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Characterization of a bio-based concrete using virgin cork aggregate

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Abstract. The field of construction, like other field besides, faces new challenges, particularly that relating to reduction of the environmental impact and the improvement of the thermal and energy performances. To this end, the work presented in this article concerns bio-based concrete which complies with the new regulatory provisions inherent in cementitious materials. This is a concrete where 25% of the mineral volume is replaced by the same plant volume (male cork) in the dry state and immersed for 2 hours in water while adding 10% of filler. A first experimental campaign was carried out in the laboratory in order to identify the rheological behavior of the composite in the fresh state and the mechanical behavior in the hardened state. The results showed that this material can be used in many civil engineering applications.

Key words: Lightweight concrete, Virgin cork, Filler, Porosity, Rheology, Strength.

1. Introduction

Sustainability, energy and environment requirements have become a major concern in European directives (2012/27/UE and 2010/30/UE, Gomes et al., 2019). To promote energy efficiency in buildings and to solve the problem of depletion of natural resources in many countries, taking into account the importance of environmental issues (Salem et al., 2020). Many researchers have been conducted in recent years and the development of more thermal insulation systems in buildings in order to reach the required economic and environmental requirements and to provide mechanical properties to ensure an adequate durability for constructions. Gomes et al., (2019). These researches have worked to develop eco-concretes that include light insulating materials with density of less than 150 kg/m^3 and a thermal conductivity of less than 0.05 W/mK (Rodrigues et al., 2009). Likewise, inorganic materials (such as porous sedimentary rocks, expanded glass, and expanded clay). Also, organic materials (such as expanded polystyrene or cork) (EuroLightConR1, 1988; Stefanidou, 2014). Moreover, some studies have developed incorporation of high thermal insulation aggregates but the latter is still not available in the market (de Fátima Júlio et al., 2016; Gomes et al., 2017). Expanded polystyrene (EPS) and cork are most commonly used as lightweight aggregates in industrial heat treatment formulations (Gomes et al., 2019).

Cork is the outer bark of the cork oak tree (Suber Quercus L) which is abundant in southern Europe and North Africa (Silva et al., 2017; Pereira, 2007; Knapic et al., 2016; Gil, 2009). It is a natural and renewable plant that is harvested every (Gomes et al., 2017; Silva et al., 2017; Pereira, 2007; Knapic et al., 2016) years when the bark becomes peelable and the material is denser. In its lifetime, the cork oak produces three types of cork, male cork from the first stripping, reproduction cork from the second stripping and reproduction cork from subsequent strips (Silva et al., 2017). Cork is a cellular material, light, flexible and permeable to gases and liquids, as well as having high insulating abilities (Silva et al., 2017; Pereira, 2007 Knapic et al., 2016). The applications of cork vary according to its quality and different properties (density, microstructure and chemical composition) shown in the table 1 and 2. (Tedjditi et al., 2020). Reproduction cork is characterized by high quality, uniform cell structure and smooth surface used in the production of cork stoppers. While male cork does not achieve the required quality, as it is characterized by a rough surface and an irregular cellular structure, so it is used in the production of shoes and cork boards (Pereira, 2007). Algeria is considered the third in the world among the countries that contain the cork oak tree with an area of 410,000 hectares, but it occupies the last ranks in terms of exploitation (Garavaglia and Besacier, 2012).

