Lightweight concrete with Algerian limestone dust. Part I: Study on 30% replacement to normal aggregate at early age

(Concreto leve com cargas de calcário argelino. Parte I: Estudo da substituição de 30% de agregado normal em idade precoce)

S. Kitouni, H. Houari
Laboratoire Matériaux et Durabilité des Constructions (LMDC), Department of Civil Engineering University of Constantine, Constantine, Algeria
souad0714@yahoo.fr

Abstract

The mechanical characteristics of the lightweight aggregate concretes (LWAC) strongly depend on the proportions of aggregates in the formulation. In particular, because of their strong porosity, the lightweight aggregates are much more deformable than the cementations matrix and their influence on concrete strength is complex. This paper focuses on studying the physical performance of concrete formulated with substitution of 30% of coarse aggregates by limestone dust. In this article an attempt is made to provide information on the elastic properties of lightweight concrete (LWC) from tests carried out under uniaxial compression conditions. The results of Young modulus, Poisson’s ratio, and compressive and flexural tensile strength tests on concrete are presented. The concretes obtained present good mechanical performances reaching 34.99 MPa compressive strength, 6.39 MPa flexural tensile strength and in front of 36 MPa Young modulus.

Keywords: lightweight aggregate concrete, limestone dust, formulation, flexural tensile strength, Young’s modulus, compressive strength.

Resumo

As propriedades mecânicas de concretos são fortemente dependentes das propriedades e proporções de agregados presentes na formulação. Em particular, devido à sua elevada porosidade, agregados leves são muito mais deformáveis do que a matriz de cimento e sua influência sobre a resistência do concreto é complexa. Este trabalho tem como objetivo o estudo do desempenho físico de concreto formulado com substituição de 30% de agregados analisar a influência das propriedades desses agregados sobre o comportamento mecânico de concretos leves depois de uma abordagem experimental. Como um primeiro passo, que caracterizou os concretos leves. Em seguida, procedeu-se à busca de uma formulação de concreto leve, adequado em termos de implementação e para substituir agregados graúdos por cargas de calcário. O concreto obtido tem bom desempenho mecânico até uma resistência à compressão de 34,99 MPa, uma resistência à tracção de 6,39 MPa à flexão e módulo de elasticidade de cerca de 36 MPa.

Palavras-chave*: concreto com agregados leves, cargas de calcário, formulação, módulo de elasticidade, resistência mecânica.*

INTRODUCTION

Lightweight aggregate concrete (LWC), popular through the ages, was reported to have a comparable or some times better durability even in severe exposure conditions [1]. Researches had been conducted worldwide on a large number of natural or artificial lightweight aggregates [2]. The mix design of lightweight concrete is complicated because it depends on the type of lightweight aggregate (LWA). The use of a local product depends on its specific properties and the requirements for a particular job. One of the methods of producing lightweight concrete is to use light aggregate instead wholly or partially of normal concrete aggregates.

The most important uses limestone dust are: in agricultural as liming material, in plastics and paper industry as filler, in iron and steel industry as flux, for flue gas desulphurization and for wastes neutralization. Since limestone dust is of varying quality it has to be further processed such as drying or screening or blended to meet the specific market requirements. There is an increasing interest to turn limestone dust into a building product [3]. Nevertheless, there are limited numbers of studies about the possible utilization strategies of limestone in civil engineering industry [4]. Using limestone as lightweight aggregate in its natural form allows economical, lighter and environmental-friendly new composite material.

The lightweight aggregate concrete, sometimes their resistance is comparable to that of conventional concrete, may allow greater flexibility in the design of structures and induce several economies. Algeria has contributed in the field of lightweight concretes by academic researches that have not known until now being implemented. This can be explained by these factors: - lack of work performed by this type of materials that give evidence of their effectiveness and may encourage operators to use in some work. - lack of information, poor circulation thereof and psychological reluctance of some operators also permanently prevented the use of this material

The limestone dust, fine materials with larger grains do not exceed 80 µm are obtained by grinding or by spraying natural limestone or not [5]. In most countries, the aggregate producers have seen their products rejected due to the presence of high levels of fillers in their sands. This constraint requires equipping career advantage in equipment for the recovery of fillers crushing to sell them separately [6]. In Algeria, more than a thousand units annually produce 68 million tons of aggregates, mainly from natural limestone.

This work is a part of extended study; its purpose is better comprehending the mechanisms that govern the behavior of lightweight concretes containing limestone dust in order to optimize its performance. Thus, we study, in this part, the influence of the substitution of 30% of the coarse aggregate with limestone dust through the study of various physical parameters.

Table I - Physical characteristics of aggregates.
[Tabela I - Características fisicas dos agregados.]

