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Coconut Shell as Substitute of Natural Aggregate in Concrete for Developing Regions – A Short Review.

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Abstract – In recent years the use of waste materials as coarse aggregate is increasing to produce environmentally-friendly concretes. Coconut shell (CS) is an agro-industrial waste available in large quantities in emerging countries such as India, Thailand and Mexico. Generally, CS is disposed in open dumps causing environmental issues. Different treatments for CS have been proposed by researchers in order to use it as aggregate in concrete. The CS has different physical properties compared to natural aggregates and its main effect in concrete mixtures is workability, hence, mechanical, microstructural and durability properties might be affected. This literature review is useful to carry out further research about low energy demand and easy implementation methodologies to use CS as aggregate in concrete for social development.

Keywords: Ecological concrete, coconut shell, waste materials, social development, aggregate

1. Introduction

Concrete is the most used construction material around the world as a result of civil infrastructural growth. The manufacture of this construction material requires large quantities of natural resources including coarse aggregates (about 70 to 80% of the total concrete volume). Generally, coarse aggregates are obtained from stones leading to the depletion of natural resources and alteration of lands because of mining activity to obtain raw materials. Large infrastructures consume massive quantities of aggregates and according to a recent ecological - economic study the overextraction and inefficient distribution are the principal causes for non-ecological and non-social development [1]. In that study the reduction of per-capita units of consumption of aggregates, the use of alternative building materials and the revival of traditional or vernacular structures are kindly suggested.

Simultaneously, there are different industrial and agricultural solid wastes which can be used as alternative coarse aggregates in concrete mixtures. The properties and positive or negative effects of these materials in concrete depend to the adopted methodology (such as crushing, agglomeration, sintering, cold bonding and autoclaving) to process it, likewise it depends to the binder type and binder dosage [2]. The first criteria to select a waste material (WM) as alternative coarse aggregate might be the workability effect of these materials on the concrete. Each WM has different physical properties compared with natural aggregates, some of these materials demand a high content of water and hence the flow of the concrete mixture is reduced. In contrast, other materials increase the flow of the concrete mixture.

Another criteria to select a WM to be used as alternative aggregate in concrete is its availability. Industrial by-products such as fly ash, ground granulated blast furnace slag and silica fume are easy to obtain in determined regions. Moreover, transportation to developing regions might be difficult and this is traducing in a cost increment for constructions. Similarly ceramic waste, glass, e-waste, plastics and concrete demolition waste are used as aggregates. Alternatively, agro-industrial wastes are available around the world and most of these materials are disposed in landfills causing contamination difficulties. Oil palm shell, palm kernel shell and coconut shell (CS) are the most common and most available agro-industrial wastes to be used as aggregate in concrete [3].

Recently, the CS as aggregate in concrete mixtures has been evaluated by several authors. CS as coarse aggregate makes a change in concrete technology because some of it physical properties such as rigidity and impact strength [4]. CS as coarse aggregate has been proposed by several researchers. Authors replaced natural or crushed aggregate with CS in concrete mixtures and it was found that about 15-20% of replacement could be the optimal because mechanical properties are maintained [5,10]. Likewise, CS as sand replacement, up to 20% by weight, has been proposed for ecological concretes, [10-13].

According to the previous statements, the use of CS as substitute of natural crushed aggregate in concrete mixtures is discussed on this paper. The discussion gives the opportunity for further works on using CS as partial substitute of natural coarse and sand aggregate for non-structural and structural concretes.

2. Physical and microstructural properties of CS

The CS is physically different to natural aggregates because the nature of the coconut fruit having a concavity. Fig. 1 shows a comparison between CS after crushing (to obtain the granulometry of coarse aggregate for concrete mixtures) and crushed coarse aggregate. It can be observed that CS is smooth on the concave face and rough in the convex face. It is reported that CS has good strength and modulus properties, is non-biodegradable and can be used readily in concrete because it might fulfil almost all qualities of concrete. These properties make the CS as suitable material to be used as partial of coarse aggregate replacement contributing to combat disposal problems and environmental issues [14].

Fig. 1: Appearance and comparison of CS and crushed aggregate particles.

The CS has high lignin content and low cellulose that makes the composites containing it more weather resistant and less absorbent [15]. The micrographs in Fig. 2 [6] shows the heterogeneity of the CS particles after crushing to replace coarse aggregate in concrete, it is observed that CS has discrete cells and continuous cells in which water can be absorbed when mixing the concrete. Considering the above the authors suggest use saturated CS particles when mixing.