Table 1. Properties of virgin and reproduction cork. (Tedjditi et al., 2020)

Authors	Surface nature (Silva et al., 2005)	Density (kg/m^3) (Fortes and Rosa, 1988)	Microstructure (Pereira, 2007)
Virgin cork	Rough	160-240	Irregular structure. Distortion in radial alignment of cell rows. Corrugation of cells
Reproduction cork	Smooth and unblemished	120-180	Structure more regular than virgin cork. Enhancement of celle corrugation

Table 2. Chemical composition of virgin and reproduction cork. (Tedjditi et al., 2020)

Author	Cork type	Suberin	Lignin	Polysaccharides (Cellulose and hemicellulose)	Extractables	Ash	Others
Pereira (2007)	Virgin cork	45	21	13	19	1.2	0.8
	Reproduction cork	33.5	26	25	13	2.5	-
Caldas (1986)	Virgin cork	45	27	12	10	5	-
	Reproduction cork	48	29	12	8.5	2.1	-

In order to avoid throwing and wasting cork as well as to expand its use, natural and expanded cork granules were incorporated into cement compounds. Bras et al., (2013) evaluated the rheological, mechanical and thermal properties of synthetic cork mortar intended for the correction of thermal bridges, they tested different doses (0-80%) of 0.5-2 mm cork granules. Merabti et al., (2021) studied the mechanical, thermal and physical properties of the composite of granular waste cork with slag cement. The size distribution of waste cork is from 2.5 to 8 mm. The slag used is granular glass furnace slag (GGBFS). Cement was partially replaced by 15%, 30% and 50% GGBFS by weight cement. They concluded that the increase in cork volume decreases density and thermal conductivity. There is a significant decrease in strength with the presence of cork. In long-term, they also note the increase of compressive strength with the addition of slag. Sudagar et al., (2018) studied the effect of waste cork residues on geopolymers based on metakaolin and zeolite. Cork residue (20%) was added.

Besides the reference geopolymer based on metakaolin also, 25, 50 and 75% metakaolin was replaced by zeolite. They concluded that the addition of zeolite improved the compressive strength of the geopolymers (the highest strength of the geopolymers was 50:50 Metakaolin: zeolite and 20% by weight of cork residue). The further increase in zeolite affected the strength of the geopolymer negatively. The adsorption increased with the increase of metakaolin in the structure. They also found that the cork residue enhanced the compressive strength as well as the adsorption properties of geopolymers. In the last two decades, most of the research focused on the use of reproductive cork, as well as the cork resulting from waste stoppers and cork boards, but what we want to discover is the possibility of using and exploiting male cork in lightweight concrete. Tedjditi et al., (2020) previously researched in this regard, where they studied the possibility of producing lightweight concrete using male cork, as they replaced the aggregates with cork (0, 25, 50, 75, 100%) by volume and concluded that the introduction of male cork in concrete leads to a decrease in the workability and viscosity. They noticed that the increase in porosity and capillary absorption reduced the mechanical strength compared to the reference concrete. They also found that concrete containing more than 50% male cork provided good thermal conductivity with a value of (0.041 to 0.56) W/m.K. To complement the research conducted by Tedjditi and in order to improve the mechanical properties as well as ensure the sustainability and durability of male cork concrete, our study aims to explore the possibility of using natural and expanded cork granules (0-4, 4-8 and 8-16 mm) with 10% of filler in the production of lightweight concrete suitable for construction use. Aggregates were replaced in term of volume by (0 and 25%) of cork aggregates. Our research includes: workability, plastic viscosity, mechanical strength.

2. Research significance

For the first time, Tedjditi et al., (2020). carried out an experimental work to develop lightweight concrete using virgin cork granules and reached good results, especially in the field of thermal insulation, but it remained unsuitable for construction. For this reason and to go deeper in this field, we completed this research, as we studied concrete with 25% of cork immersed in water for 2 hours (concrete that provided the best results) with increasing the amount of cement also adding 10% of filler in order to improve the mechanical properties.

3. Experimental program

The experimental program was carried out at EOLE (Water and Structures in Their Environment) laboratory which is situated in Abou Bekr Belkaid Tlemcen University, Algeria.

3.1. Materials

Male cork concrete mixtures were made by using:

Composite Portland cement (CPJ-CEMII/A 42.5 N) which presents an apparent density of 1011 kg/m^3, particle density of 3024 kg/m^3 and Blaine specific surface area of 3142 cm^2/g, produced by Beni-Saf Cement Company situated in western Algeria.