Measured properties	Sand 0/3	Granular 3/8
Absolute density (t/m^3)	2.62	2.56
Apparent density (t/m^3)	1.46	1.33
Equivalent sand (%)	Esp = 65	/
	Esv = 69	/
Blue methylene value	0.38	/
Absorption coefficient	0.14	2.28

Table II - Physical characteristics of limestone dust.
[Tabela II - Características físicas das cargas de calcário.]

Limestone dust	Specific weight	Whiteness	Oil absorption	Moisture
	2.7kg/L	92%	18%	0.1%

EXPERIMENTAL PROCEDURE

In this study, we developed a concrete based on following local materials: the aggregates used in this study are taken from the Career of ENG El-Khroub (Constantine, Algeria), the sand and gravel crushed class are respectively (0/3 mm) and (3/8 mm). The physical properties of aggregates are presented in Table I.

The limestone dust is from giant career (ENG) of eastern Algeria. The physical and chemical properties of the filler are summarized in Tables II and III.

The cement used is cement CEMII / A (CPJ 42.5). This cement is from a single supply of cement El-Hamma (region of Constantine Algeria). The elemental composition of the cement is presented in Table IV.

For making different mixtures we used tap water. The plasticizer used was a superplasticizer SP40. This superplasticizer is part of plasticizers obtained based polymelamine sulfated.

The formulation of concretes is given for 1 m^3 in Table V, Dreux method was used.

Two families of tests were carried out to characterize our mixtures in laboratory: fresh testing to assess the density, air content and slump and the hardened state tests to determine the mechanical performance. The concrete mixing in the laboratory was conducted in a mixer (Fig. 1) with a vertical axis and planetary movement of capacity 250 L. To measure the fresh density, concrete molds 4 cm x 4 cm x 16 cm were prepared. The molds were weighed empty and full. Density was deduced. On the other hand, the extent of slump was achieved by using the cone Abrahms' (Fig. 2). In addition, the measurement of air content was performed using a hydrometer (Fig. 3) of 7 L model control.

In the cured state, the compression test is carried out on cylindrical specimens of 16 cm x 32 cm (Fig. 4), the testing machine is a press force of a maximum capacity 100 kN (Fig. 5). The elastic modulus is determined during compression tests on cylindrical specimens (16 x 32).

These test specimens are equipped with a two axial extensometer sensors for measuring longitudinal and transverse deformation under increasing loads to a maximum

Table III - Chemical compositions of the limestone dust.
[Tabela III - Composição química das cargas de calcário.]

	SiO_2	Fe_2O_3	MgO	Loss on ignition	Al_2O_3	$CaCO_3$	SO_3	pH
Content %	0.06	0.02	0.01	43.8	0.09	99	0.01	9

Table IV - Chemical composition of the clinker.
[Tabela IV - Composição química do clínquer.]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Chlorides	Free CaO	Insoluble residues	loss on ignition
27.83	6.21	3.12	57.22	0.94	2.02	/	/	0.00	0.88	2.28	2.41

Table V - Formulation of concrete for 1 m^3.
[Tabela V - Formulação de concreto para 1 m^3.]

Materials used	Amount	Unit
Cement (C)	350.00	kg
Water (W)	199.00	L
W/C	0.56	/
Sand	691.60	kg
Granular (3-8)	726.18	kg
Limestone dust (20ì)	311.22	kg
Superplasticizer	10.50	L

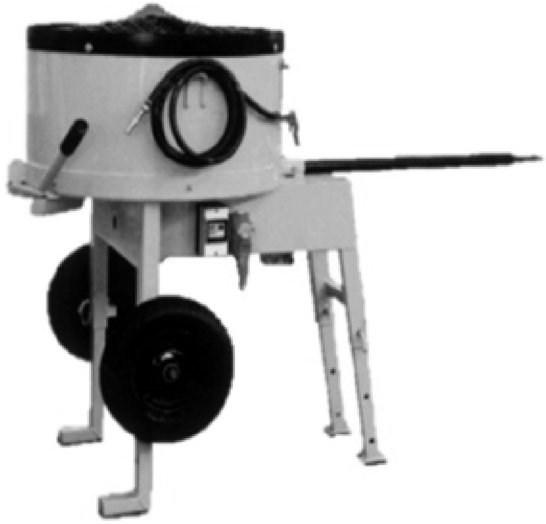

Figure 1: The mixer.
[Figura 1: Misturador.]

