Cork Granules as Lightweight Aggregate

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A version of this paper has been published in: Dhir, R.K., Dyer, T.D. and Halliday, J.E. (Eds.). *Sustainable Concrete Construction*. Thomas Telford, London. 2002, pp. 253-262.

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ABSTRACT. A large amount of waste is generated during the manufacture of bottle stoppers from the cork industries in granular form. These granules are lighter than many lightweight aggregates presently used for making lightweight concrete. This paper discusses the properties of cork and its compatibility with cement. Some physical and mechanical properties of cork cement composite materials are also presented.

Keywords: Lightweight, Aggregates, Cork, Cement, Waste, Wood, Composite, Cellular materials.

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INTRODUCTION

Cork is obtained from the bark of Cork Oak trees (*Quercus suber*), which are grown mainly in Portugal, Spain, and Algeria. Another oak, that produces cork, is *Quercus occidentalis.* Both species are alike differing only in their foliage and in the ripening season of their fruits [1]. Half of the bark of these trees is carefully removed every 9 -12 years. The bark is then subjected to various processes including seasoning, cleaning, boiling, drying and removal of outer surface material. Bottle stoppers are punched from the processed bark, which leaves holes in the strips. This residual material is estimated to be more than 75 % of the harvested cork [2], and is ground into small granules. The lighter material is agglomerated and used to make panel like products. However, a large amount (20 to 40 % by weight) of the material with higher density remains unutilised [3]. Some of these wastes are burnt for process heat, while the remaining cork waste is used for land filling [4]. The density of residues is lower than that of most of the lightweight aggregates (about 300 kg/m^3) used for concrete. Therefore this property of cork could be exploited to make lightweight cementitious composites. Besides the lower density there are many other advantages associated with cork attributed to its cellular structure and chemical composition. Some of these advantages are low thermal conductivity, good sound absorption, and water resistance

Wood is used in various forms to make cementitious composites and considerable research has been done in this area. A wide range of research papers exists and have been reviewed in detail in the books [5, 6] and proceedings [7-10]. From the literature it appears that not all wood species are compatible with cement. Some of the wood species, generally hardwoods, retard cement hydration. However, there is very limited information available on the use of bark material, like cork, in cementitious composites. Aziz *et al*. [11] used cork granules obtained from packing wastes of fruit stalls in Singapore to make cork cement products. They mixed cement and cork in the ratio of 1:1 to 1:3 by volume and made concrete specimens with a density range of 475 to 890 kg/m^3, which had compressive strengths in the range of 4.2 to 12.0 MPa and tensile strengths between 0.6 and 2.0 MPa. They did not report any compatibility problems between cement and cork. Hernandez-Olivares *et al*. [1] used waste cork granules with gypsum for making composite materials. They found good thermal insulation properties of the composite. Based on scanning electron microscopy (SEM) examination of the bond between gypsum plaster and cork, they reported good compatibility between gypsum and cork. From these two papers, it appears that the chemical compatibility between cork and cement was not tested, which is done generally in wood-cement composites. Nevertheless cork is a lightweight, resilient, chemically stable and fire resistant material. It has very good thermal and sound insulation properties and it is impervious to liquids [12]. Therefore it could be used as a lightweight aggregate in concrete.

In view of this a research study is underway at the Forest Products Research Centre (FPRC), Buckinghamshire Chilterns University College (UK) to explore the use of waste cork granules as lightweight aggregate in cementitious composites. This paper reviews properties of cork as a lightweight aggregate and discusses some of the results of the present study.

CORK: AS AGGREGATE

Source

More than 33 % of the world's cork oak forests are found in Portugal, which produces more than 50 % of the world's cork. The average yield per year is estimated to be 170 thousand tons per year [13]. Furthermore, the country imports cork and manufactures 70 % of the world's cork products [14]. Presently the world's cork production rate is 340 thousand tons per year [13]. It is therefore expected that about 68 to 85 thousand tons of cork waste is generated annually from the cork industries.

Structure of Cork

Cork is a cellular material. The cells of cork are roughly hexagonal on the tangential face and rectangular on the radial and axial faces [15]. The cork microcells are generally made of 14-sided polyhedrons, slotting in one against each other and filled with gases. The gases have not been analysed but are likely to be similar to air [16].

In order to confirm cell shape in the cork samples, a scanning electron microscope (SEM) was used. An SEM micrograph of cork is shown in Figure 1. While looking at the section perpendicular to radial direction, it was confirmed that these cells look more or less like closed hexagonal prisms. From other angles, these hexagonal prisms were found to be stacked in rows parallel to the radial direction. Fortes and Rosa [17] also reported similar observations.

