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Development and characterization of blended cements containing seashell powder

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HIGHLIGHTS

- An innovative method is proposed to develop blended cements using seashell and/or pozzolan.
- 34 types of cement were prepared and their physical/chemical properties were studied.
- Influence of using seashell and/or pozzolan on cement properties was discussed.
- This approach enhances sustainability and reduces costs of cement production.

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ABSTRACT

This study evaluates potentiality of waste seashell to be used as additives in production of blended cement. Cements with binary blends of ordinary Portland cement (OPC) and seashell powder (up to 30% by mass) as well as ternary blends of OPC, seashell powder (up to 7% by mass) and natural pozzolan (up to 30% by mass) were developed and their characteristics were investigated in terms of density, fineness, specific surface, chemical composition, and setting time. Properties including compressive strength, flexural strength, and water demand were determined for mortars made of the developed cements. All the properties characterized for the blended cements were compared with those of the OPC as well. Setting time of all the blended cements was higher than that of the OPC, which is beneficial for construction in hot climate. All the blended cements containing seashell powder, presented compressive strength relatively close to that of the OPC at all three ages of 3, 7, and 28 days, demonstrating competitiveness of the produced blended cements with OPC. Results indicate that seashell powder can be used as cement replacement in developing blended cements not only to enhance sustainability and reduce costs of production, but also to promote the properties and performance of concrete.

1. Introduction

Demand of paying a considerable attention to the environmental protection, on one hand, and the optimum utilization of the non-usable raw materials for achievement of sustainable development, on the other, necessitate civil engineers not only think over designing structures to meet serviceability requirements, but also consider how their projects impact the environment. Therefore, taking into account the environmental issues has to be a main concern of civil engineers in designing structures in order to step forwards towards the path of sustainable development. Producing and utilization of more environmental friendly cements and concretes would represent a key contribution to achieve the goal of sustainable development. Worldwide, today's concrete production is estimated to be around six billion tons per year [1]. However, demand for concrete as a construction material is constantly increasing, that results in increasing usage of concrete-making materials, such as cement and aggregate. Intensive consumption of natural aggregate leads to depletion of these natural resources [2–5], while negative environmental issues (e.g. damage to landscape and disruption of eco-system, water, soil and air contamination) may emerge upon inconsiderate quarrying activities during extraction of the natural aggregates [6,7]. On the other hand, the cement industry is faced with a number of challenges including depletion of natural raw material resources, demands for increasing cement production, necessity of reducing energy consumption during production of Portland cement clinker, and environmental

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concerns regarding greenhouse gas emissions. Producing one tone of Portland cement causes emission of about one tone CO_2 greenhouse gasses [8,9]. It is estimated that the cement industry is responsible for 5–8% of CO_2 emission in the world [10,11]. Besides, about 2% of world energy consumption is attributed to the process of cement production [9]. These challenges motivate the cement industry to improve their production methods and cement formulations in order to meet the goal of sustainable development.

Application of locally available waste seashell as construction material can reduce risk of depleting natural aggregate resources, environmental problems linked to the climate change, and represent a cost effective solution for manufacturing the construction materials. The most promising applications of the waste seashell in construction sector are replacement of natural aggregates in producing concretes and mortars or adding filler in manufacturing of Portland cement. The seashell must of course have controlled characteristics and properties to be suitable for concrete production, whether it is used as aggregate or cement replacement. Many studies have been carried out to investigate application of seashell as a partial or total substitute for fine and coarse aggregates. In general, the main criteria that determines the maximum level of replacement of fine or coarse natural aggregates by seashell aggregates in concrete is to produce a concrete without decreasing significantly compressive strength and workability [12]. In both cases of applying seashells as fine or coarse aggregates, additional cement paste is necessary to achieve desired workability due to the angularity of the seashells aggregates [13–15]. The crushed seashells as replacement for coarse aggregate are more suitable to produce lightweight and low strength concretes, due to the excessive flakiness of the seashell particles [12,14] . A study was conducted by Nguyen et al. [14] to recycle seashells as coarse aggregate for the producing low strength concrete. The coarse aggregate fraction was partially replaced (either 20% or 40% by mass) by seashell, and results of their work showed achieving concretes with compressive strength of about 15 MPa, whereas compressive strength for the control specimen (0% replacement of coarse aggregate by seashell) was about 16 MPa. Even total replacement of natural coarse aggregate by the seashell gravel, demonstrated the possibility of developing structural lightweight concrete, whose 28-days compressive strength surpasses the minimum strength recommended by ASTM C330 [16] standard (17 MPa) [17].

The potentialities of crushed seashell as fine aggregate in concrete composition were assessed by many authors [12–15,18–21]. However, there is no unanimous idea about the effect of using crushed seashell as partial or total replacement of fine sand in concretes and mortars. Yang et al. [22] replaced 5, 10, 15 and 20% of fine aggregate less than 5 mm size) by crushed seashells, and found that the compressive strengths of the produced concretes at 28 days were not significantly reduced by increasing ratio of seashell aggregate. Safi et al. [15] developed a self-compacting mortar with total substitution of sand by seashell. They found that the produced mortar had suitable flowability to be poured without vibration, and no visual sign of segregation or bleeding was detected. Their results also showed compressive strength and elastic modulus at 28-days, are slightly decreased as 100% of sand is replaced by crushed seashells. Wang et al. [18] used crushed seashell to replace the river sand in six weight replacement ratios 0%, 5%, 10%, 20%, 30%, and 40%) and concluded that the replacement ratios up to 10% do not reduce significantly the concrete compressive strength at 28 days. However, for the replacement ratios higher than this limit >10%), 28 days compressive strength decreases significantly, but the resultant compressive strength still meet the characteristics for a normal strength concrete in the class of C20. It is worth noting that the discrepancy between the reported results in the literature is affected by different physical and chemical properties of the seashell aggregates as well as their morphology [23].

Manufacturing of cement with additive of seashell powder is an economical and sustainable strategy due to the decreasing ratio of clinker in cement, and providing a solution for the problem of waste management [23,24]. It was shown by many studies that the chemical composition of seashells includes higher than 90% calcium carbonate ($CaCO_3$) by weight e.g. [7,15,21,22,25,26]. This composition is almost like limestone powder used to produce Portland-limestone cement (PLC). Therefore, seashell can be considered as potential replacements of conventional limestone (usually extracted from crushing quarried limestone rocks) in cement industry. Almost all the cement standards permitted replacement of Portland cement with limestone powder up to 5% by weight. According to ASTM C595 [27] standard (American standard) and some others, (Canadian standard CSA A3000 [28], New Zealand standard, NZS 3125 [29]) PLC are permitted to contain up to 15% of fine limestone. The European standard EN 197-1 [30] permits CEM II Portland limestone cements to contain up to 35% limestone.

Despite the considerable potentiality of seashell for partial replacement of cement, yet limited researches have been executed on this issue, especially as cement is replaced by a blend of different proportions of both seashell powder and another supplementary material (like natural pozzolan). Lertwattanaruk et al. [23] found that cement replacement by seashell powder is beneficial not only in terms of enhancing sustainability (due to reduction in CO_2 emissions) and reducing cost linked to manufacturing of cement (due to decreasing ratio of clinker in cement), but also due to potentiality of seashell powder to promote the properties and performance of concrete. They showed that by increasing the dosage of seashell content (from 5% to 20% by weight) in mixture of blended cements, setting time of the resultant cement was extended; this is an important advantage for construction in hot

(a) (b)

Fig. 1. (a) Seashell sample used in the present study (before crushing) (b) size and configuration.