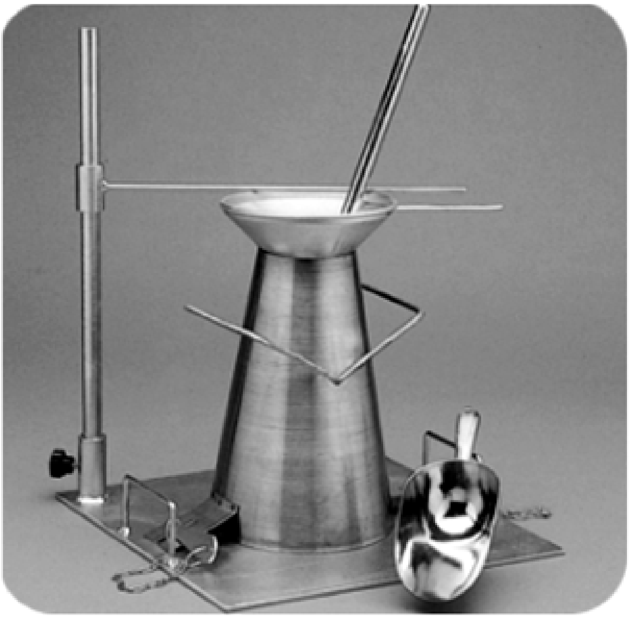

Figure 2: The cone Abrahams'.
[Figura 2: Cone Abrahams.]

Figure 3: The hydrometer.
[Figura 3: Hidrômetro.]

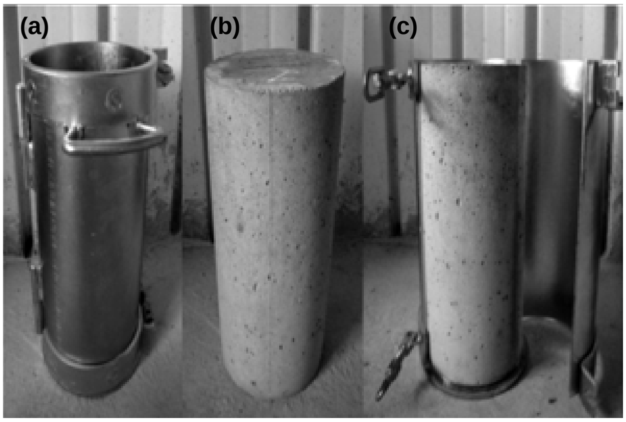

Figure 4: (a) Mould utilized, (b) cylindrical specimen, (c) cylindrical specimen in mould.
[Figura 4: (a) Molde utilizado, (b) amostra cilíndrica, (c) amostra cilíndrica no molde.]

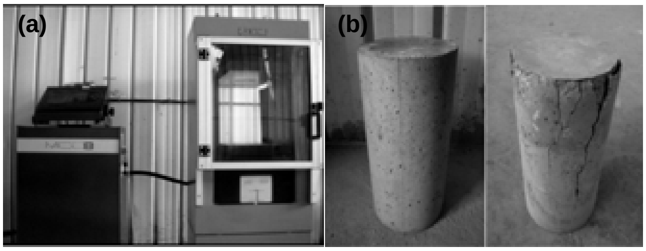

Figure 5: (a) Compressing machine, (b) cylindrical specimen 16 cm x 32 cm before and after test.
[Figura 5: (a) Maquina de compactação, (b) amostra cilíndrica 16 cm x 32 cm antes e depois do teste.]

stress (Fig. 6).

The flexural tensile test is carried out on prismatic samples of 7 cm x 7 cm x 28 cm (Fig. 7).

The measurement of shrinkage was carried out on prismatic samples of dimensions 7 x 7 x 28 cm^3). These specimens are provided with metal contacts at each end and placed vertically in the retractometer, which allows the monitoring of the change in length of the sample.

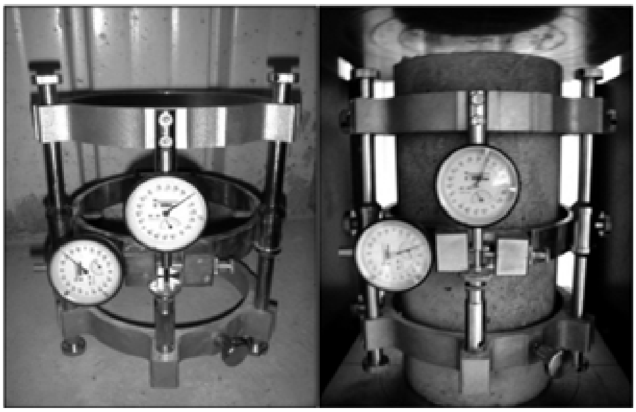

Figure 6: (a) Extensometer, (b) cylindrical specimen 16 cm x 32 cm before testing.
[Figura 6: (a) Extensômetro, (b) amostra cilíndrica 16 cm x 32 cm antes do teste.]