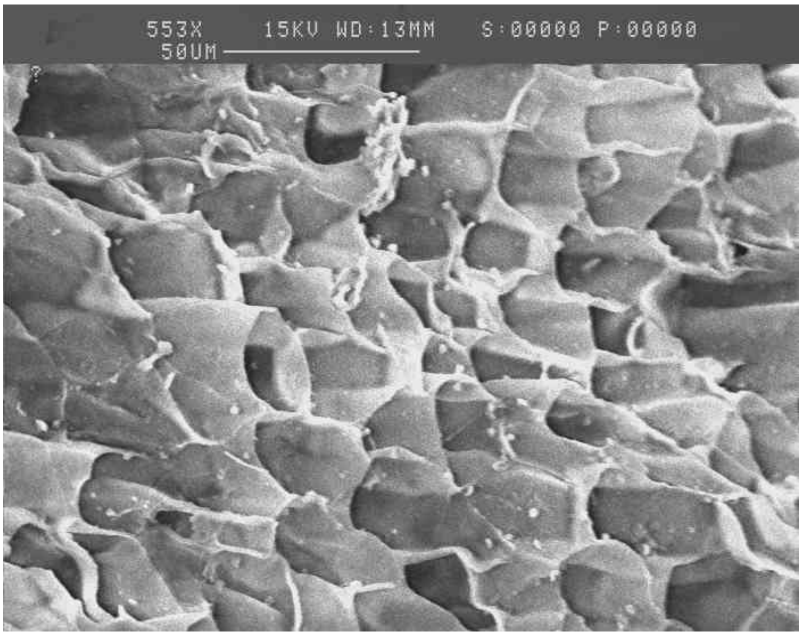


Figure 1: SEM micrograph of cork showing structure of cork cells

Cork contains about 85 % voids in closed cells [15]. The cells in cork are very small. It has been reported that there are about 30 to 42 million cells in a cubic centimetre of cork [16]. They are much smaller than those in normal foamed plastics, and comparable with those in micro porous foams.

Mechanical Properties

Under compression, cork deforms due to bending and buckling of the cell walls. This results in large recoverable strains of about 100 %. Whereas tensile stress unfolds the corrugations and straightens the prism walls. Tensile strain is recoverable up to approximately 5 %. Beyond this any tensile force stretches the cell walls and then breaks them [12].

Typical mechanical properties of cork from various sources are given in Table 1. The density of cork is comparable with that of group 1 aggregates Perlite and Vermiculite. For which ASTM C332 prescribes limit of 120-196 kg/m^3 and 88-160 kg/m^3 respectively [20].

Table 1: Comparison of the physical properties of cork and conventional wood [15, 18,19].

WOOD	**DENSITY (kg/m^3)**	**TENSILE STRENGTH (MPa)**		**COMPRESSIVE STRENGTH (MPa)**	
		Parallel	Perpendicular	Parallel	Perpendicular
Cork	170	1.1± 0.2^a	1.0 ± 0.2^b	12.5^c	12.5 ^{c}
Softwood					
Scots pine	510	110	--	47	5.5
Douglas Fir	545	138	209	50	6.9
Hardwood					
Ash	689	136	---	53	10.1
Beech	690	180	---	56	10.5

a = axial and tangential, at 9 % strain,
b = radial, at 5 % strain,
c = in all three directions at about 86 % strain

Chemical Composition of Cork

The chemical composition of cork varies slightly according to the findings of different research groups, which may be due to the different sources of the cork. A typical range of chemical constituents of cork is given in Table 2. The main characteristic of the chemical composition of cork is the presence of 'suberin' as the main cell wall component. Suberin is an unsaturated fatty acid and in cork its amount varies between 35 to 41 %. Cork also contains a high amount of extractives. Waxes are associated with suberin and amount to approximately 5%; tannins and other phenolic substances correspond to approximately 7% of the cork material [21]. The walls of cork cells are covered with layers of suberin and waxes which make them impervious to air and water and resistant to attack by many acids [22]. In a recent study, conducted by Gil *et al*. [23] using NMR techniques, it was verified that suberin is responsible for the water impermeability of cork.

Table 2: Chemical Composition of Cork [21]

COMPONENT	CONTENT (% WT.)	
Ash	0.53 – 0.91	
Total Extractives	14.1 - 16.9	
Dichloromethane		6.3 - 7.9
Ethanol		4.5 - 5.8
Water		1.9 - 3.2
Suberin	35.2 -41.2	
Insoluble lignin	19.5 - 21.0	
Soluble lignin	1.2 - 1.6	
Polysaccharides	15.7 - 21.3	

Comparison of Cork and Wood

Considerable differences have been found between cork and wood. Moreover, cork granules can be considered as a lightweight aggregate rather than reinforcing fibres. The most characteristic difference in chemical composition between cork and wood is presence of suberin in cork. Suberin is a polymer, made up of long- chain aliphatic alcohols and acid monomers. It is hydrophobic and when combined with waxes, it contributes significantly to the impermeability of cork [21]. The other main difference is cork's lower cellulose and hemicellulose content. These compounds are mainly composed of sugar, which retards hydration of cement. Therefore, the reduced amounts of cellulose and hemicellulose are beneficial from the cork-cement compatibility point of view.