Sand with grain size 0–4mmand gravel with grain size 4–8mm and 8–16 mm, purchased from national company of aggregates situated in Sidi Abdelli, Tlemcen Algeria.

Superplasticizer water reducer modified polycarboxylate which have density of 1060 kg/m^3, purchased from Orachem Concrete Company located in Boutlelis, Oran, Algeria.

Table 3. Physical properties of mineral aggregates (Tedjditi et al., 2020)

Mineral aggregate	Bulk density (kg/m^3)	Particle density (kg/m^3)	Water absorption (%)	Inter particle porosity (%)
Sand	1636.4	2701.1	1.71	39.4
Gravel 4-8	1310.9	2592.2	1.59	49.4
Gravel 8-16	1179.6	2580.0	1.22	54.3

Table 4. Physical properties of virgin cork aggregates (Tedjditi et al., 2020)

Cork aggregate	Apparent density (kg/m^3)	Particle density (kg/m^3)	Water absorption (%)	Inter particle porosity (%)
Cork 0-4	88.9	218	168.67	59.2
Cork4-8	83.8	184	116.78	54.5
Cork8-16	86.0	223	68.89	61.4

Virgin cork granules with grain size 0–4 mm, 4–8 mm and 8–16 mm grinded and sieved in the laboratory.

a. Cork 0-4 mm b. Cork 4-8 mm c. Cork 8-16 mm

Fig. 1. Different sizes of the used virgin cork granules, (Tedjditi & al, 2020).

3.2. Mixture design and mixing procedure

Based on Tedjditi (2021) search, the absorption results showed that this cork can absorb twice of its weight. Also, the cork absorption varies from one category to another, so that the smaller size of aggregate is the most absorbent (the highest absorption of cork aggregate was (0-4) mm).

Table 5. Water absorption ratios of dry cork classes.

Dry cork classes (mm)	0 – 4	4 – 8	8 – 16
Water absorption ratios (%)	92	60	39

According to Tedjditi (2021) research, two hours were chosen exactly because this time corresponds to the beginning of the phase, which is characterized by relatively slow absorption kinetics. As well as concrete with 25% of cork immersed in water for 2 hours showed good fresh homogeneity resulting a significant improvement in the consistency of cork concrete (Tedjditi et al., 2022).

Six concrete mixtures were prepared. Two control mixes, the first was regular concrete and the second was concrete with 10 % Filler as well as two mixtures in which the proportions of sand and gravel 4-8 mm and gravel 8-16 mm, in size, were replaced by their equivalent of virgin cork 0-4 mm, 4-8 mm and 8- 16 mm, respectively. Ratio: 25%. In the first mixture, we used dry cork. In the second mixture, we soaked the cork for two hours in water before using. A superplasticizer of 0.7% by weight of cement was used.

Table 6. Mixture proportions for studied virgin cork concretes in kg.

Concrete code	Reference Ordinary Concrete OC	Reference OC+10%Filler OC-F10	OC+25% Dry cork OC-25DC	OC+25% Cork 2H in water OC-25HC	OC+10%Filler+25% Dry cork OC-10F-25DC	OC+10%Filler+25%Cork (2Hwater) OC-10F-25HC
Water/Binder	0.45	0.45	0.45	0.45	0.45	0.45
Cement	450	450	450	450	450	450
Mix water	202.5	223	202.5	202.5	223	223
Cork abs water	/	/	19.02	21.3	17.86	21.3
Total water	202.5	223	221.52	223.8	240.86	244.3
Super-plasticizer	3.6	3.5	3.6	3.6	3.5	3.5
Sand	700.2	658.46	525.15	525.15	493.84	493.84
Gravel 4–8	161.6	152	121.21	121.21	113.98	113.98
Gravel 8–16	788.2	741.23	591.13	591.13	555.91	555.91
Filler	/	45	/	/	45	45
Cork 0–4	/	/	11.92	11.92	11.2	11.2
Cork 4–8	/	/	3.08	3.08	2.89	2.89
Cork 8–16	/	/	15.9	15.9	14.95	14.95