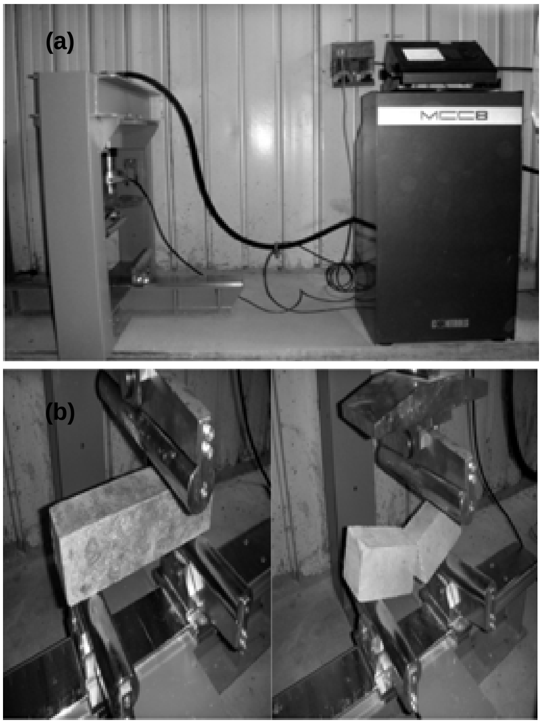

Figure 7: (a) flexural tensile machine, (b) the beams specimen 7 cm x 7 cm x 28 cm before and after test.
[Figura 7: (a) Maquina de tração a flexão, (b) amostras de 7 cm x 7 cm x 28 cm antes e depois do teste.]

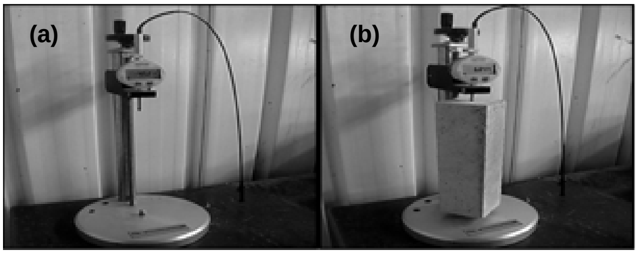

Figure 8: (a) Retractometer, (b) beam specimen 7 cm x 7 cm x 28 cm during test.
[Figura 8: (a) Retractometer, (b) amostra de 7 cm x 7 cm x 28 cm durante teste.]

Measurements were made in the environment at a temperature 20 ± 2 °C and humidity 60 ± 5% (Fig. 8).

RESULTS AND DISCUSSIONS

The density of freshly mixed concrete can be easily determined as the density of fresh state (see Table VI).

Table VI - Properties of fresh concrete.
[Tabela VI - Propriedades do concreto fresco.]

Density (kg/m^3)	Slump (cm)	Air content (%)
2195	24	2.6

The density of concrete is measured by difference weighing mold 4 x 4 x 16 cm^3 and is equal to 2195 kg/m^3. If we consider a normal concrete having a density 2400 kg/m^3, we can notice a weight gain 9.33%. Usually, the presence of limestone dust accelerates the hydration process of C3S especially at young ages. This process could be related to a change in the hydration of C3S surface and its nucleation. In addition, its presence can affect the viscosity of fresh concrete which promotes increased density in the fresh state by reducing pores (modification of the microstructure) [7]. In the present work, we found a slump equal to 240 mm (see Table VI). This value is consistent with that found in other studies for the same rate of substitution of coarse aggregates (30%) [8]. On the other hand, the concrete composition adapted showed good handling conditions. In addition, no segregation phenomenon was noticed; water absorbed and conserved by limestone dust helps the fresh concrete to oppose to bleeding, and confer cohesion that maintains the homogeneity (no segregation). On the other hand, the extreme thinness of limestone dust promotes good workability [9]. In general, the air content shall not exceed 4%. The amount of air recommended by the ACI 211.2 is 4-6% for a 190 mm slump. In our work, the air content is 2.60% (see Table VI). Quantitative evaluation of air content is not only to know the exact composition of a unit volume of concrete, but it can also predict the mechanical properties of hardened concrete [10]. Indeed, the air content affects the compressive strength and generally it decreases the mechanical properties and creates unsightly siding [11]. As a result, it is sometimes beneficial to add air content in lightweight concrete, even if the environment does not require this precaution. In this case, air bubbles stabilize the fresh concrete by reducing bleeding and segregation if they exist. This stabilizing effect can even neutralize the reduction in mechanical properties [12].