Table 3: Comparison of chemical composition of cork and conventional wood fibres [18, 21].

PRINCIPAL CONSTITUENT (WT. %)	WOOD		CORK
	Softwood	Hardwood	
Cellulose	40-45	45-50	9
Hemicellulose	20-30	20-35	~11
Lignin	26-34	22-30	22
Extractives	0-5	0-10	15-20
Suberin	---	----	40

A comparison of various strength properties of wood and cork are presented in Table-1. It can be seen that the woods listed are stronger than cork. This may be due to the fact that wood is a cellulosic material containing fibre, whereas cork is a granular material and contains only 9 % cellulose in comparison to wood, which contains 40-50 % cellulose.

PRESENT WORK

In order to understand cork-cement interactions and the effect of various parameters such as particle size, density, and amount of cork in the cement matrix on the physico-mechanical properties of concrete, five different grades of cork granules were obtained from a cork industry in Portugal. The mean particle size of these granules varies between 0.1 to 2.5 mm. Bulk density is between 126 to 370 g/cm^3 and particle density 233 to 583 g/cm^3.

Experiments are in progress on effect of cork on:

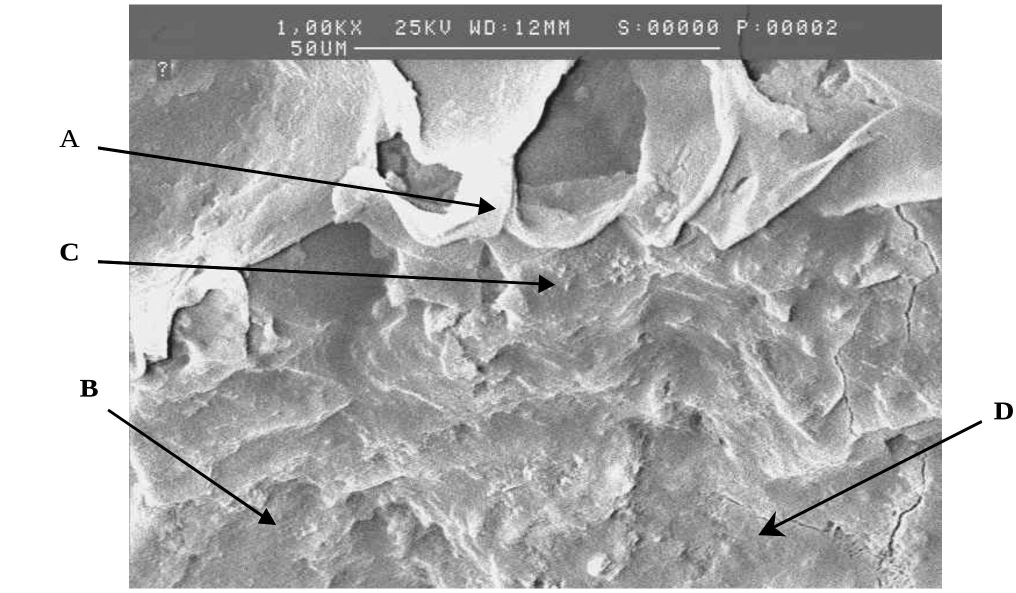
i) Cement hydration using a semi adiabatic calorimetric technique,
ii) Mechanical properties by Compression and Flexural tests,
iii) Bonding by SEM studies and
iv) Mineralogical studies by X-ray techniques.

The initial results have been encouraging. It seems that cork is quite compatible with cement. Cork–cement bonding is also found good as can be seen in Figure 2. It can be noted that after cracking of the cement paste, the bond between cork cell and the cement paste is intact. The strength property results indicate that cork granules considerably reduce the strength of the composite; but significantly contribute in enhancement of toughness of the composite. As can be seen in the Figure 3, the composite specimens failed after achieving much more deformation than the pure cement specimen. The advantage of using cork granules is that they contain several open cells at their surfaces. This facilitates good bonding with the cement paste, as can be seen in Figure 2. Since cork contains about 85 % by volume of air voids, its addition to cement matrix reduces density of the concrete. It would result in reduced thermal conductivity and better sound absorption properties of the concrete.

