1631.17 kg/m³; this is within the limits and is called a lightweight concrete.

Another study concludes that the compressive strength at 28 days of normal curing of concrete with wood ash addition decreases as the wood ash content increases in amounts expressed as a percentage over a range of 0 to 30 (Sashidhar & Rao, 2010)..

In the results obtained from the samples of 28 and 60 days of age, a comparison of the percentages of wood ash contained in the mix in relation to its compressive strength is established, for the case of 0%, the highest strength values are considered. The appropriate percentage for replacing cement with wood ash is 20% (Abdullahi, 2006). (Abdullahi, 2006).

In addition, the compression tests of cylindrical samples with a water/cement ratio of 0.60 executed at 7, 28 and 56 days, manifest that the mixture with 10% obtained the highest compressive strength defining it as a recommendable percentage, which indicates an inversely proportional relationship, i.e.; the higher the wood ash content the lower the compressive strength (Elahi, Qazi, Yousaf, & Akmal, 2015).

On the other hand, in the use of wood ash as a partial replacement of cement content in a mixture with sand as fine aggregate for making blocks with an age of 7, 14 and 21 days, the optimum compressive strength is given by 15 % replacement of cement after 21 days of curing (Subramaniam, Subasinghe, & Fonseka, 2015).

For this reason, the present work starts with the design of a concrete for a compressive strength of 180 kg/cm2 with the incorporation of wood ash as a light aggregate in partial substitution of the fine aggregate, which will be added in percentages from 0, 30, 50 to 70%, verifying the density as a whole and the compressive strength of the concrete in hardened state, to establish guidelines on the behavior of the concrete in relation to the mentioned properties.

The wood ash is obtained by means of a calcination process at an average temperature of between 580 and 600 °C (Aramayo, Buncuga, Cahuapé, Forgione, & Navarrete, 2003). (Aramayo, Buncuga, Cahuapé, Forgione, & Navarrete, 2003).With the partial use of this aggregate, a concrete with different characteristics from the conventional one will be sought, with some special properties that light concrete has, among which we can highlight the thermal and acoustic insulation and fire resistance, for which its density should not exceed 2000 kg/m3 (Short & Kinniburgh, 1977)..

This type of concrete would constitute a great construction alternative for civil works in general, and for our country an answer to the current problem of housing costs because of its light weight and the use of wood waste, it would be more economical and convenient, thus allowing savings in materials, reduction of section areas, as well as the possibility of erecting structures on land with low bearing capacity and in turn contribute to greater innovations in construction works.

Methodology

To meet the parameters of a lightweight concrete made with wood ash as a partial substitute for fine aggregate, an analysis is required by means of concrete specimens with different contents of wood ash; which after being tested in compression at the age of 7, 14 and 28 days, externalize the mechanical behavior of the concrete.

For this purpose, it is necessary to select a representative set of elements called sample whose purpose within this experimentation will be to reflect the characteristics of a concrete made with wood ash as a partial substitute for fine aggregate.

The fine and coarse aggregates come from the Villacrés quarry, located in the parish of La Península, 5 kilometers east of the city of Ambato. The wood ash that partially replaces the fine aggregate was produced in a brick kiln located on the property of the Villacris family, in the Cevallos canton, Francisco Arias neighborhood, province of Tungurahua.

Section 5.3.1 of NTE INEN 1576 states that the number of molded cylinders should be as indicated in the specifications in NTE INEN 1855-2, which indicates that at least two specimens of mixtures should be prepared for each resistance test. A test will be the result of the average of the resistances of the specimens tested at the specified age. (NTE-INEN-1576, 2011).

Considering the above and for greater reliability, three cylindrical specimens will be prepared for each age 7, 14 and 28 days, which in turn correspond to four percentages of partial substitution of fine aggregate by wood ash, which are 0, 30, 50 and 70 %; that is to say, the sample totals 36 specimens according to the following table:

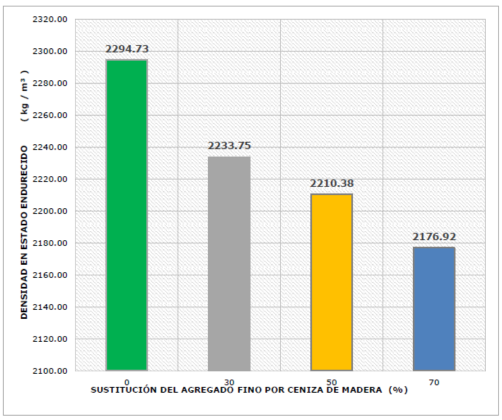
Table 1. *Definition of the sample*

Age in days	**Partial Substitution in %**			
	Partial Substitution in %			
	0	**30**	**50**	**70**
7	3	3	3	3
14	3	3	3	3
28	3	3	3	3
Subtotal	9	9	9	9
Total	36			

Results

Based on the density of conventional concrete, we have a decrease of 2.66%; 3.68% and 5.13% when replacing the fine aggregate by 30%, 50% and 70% respectively, as can be seen in Figure 1.