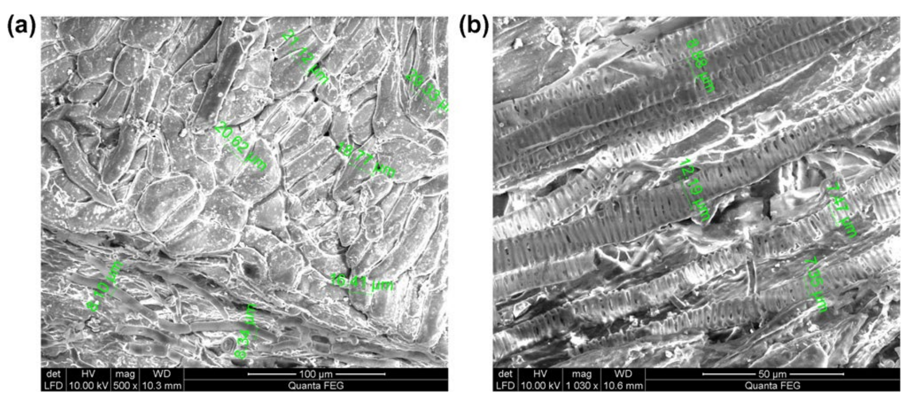

Fig. 1: SEM images published by Gunasekaran et al. 2012 of CS a) without and b) with soaking of 24 hours

When CS is grinding to be used as sand replacement water absorption can occur because the CS absorb water itself and may create osmosis pressure on the concrete matrix. However, a study reported less than 5% of water absorption in concretes when CS, which passes a sieve of 4.75 mm, is used as sand replacement up to 10% [13]. However, the use of superplasticiser is also recommended when using CS as sand replacement.

3. Discussion about the performance of CS as coarse and sand aggregate in concrete.

Various researchers used CS as substitute material of aggregate in concrete mixtures to combat environmental issues. Most researchers are focus on the evaluation of the mechanical properties of the concretes containing CS. Mechanical properties such as compressive strength and flexural strength has been considered as first criteria to evaluate concretes.

As mentioned in the last section, CS has different forms when compared to natural aggregate, this reduced its movement and the movement of aggregates during the mixing process. The density of the concrete containing CS is about 75% the density for conventional concrete, considering the above, concrete containing CS may be considered as light weight concrete [16]. This depends as the content of CS is increased in the concrete mixture.

Once workability problems are resolved in concrete containing CS as aggregate substitute, the mechanical properties are evaluated. According to the literature review, a concrete containing CS as aggregate satisfies the basic mechanical properties of compressive strength without segregation and bleeding during the mixing process and fresh state [4]. Likewise, the slump values at various percentages of CS meets the standard requirements and a homogeneous and compactable matrix is obtained as observed and described by other authors [9].

The variety in results in mechanical properties from different studies might be attributed to the nature of the CS. This material is organic and hence its microstructure can differ from regions depending of the soil where it is cultivate in by the harvesting methods. According to a publication, the CS needs to be cleaned to have a material free from fibres and husk. Likewise, the ratio between thickness and the lateral dimension of the CS particles must be equal to avoid problems with shape and hence workability of concrete [17]. Cleaning, drying, fibre removal and crushing or milling could be a consuming time process. However, a proper material to be used as replacement of aggregate in concrete is obtained and this helps to reduce environmental issues and according to the findings by some authors, it also has economic benefits in the construction industry [4, 16, 18].

The use of a supplementary cementitious material, such as fly (FA) as or ground granulated blast-furnace slag (GGBS), as cement replacement in concretes containing CS as coarse/sand aggregate is a good alternative to enhance mechanical properties of the concretes due to the improvement of the cementitious matrix to diminish the non-positive effects when using a high content of CS. As well, the use of a cementitious material enhances the workability of concrete when mixing. A review paper reported that the use of 30% of FA and 25% CS as aggregate is a suitable option for concretes in terms of compressive strength [18]. Another research evaluated the use of GGBS in concretes containing CS as substitute of natural aggregate and the results revelated that the use of GGBS has positive effects on the compressive strength of concrete in bout 15% due to pozzolnic reactions [9]. This is a positive effect to diminish the reduction of the mechanical properties reported by some studies.

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4. Conclusions and further works

According with this short review about the use of CS as partial replacement of coarse and sand aggregate in concrete mixtures, the following conclusions and further works can be draw.

The use of CS as partial replacement of coarse/sand aggregate can be used in about 15 to 25% without having negative effects on the mechanical properties of concretes. However, a saturation condition for the CS is recommended to prevent water absorption during mixing. Also, chemical pre-treatment for the CS can be considered when using dry CS particles as substitute of coarse aggregate.

The use of agro-industrial waste materials as cement replacement in concrete containing CS as coarse/sand replacement might be an excellent option to combat environmental issues, however, it requires a detailed evaluation because these materials also absorb water during the mixing of concrete mixtures. Likewise, some of these materials are used discreetly because some adverse effects in concretes, such as the decrement of compressive strength when are using in large quantities, due its proper nature.

Alkali-aggregate reactions must be evaluated because the nature of the CS and the alkaline environment of the concrete. This should be analysed over time.

An evaluation about the use of additives for concrete containing CS as coarse/sand aggregate is mandatory because the interaction of chemical compounds with materials from organic nature.

Durability studies of concretes containing CS as coarse and sand replacement in strongly needed. CS is an organic material and disintegration due to alkalinity of the concrete could occur as the time pass. Likewise, the growth of microorganism might be reported.

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