Cork granules can be advantageous due to their negligible Poisson’s ratios in the tangential and axial directions with respect to the radial direction [12]. When load is applied on the cork cells, the gas within the cells is compressed and therefore no lateral expansion takes place. This implies that when the composite is loaded the cork granules exert very little lateral pressure, which will reduce the lateral splitting of composite.

The problem with the use of cork is that it has very poor strength. However, the lower strength at high deformation of the resultant concrete can be exploited for advantage in use as crushable concrete in the stop barriers for moving vehicles or as ‘bullet traps’. In such applications the material should absorb large amounts of energy of the moving objects. It does not imply that cork cement concrete can not be used for structural purposes. It can be used as lightweight weight concrete and if required its strength could be enhanced by the addition of synthetic fibres.

Cork is a durable material. Its lifetime is more than 170 years [13]. From ecological point of view also use of cork is beneficial because cork is regenerated from trees and there is no need to cut any tree.



A: cork cell wall, B: hydrated cement paste, C: good bonding between cork cell wall and cement paste and D: crack in cement paste

Figure 2: SEM micrograph of fractured cork cement composite specimen.

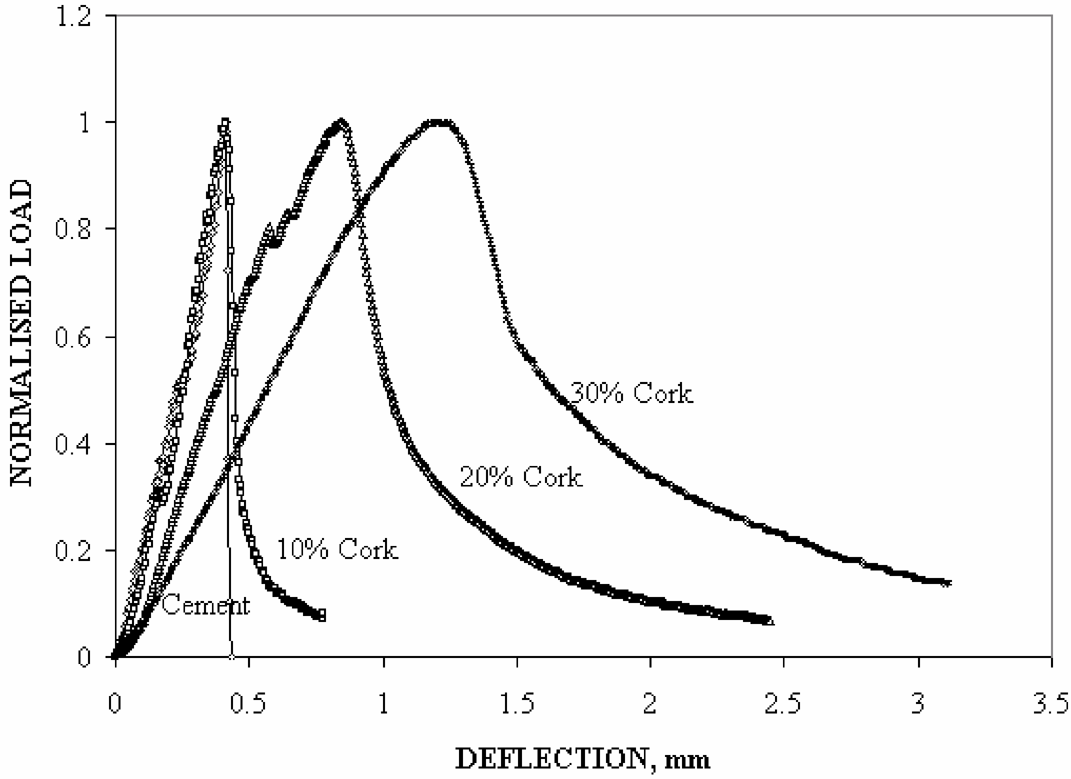


Figure 3: Normalised load-deflection curve of cork cement composites in 3-point bending.

CONCLUSION

Cork is a lightweight, water resistant, cellular material available as waste in large quantity. Preliminary results indicate a good compatibility between cork and cement. As expected, cork does reduce the strength properties of the concrete product. However, the concrete can attain reduced density and improved functional properties such as thermal conductivity and sound absorption. A wide range of cork granules available means that suitable mixes may be designed for a number of specific applications. However, before cork can be fully exploited in practice, there is a need to undertake more research in order to gain a broader insight into the behaviour of these new composite materials.

ACKNOWLEDGEMENT

The first author thanks the Director, Central Building Research Institute (CSIR), Roorkee (India) for grant of study leave to him for undertaking this study.

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