In the vertical axis mixer, virgin cork granules with their own absorbent water were introduced (Table 5) and mixed for 90 seconds. Then cement, sand and 50% superplasticizer were added and mixed for 4 minutes (water was added gradually for 90 seconds), after the gravel and the remaining superplasticizer water were added and mixed for 1 minute. Finally, the mixture was stirred for 90 s. After removal from the molds, the test samples were treated with water until the day of the test. Cross-sections were obtained from cylindrical samples with a diameter of 110 mm and a height of 220 mm in Fig. 2. The images of the samples show the absence of separation marks, indicating good homogeneity of all the finished mixtures (Fig. 3).

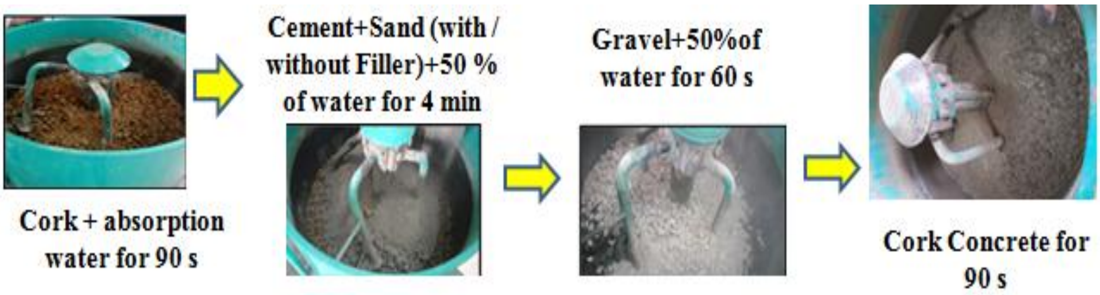

Fig. 2. Protocol of mixing cork concretes (Tedjditi et al., 2020)

Fig. 3. Cross section of reference and male cork concretes

4. Testing procedures

4.1. Workability

Workability of the developed virgin cork concrete mixtures was determined by using slump test.

4.2. Plastic viscosity

Plastic viscosity tests were conducted using coaxial vane geometry rheometer. The rheometer is equipped with a Heidolph agitator (Fig. 5). Plastic viscosity tests were carried out 10 min after finishing mixing procedure. The obtained raw results present a relationship between torque and rotational speeds.

Fig. 4. Slump test

Fig. 5. Rheological Laboratory apparatus

4.3. Mechanical properties

Mechanical properties of the prepared concretes were measured at the age of 7, 28 and 90 days. Measurements of compressive strengths were carried out on cylindrical samples (110 mm in diameter and 220 mm in height).

Fig. 6. Compressive strengths test

5. Results and discussion

5.1 Workability

Figure 7 shows the workability of virgin cork. As can be seen, the presence of virgin cork used does not play an important role in the workability of the mixtures. The mixtures maintained approximately the same workability in the presence or absence of virgin cork. For example, the workability of reference concrete (containing 0% virgin cork) was (195-200) mm. However, this slack became (194-205) mm when the virgin cork was added. Concrete has maintained a very wet texture