Figure 1. Percentage of Substitution vs. Density in the Hardened State



The density of wood ash concrete decreases as the percentage of substitution increases. However, these densities exceed that of a lightweight concrete, which is 2,000 kg/m³.

According to Figure 2, the compressive strength of the conventional concrete is found to be within the upper and lower limits defined in [37] for 7, 14 and 28 days of age. Being the maximum resistance of 186.49 kg/cm² which defines it as a concrete suitable for construction since it complies with the proposed design.

Figure 2. Age vs. Compressive Stress / Conventional Concrete

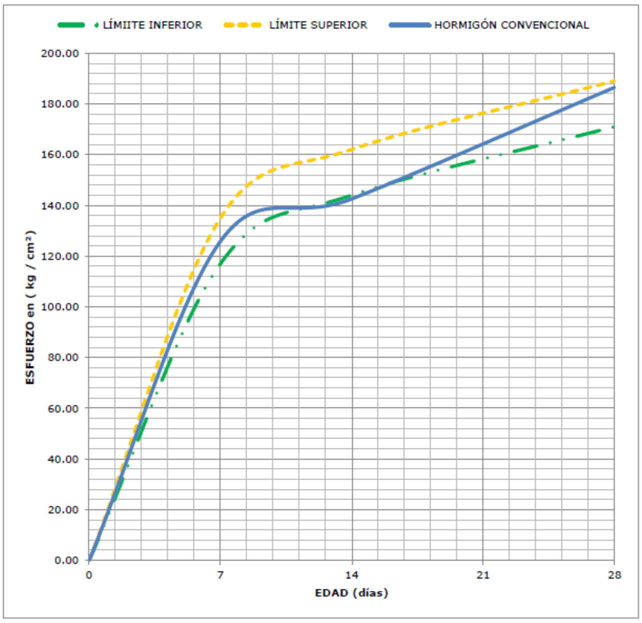


Figure 3 shows that the compressive strength of the concrete with a 30% substitution of fine aggregate is within the upper and lower limits defined for 7, 14 and 28 days of age. The maximum resistance is 180.06 kg/cm², which defines it as a concrete suitable for construction since it complies with the proposed design.

Figure 3. Age vs. Compressive Stress / Replacement at 30%.

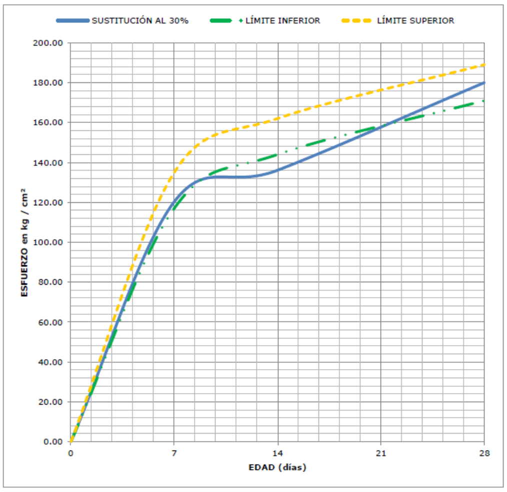


Figure 4 shows that the compressive strength of concrete with a 50% substitution of fine aggregate is below the upper and lower limits defined for 7 and 14 days of age. However, at 28 days of age it reaches a maximum strength of 172.85 kg/cm² according to the limits.

Figure 4. Age vs. Compressive Stress / 50% Replacement

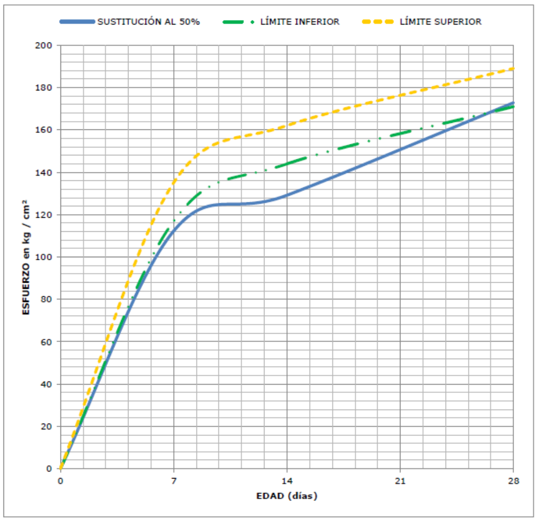
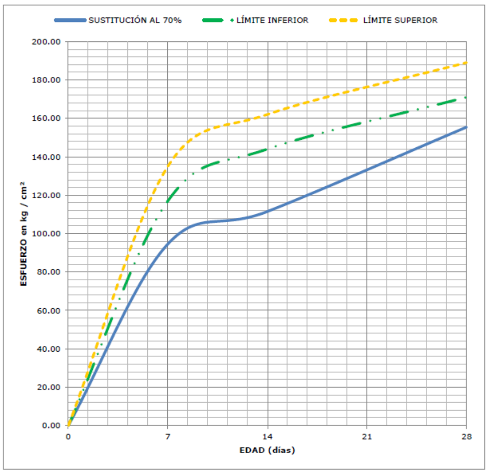