The density of hardened concrete specimen is obtained from tests with deadlines (4, 7, 14, 28 days), each value corresponding to the average of three measurements. Fig. 9 illustrates the evolution of the density function of the age of the concrete; there was a decrease in the density of concrete with age [13]. Declining value of the density compared

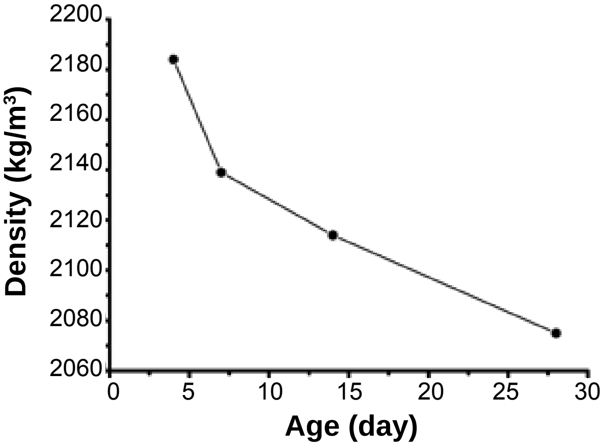

Figure 9: Evolution of the density of the hardened concrete with age.
[Figura 9: Evolução com o tempo da densidade do concreto endurecido.]

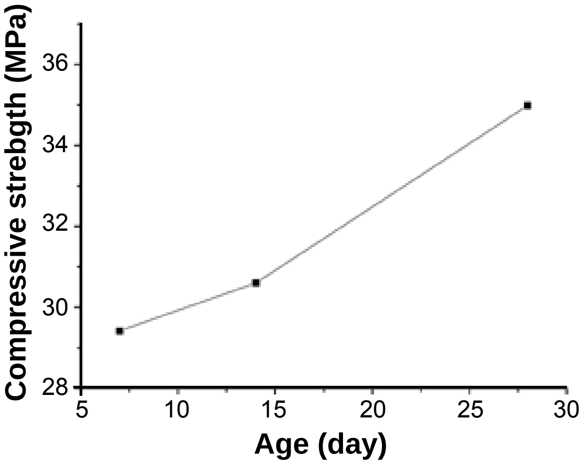

Figure 10: Compressive test results at different ages.
[Figura 10: Resultados dos testes de compressão em diferentes tempos.]

to the known normal concrete reduces the weight of the structural elements. Concretes with similar densities are not only relatively lighter but can reduce the rate of sonic and thermal transmission [14].

The compressive strengths data for 7, 14 and 28 days of age are plotted in Fig. 10. Each value is averaged from the results of three values. As expected, the compressive strength increased with age in the concrete specimens. The use of limestone dust in concrete formulation generates an acceleration of its mechanical strength at early ages [15, 16].

When the fine particles of limestone are well deflocculated by the superplasticizer, they promote hydration of the cement and cementitious matrix leads to a denser structure. This effect has a significant influence on the mechanical strength up to 28 days and then become less significant thereafter. The positive influence of the fineness of aggregates on concrete strength is verified by previous work [17, 18] and verified mainly for concrete with a low percentage of fine lightweight aggregates (our case), while it is negligible for large fractions. Commonly, the compressive strength of concrete made of fine aggregates is 40% higher than the compressive strength of concretes containing large aggregates and 68% higher than the compressive strength of concretes based sintered aggregates [19]. In other way, limestone dust have a porous structure, its water absorption is higher compared to normal concrete [20]. This absorption of water has a beneficial effect on the compressive strength especially when they are used dry (our case) [21]. The ratios of 7-day to 28-day compressive strength is 0.82. Thus, the 7 days compressive strength corresponds to 82% 28-day compressive strength. It indicates that the compressive strength does not benefit very much from a further improvement in the matrix strength. This may be attributed to the influence of weaker mechanical properties of lightweight aggregates. Research shows that, for concrete with a weak aggregate, highest strength of the concrete was reached at an earlier age. Usually, compressive strength of 7 days can reach 90% compressive strength of 28 days [22]. The 28-day compressive strength in dry condition was 36 MPa. This value has been found by other studies [23] and according to the standards ASTM it is similar to the typical values of the compressive strength obtained with the concrete using this type of aggregates [24]. In addition, considering the lower limit of structural lightweight concrete proposed by ACI 363R-92 [25], our concrete may be considered as a structural concrete. According to RILEM classification, lightweight concretes for structural uses have a density ranging from 1600 to 2000 kg/m^3 and a compressive strength greater than 15 MPa [26]. The main factors influencing the compressive strength of lightweight aggregate concrete is concrete composition and physical properties of aggregates principally the inherent resistance of lightweight aggregate [27]. The effect of lightweight aggregate concrete strength is larger than normal aggregates of normal concrete. The resistance of the aggregates normal concrete is 1.5 to 2.0 higher than the normal concrete resistance, while the resistance of lightweight aggregates is considerably lower than that of the lightweight concrete [28]. For a given w/c, the compressive strength of lightweight concrete is controlled by the feature of lightweight aggregates, as indicated in ACI 213 codes as the strength ceiling of LWC. The compressive strength of LWC can be divided into two phases. The mortar phase containing cement, water and sand mainly supports the strength of LWC, and the LWA phase mainly reduces the density of LWC [10]. This resistance cannot depend directly on the size of the aggregates but may depend of the density [20]. However, its dependence is insignificant for aggregates having a density greater than 1400 kg/m^3 [21]. In our case, the compressive strength may not depend on the density of limestone dust equal to 2700 kg/m^3 (see Table II). Compared to the compressive behavior of concrete, the tensile behavior has received a little attention in the past, partly because it is a common practice to ignore tensile resistance in reinforced concrete design. Interest in tensile properties has grown substantially in recent years partially due to introduction of fracture mechanics into the field of concrete structures. In addition, the flexural tensile of concrete is important to resist cracking from shrinkage and temperature changes. Similar to rigid aggregates concrete, the unreinforced flexural tensile strength of lightweight concrete is relatively low, especially as crack propagation occurs through lightweight aggregates, in planes that may intersect the largest number lightweight aggregates [5].