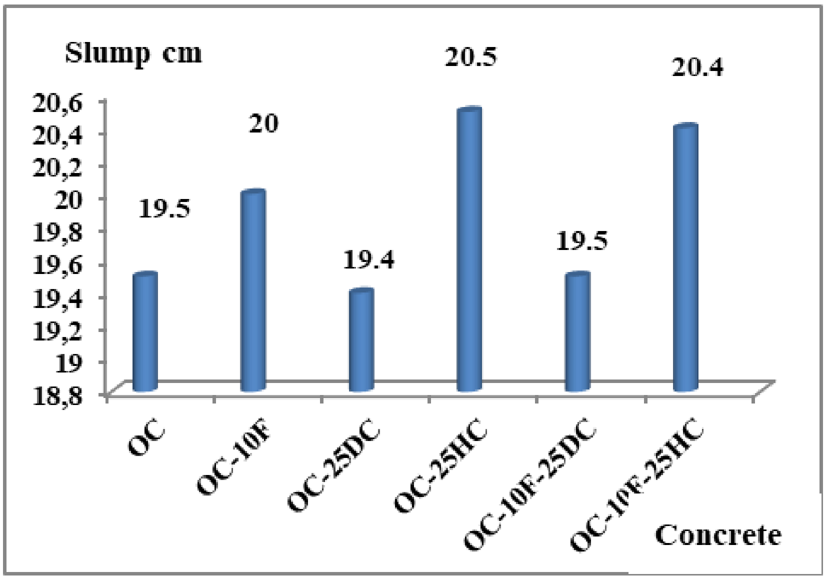

Fig. 7. Workability of the different mixtures.

5.2. Plastic viscosity

Figure 8 shows the evolution of the concrete viscosity with the addition of filler and virgin cork. The results indicated that the addition of filler and cork leads to a decrease in the viscosity of concrete. It is important to note that during the tests, the mixtures showed good homogeneity, that is, signs of separation were absent. (The viscosity of the plastic has decreased from 15 Pa for reference concrete to 0.4 Pa for OC-10F-25HC concrete). Remarkable is the fact that with workability, the viscosity of the plastic decreases with the addition of filler and virgin cork. This decrease could be related to the lower value of filler adsorption than that of cement and the lower density of cork grains, allowing for less friction and less resistance to flow. It can also due to the reduction of paste volume with adding cork amount and which allows more freedom for cork particles to circulate in the mixture.

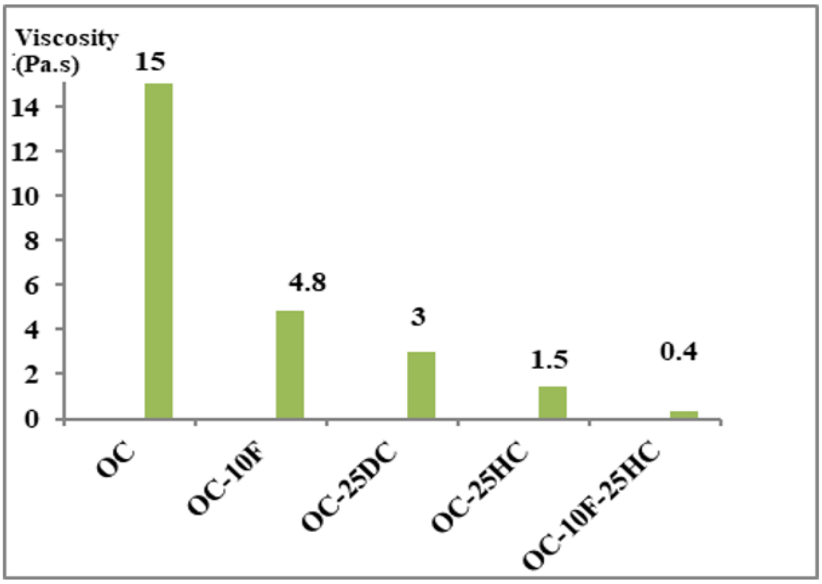

Fig. 8. Evolution of the concrete viscosity with the addition of filler and virgin cork.

5.3. Mechanical properties

5.3.1. Compressive Strength

The compressive strength obtained at 7, 28 and 90 days for the mixtures produced are summarized in Fig 9. Each value represents the average of three different samples. Despite the reduction in mechanical strengths compared to reference concrete, the results show that with the addition of virgin cork, the compressive strength decreases but increased slightly with the addition of filler which ranged between 6.3 and 12.7 MPa at 90 days Compared to (6.2- 8.3) MPa that Tedjditi found at 28 days for the same proportion of cork (25%) (Tedjditi et al., 2022).