Figure 5 shows that the compressive strength of concrete with a 70% substitution of fine aggregate is below the upper and lower limits defined for 7, 14 and 28 days of age. The maximum resistance is

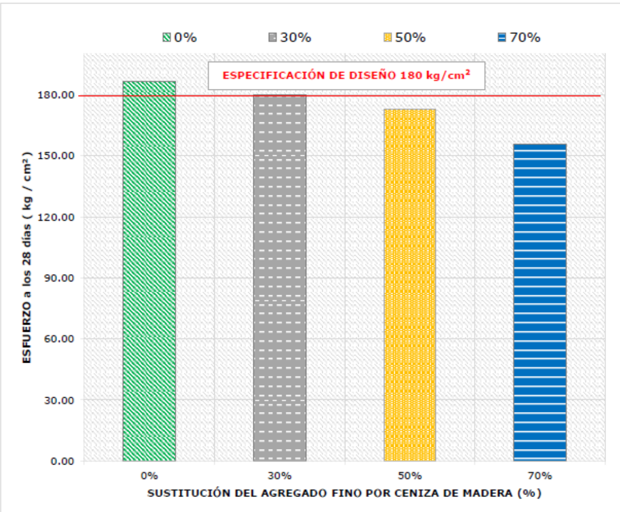
155.40 kg/cm², which shows a decrease of 16.67% with respect to the design.

Figure 5. Age vs. Compressive Stress / Replacement at 70%.



According to Figure 6, there is an inversely proportional behavior due to the decrease in compressive stress at 28 days, produced by the increase in the percentage of fine aggregate substitution.

Figure 6. 28-day compressive stress vs. percentage of substitution



Both conventional and 30% substitution concrete meet the design specification with stresses equivalent to 104% and 100% respectively. However, the 50 and 70 % substitution concretes do not meet the design specification as they represent stresses of 96 and 86 % respectively.

Conclusions

The concrete obtained by partially replacing the fine aggregate with wood ash does not reach the classification of lightweight concrete because its density is not in the range of 1200 to 2000 kg/m³. The concrete with 30% substitution presents a decrease in its real density of 2.66% with reference to conventional concrete (from 2294.73 kg/m³ to 2233.75 kg/m³).

The concrete with 50% substitution shows a decrease in its real density of 3.68% with reference to conventional concrete (from 2294.73 kg/m³ to 2210.38 kg/m³). The concrete with 70% substitution shows a decrease in its real density of 5.13% with reference to conventional concrete (from 2294.73 kg/m³ to 2176.92 kg/m³). The inclusion of wood ash maintains the homogeneity of the concrete in view of its correct distribution with the components of the mix.

The concrete with 30% substitution shows a decrease in compressive strength of 3.45% with respect to conventional concrete (from 186.49 kg/cm² to 180.06 kg/cm²). The concrete with 50% substitution shows a decrease in compressive strength of 7.31% with respect to conventional concrete (from 186.49 kg/cm² to 172.85 kg/cm²). Concrete with 70% substitution shows a decrease in compressive strength of 16.67% with respect to conventional concrete (from 186.49 kg/cm² to 155.40 kg/cm²).

The concrete resulting from this research could be used mainly in the construction of prefabricated masonry used in the division of rooms. Initially; if there is availability of wood ash indicated as kiln waste, the concrete with a substitution of 30% of fine aggregate has a cost of 96.89 USD/m³, resulting more economical than the conventional one; in a percentage equivalent to 1.88.

In the opposite case, the alternative of producing ash using low-cost waste wood is proposed, so the processed concrete is priced at 113.94 USD/m³, being 13.33% more expensive than conventional concrete; then the economic benefit becomes functional when the fine aggregate (sand) is scarce at the construction site or its value is high due to transportation issues.

Based on compliance with the design strength of 180 kg/cm², the suggested percentage of substitution will be that which does not exceed 30%. The fineness of the wood ash generates a greater demand for water in the concrete, therefore, a correction for humidity should be made and if necessary, a superplasticizing additive should be added to maintain a slump between 6 and 9 centimeters.

In addition to partially replacing the fine aggregate, it is possible to opt for partial or total replacement of the coarse aggregate with lightweight aggregates, given that in weight and volume it is the component with the greatest presence in the concrete.

To accelerate the combustion process, use wood that is superficially dry. Use an industrial kiln, since it allows temperature control and uniform calcination of the wood. Sieve the ash obtained in order to eliminate charcoal residues and obtain a material of homogeneous granulometry. To store the produced ash in double plastic bags, as well as in a dry and fresh environment.

Work with a dosage by volume so that the wood ash content does not hinder the workability of the mix. Use a content ratio: maximum percentage of coarse aggregate/maximum percentage of fine aggregate of 50/50, which implies a greater quantity of wood ash in replacement of the fine aggregate and therefore a reduction in the real density of the concrete. Carefully handle the specimens in fresh state to avoid surface irregularities that hinder the transmission of loads during the compression test.

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