The flexural tensile of concrete specimens was measured up to 7, 14, 28 days of curing (Fig. 11).

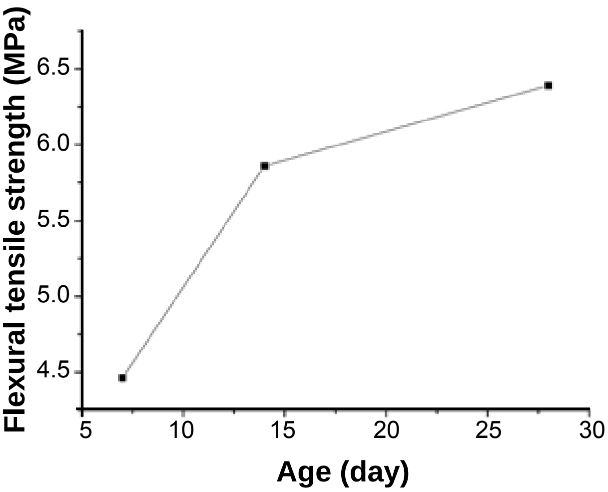

Figure 11: Flexural tensile test results at different ages.
[Figura 11: Resultados dos testes de tração flexão em diferentes tempos.]

It can be seen that flexural tensile strength increased with age. The variation of flexural tensile strength shows trend, similar to that of compressive strength. Contrary to what one might think, the flexural tensile strength of lightweight concrete does not depend on the density of the concrete and is not necessarily controlled by the flexural tensile strength of lightweight aggregate used. However, it is mainly related to the compressive strength. On the other hand, when different sized aggregates (coarse and fine) are used, the variation of the compressive strength of concrete with density usually follows a law of regression, along the flexural tensile strength varies moderately linearly with the density (Fig. 12) [19].

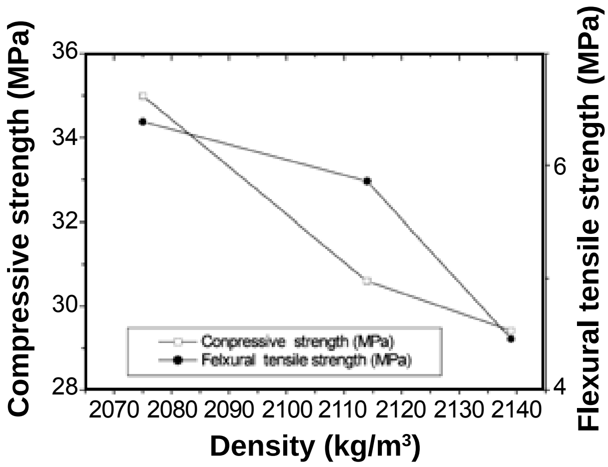

Figure 12: Evolution of compressive strength and flexural tensile strength with density.
[Figura 12: Evolução da resistência à compressão e resistência à tração flexão em função da densidade.]

After 7 days of curing, our concrete develops flexural tensile resistance averaged about 4.46 MPa to about 6.39 MPa at 28 days. These results are comparable to results of previous work [29]. For building materials to be used in structural applications, the minimum flexural tensile strength requires is 0.65 MPa [4]. The 28-day flexural tensile strength is about 17% of the 28-day compressive strength and is comparable with other published data. Generally, the compressive strength is over 15 MPa and the flexural tensile strength is over 3 MPa. These results indicate that the lightweight aggregate using 30% limestone dust could be applied to structural lightweight concrete products [30]. The increase in the flexural tensile strength has the advantage that the corrosion resistance of such concrete will be improved. The flexural tensile strength of concrete is one of the parameters that control the rate of reinforcement corrosion. Therefore, increased flexural tensile strength of concrete indicates the potential for an increase in the useful service life of the concrete structures [31].