The results on compressive strength seem to indicate that the developed concretes are classified according to the RILEM recommendation in class II for lightweight concrete (Table 7). These concretes can be used both for structural and insulating elements.

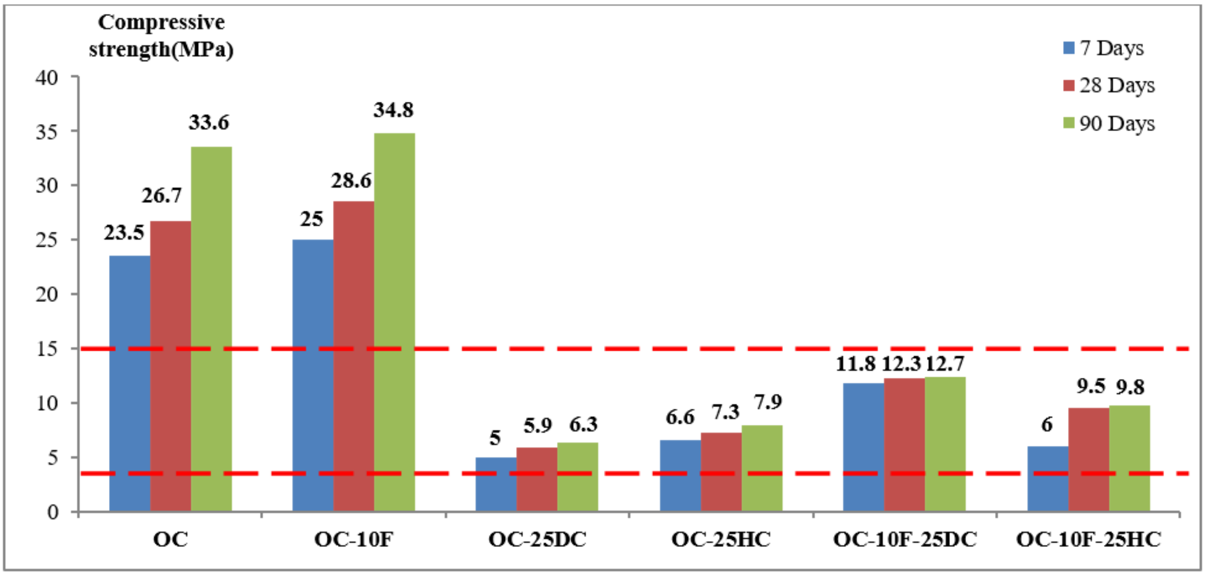

Fig. 9. The compressive strength at 7, 28 and 90 days.

Table 7. Recommendation of functional classification of lightweight concrete (Rilem-LC2, 1978)

Class	I	II	III
Type of light concrete (LC)	Structural LC	Structural & insulating LC	Insulating LC
Oven dry density (kg/m^3)	< 1800	For information only	For information only
Compressive strength (MPa)	> 15	> 3.5	> 0.5
Coef. Of thermal conductivity (W/m K)	__	< 0.75	< 0.30

6. Conclusions

In this work, an experimental investigation on the potential of using virgin cork and filler to develop lightweight concrete intended for building applications was conducted. The experiments were carried out on six mixtures containing, in volume of aggregates: 0 and 25% of virgin cork granules with or without filler. In summary, the study unveils the following: In fresh state, by introducing virgin cork into concrete, the workability and the plastic viscosity were mostly the same. Despite the remarkable reduction in mechanical strengths compared to reference concrete, virgin cork and filler composites presented good mechanical properties as structural materials. For instance, the compressive strength ranged between 5 and 12.7 MPa. According to the tentative recommendation of functional classification of lightweight concrete. To complement this research, we look forward to conducting future porosity, permeability and chloride diffusion experiments to ensure the durability of the studied concrete.

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