The elastic modulus of concrete is a basic parameter needed for estimating the instantaneous and time-dependent deformations due to load, the pre-stress losses and the tensile strain capacity. The elastic modulus of concrete can be determined by static modulus of elasticity tests or by the secant modulus of the stress-strain curves resulting from compressive tests. In this study, the second method was used. In Fig. 13, a quasi-linear stress-strain is observed. The bottom part is steep for lightweight concrete and is linear up to a very high percentage of the ultimate strength. This behavior is explained by the lesser development of micro cracks in the aggregate-paste interface for low loads [32]. In other way curve of linear regression trend is similarly represented (Fig. 13) and shows a very good stress-strain relationship ($R^2 = 0.99$).

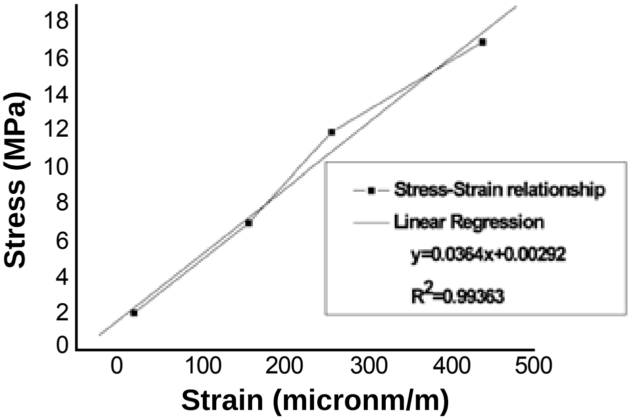

Figure 13: Elastic modulus at 28 day.
[Figura 13: Módulo de elasticidade em 28 dias.]

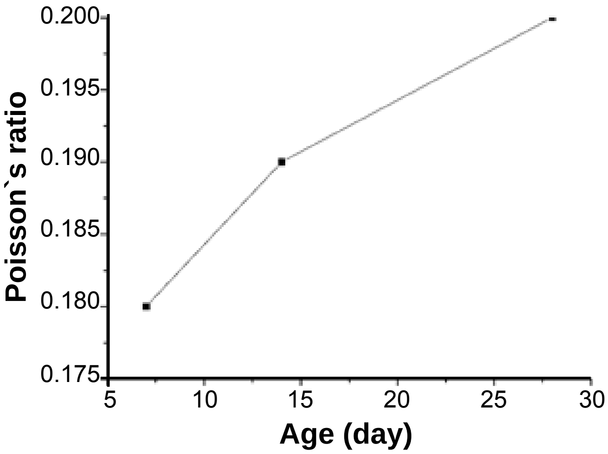

Figure 14: Poisson's Ratio results at different ages.
[Figura 14: Resultados do coeficiente de Poisson em diferentes tempos.]

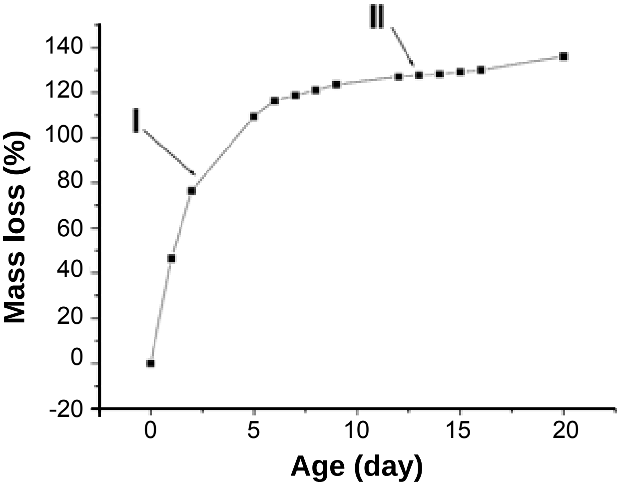

Figure 16: Mass loss test results at different ages.
[Figura 16: Resultados dos testes de perda de massa em diferentes tempos.]

Indeed, for ordinary concrete, the development of discontinuity interfaces leads to a deformation, which increases faster than the nominal stress applied, so that the stress-strain curve has a curvature more pronounced. Since the contact paste-aggregates is better and their modules are generally equivalent, the behavior of lightweight aggregate concrete is similar to that of a homogeneous material [32]. The E value of the concrete at 28 days is about 36.40 GPa (Fig. 13). Perhaps the presence of inner water in limestone dust or a continuing hydration has prevented any degrading effect on the E value [33]. The E of lightweight aggregate concrete is usually between 40% and 80% of ordinary concrete of the same strength [2]. In the main, the development of E is influenced by type of coarse aggregate, type of cement, w/c ratio of the mix and curing age. In other way, an important impact of the density of the aggregates on the Young's modulus was observed for aggregates having a density greater than 1400 kg/m^3 (our case) [21].

The Poisson's values of the mixes are presented in Fig. 14. Each presented value is the average of three measurements. There is only limited reliable information available on the Poisson's ratio of lightweight concrete in tension and in compression. The major difficulty in Poisson's ratio tests is to measure accurately the lateral strain which is rather small compared with the axial strain. Fig. 14 shows that the Poisson's ratio in uniaxial compression varies between 0.18 and 0.20. The 28-day Poisson's ratio of the concrete samples was assumed to be 0.20 which is similar to that reported by others [34].

The shrinkage measurement is realized on prismatic specimens of dimensions (7 x 7 x 28 cm^3). Among the known types of shrinkage, we focus in this study drying shrinkage (shrinkage of hardened concrete beyond 24 h). This test is intended to measure, a function of time, the dimensional shrinkage changes due to the hydration and drying effects of specimen preserved in the hardened state after stripping in a room with controlled atmosphere. The measurements were carried out on three prismatic specimens of dimensions 7 x 7 x 28 cm^3 at low deadlines just after 24 h. One condition for shrinkage is considered: the water exchange with the atmosphere of the material is possible. Shrinkage evolution is shown in Fig. 15, the frequency of measurement increases with time ranges from 110 μ/m to 182 μ/m. In the lightweight concrete, the intensity of drying shrinkage, influenced by the volume fraction and the permeability of the cement matrix is related to the degree of saturation of the aggregate. The water absorbed by lightweight aggregates can limit effectively the shrinkage of concrete [35]. Lightweight concretes exhibit a decrease of shrinkage which varies in the interval 30-50% compared to normal concrete [36]. Fig. 15 shows a continued expansion up to 7 days. Therefore, the stresses induced by restrained shrinkage condition are also largely reduced. The low intensity of the stresses induced in the lightweight concrete is the result of low elastic modulus of aggregates. The observed expansion is associated with the continuing hydration of the cement paste, made possible by the available water in the aggregates. Indeed, the water absorbed during the mixing keeps the internal moisture of the material over a longer period and thus improves the hydration of the matrix. Generally, this effect increases with decreasing grain size and increasing the volume fraction of aggregates [37]. Shrinkage variation as function of time depends on the water cement, cement type, the degree of hydration of the cement, the elastic modulus of the lightweight aggregate and the amount of water confined in these aggregates. At young age, the drying shrinkage of lightweight concrete is high and 5-40% higher than that of normal concrete, specifically lightweight concrete developed using fine aggregates size. When shrinkage is prevented, it induces tensile stresses which can rapidly exceed the tensile strength. To avoid the risk of cracking due to shrinkage, the concrete must have a flexural tensile strength and tensile deformation ability higher [38].

The appearance of mass loss curve is shown in Fig. 16. The curve shows two areas in which the phenomenon kinetics varies. The first zone (I) corresponds to a significant loss of water in the material, with a very high rate of evaporation. This diffusion area located at the surface of the material allows the upwelling capillary water, its evaporation and its evacuation to the external environment. The second zone (II) corresponds to the period with constant rate drying. This phase corresponds to the transfer of moisture to the surface by capillary effects. This is an area with initial moisture content and is, for its part, in the furthest zone of the surface. It supplies the diffusion area by capillary effects. When the concrete dries, it produces a migration of water to "diffusion area." The water evaporates and it is necessary to supply the surface to maintain equilibrium moisture. Until the concrete has enough water to supply the "diffusion area", the drying rate remains constant [39]. From certain water content called critical, liquid water can not reach the surface. A gradient of water content is formed and the drying rate decreases. This latter is governed by vapor diffusion. Consequently, dried area appeared in concrete surface, the diffusion area move away the surface by keeping almost the same thickness and the area of the initial water content decreases, until it disappears at the end of drying.

External conditions (geometry, drying surface) play an important role in this step. Substitution of coarse aggregate by limestone dust in concrete has involved a significant increase in mass loss during the first seven days. These results may be related to the porosity of limestone dust.

CONCLUSION

This paper demonstrates how the use of technology can transform the cause of social and environmental disaster into a natural resource and, hence, can be used in the post disaster rehabilitation construction projects. It is confirmed that limestone dust can be used as a resource in concrete production and can be used in low cost construction especially in seismic zones. Concrete with 30% replacement level of limestone dust which attained 34.99 MPa compressive and 6.39 MPa flexural tensile strength values, satisfies the requirements for a building material to be used in the structural applications. Further tests should be performed in order to analyze other mechanical properties. This first experimental work showed that limestone dust can be used for the production of concrete with acceptable mechanical properties. However the complete investigation of limestone concrete, should include further tests concerning mainly with their durability. To investigate the utilization of limestone dust for the production of high strength building products, like concrete paving blocks, new specimens with higher cement content must be prepared and tested. Also the use of other types of cements, like cements with high Blaine value, may be investigated.

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