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Performance of mussel shell as aggregate in plain concrete

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HIGHLIGHTS

- Mussel shell as fine and coarse aggregate in plain concrete was studied.
- Main mussel properties that affect concrete behaviour are shape and organic matter.
- Flaky shape worsened consistency and paste-aggregate bond and improves water penetration.
- Organic content decreases a paste-aggregate bond and increases porosity, affecting hydration.
- Mussel shell can be used as aggregates up to 25% (sand or gravel) and 12.5% (together).

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ABSTRACT

In this work the performance of mussel shell as aggregate in plain concrete has been studied. The mussel shell used came from the cannery industry, which produces more than 1 million tonnes of shell by-product a year worldwide. The mussel shell has been heat-treated at 135 °C for 30 min and then crushed and sieved into sand and gravel. The new aggregates have been studied by X-ray diffraction (XRD), TGA and SEM microscopy.

Then two different conventional concretes were designed, a non-structural concrete (NSC) and a plain structural concrete (SC). In both of them the natural aggregates (sand, gravel, and both sand and gravel) were replaced with mussel shell aggregates at different percentages. All concretes were characterized in fresh and hardened states (microstructure, workable life progression, workability, compressive and splitting strength, longitudinal modulus of elasticity, weight loss and water permeability).

The results lead to establishing that with this treatment, mussel shell replacement should be limited to 25% of fine or coarse aggregates, or 12.5% of both fine and coarse aggregates. With these percentages the NSC and the SC will display a correct behaviour.

1. Introduction and objectives

Bivalve molluscs represent almost 10% of the world's total fishery production, being 26% of the entire volume and 14% of the entire value of the world's total aquaculture production. In fact global bivalve mollusc production (capture plus aquaculture) has increased substantially in the last fifty years, going from nearly 1 million tonnes in 1950 to about 14.6 million tonnes in 2010. By species, bivalve mollusc production via aquaculture in 2010 consisted of 38% clams, cockles and arkshells, 35% oysters, 14% mussels and 13% scallops and pectens.

China is by far the leading producer of bivalve molluscs, with 10.35 million tonnes in 2010, representing 70.8% of global molluscan shellfish production and 80% of global bivalve mollusc aquaculture production, as all of the Chinese bivalve production is cultured. Japan is the second largest producer, far behind China with a production in 2010 of approximately 819,131 tonnes, followed by the United States of America (676,755 tonnes), the Republic of Korea (418,608 tonnes), Thailand (285,625 tonnes), France (216,811 tonnes) and Spain (206,003 tonnes). Other main bivalve producing countries are Canada, Chile, Italy and New Zealand.

Unlike most other aquatic species, wild mussel production is much smaller than cultured mussel production. There are four common mussel species [1]. Namely, the blue mussel (*Mytilus edulis*) mainly produced in France and the Netherlands, and farmed along the northeast coast of North America and the Pacific Northwest. The Mediterranean mussel (*M. galloprovincialis*) which is greatly produced in China, northwest Spain and the northern shores of the Mediterranean Sea, with production also reported in southern Mediterranean countries, the Russian Federation, the

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Ukraine and South Africa. The Asian green mussel (*Perna virids*) which is widely distributed in the Indo-Pacific region, extending from Japan to New Guinea and from the Persian Gulf to the South Pacific Islands. Finally, the Greenshell (*Perna canaliculus*) which is native to New Zealand, although farms are limited to areas that are suitable for growth (high subtidal and sheltered inshore areas), with New Zealand mussels currently being exported to about 60 countries.

The trophic conditions of Galician "Rías" or inlets, coastal ecosystems in the northwest of the Iberian Peninsula, makes them exceptional sites for the extensive culture of mussels (Mytilus galloprovincialis) on floating rafts [2]. Consequently, these "Rías" support the highest mussel production in Europe, where over three thousand rafts (with an area of 500 m^2 and 500 hanging ropes 12 m long) [3].

As it is well known, shell is about 33% of the entire weight of mussel shell waste. Thus, it can be confirmed that the canning industry generates 25,000 tonnes of mussel shell waste every year in Galicia and over 1 million tonnes worldwide. This implies a significant waste problem on a global scale [4], being Galicia the third greatest worldwide producer of mussels aquaculture after China and the first of the EU [1,5–7]. Furthermore, in recent years the construction field has become increasingly aware of the need to change towards sustainability. Therefore, some works have been developed in recent years that study the use of mussel shell waste as construction material, using it as an aggregate or filler to be incorporated into concretes or mortars.

Periwinkle shells are one of the most common molluscs used in concrete, and they have been used as a substitute for natural coarse [8–11] and fine [12] aggregates. Oyster shells have also been studied as a substitute for fine aggregate in concrete [13–15] and for both fine and coarse aggregate [16]. Finally, Cockle, scallop and mussel shells have been studied as coarse aggregate [17–20], and also as sand [4,14] in concrete. All of these studies concluded that the workability, density and compressive strength of concrete decrease as the percentage of seashells increases. It was also determined, that the use of seashells affects the tensile splitting strength, modulus of elasticity, drying shrinkage and water permeability of concrete.

However, most of these authors do not mention having carried out any cleaning or deworming treatment on the seashells [18,20,21] and a few have used waste shells after some form of complex cleaning. Some of them have cleaned shells for 24 or 4 h [11,15,22] in a laboratory oven (110 °C or 105 °C), others have heat treated them at 250–300 °C [17] and others authors have washed and air dried the seashells at room temperature [8,9]. In one case the shells were cleaned with bleach, white vinegar solution, baking soda and using different abrasives [14].

In this study, the behaviour of shells as aggregates in concrete has been analysed. However, the most significant difference between this study and others, is the fact that the mussel shells were industrially manufactured with a simple treatment, involving low energy consumption and resulting in a commercial by-product. Mussel shell brought from the canneries is heat treated at 135 °C for 32 min, using the treatment required by European regulations for poultry feeding as a reference [23]. This process not only provides security guarantees for handling mussel shells, but also allows the product to be marketed as feed complement for farmed animals, and for the manufacture of organic fertilisers or soil improvers.

Therefore, the first step was to thoroughly study the mussel shell properties, in order to determine if this simple treatment is enough to achieve a suitable by-product. A full characterization and specific tests for aggregates in concrete were performed. Thus, X-ray diffraction (XRD), TGA and SEM microscopy, leaching, have been used to characterize the different size fractions of the mussel shells. Then, the specific tests of aggregates for concrete (density, water absorption, Los Angeles, chloride and sulphate content, etc) were developed.

After that, the next stage was to study concrete behaviour when each natural aggregate size fraction (fine or coarse) is replaced separately but also, when both are substituted at the same time. The substitution rates of each size fraction separately were 25%, 50%, 75% and 100%. When both fractions are replaced together, the percentages used were 5% and 12.5%. The concrete properties analysed were workability, water absorption, fresh and hardened densities, workable life progression, compressive and splitting tensile strength, modulus of elasticity, weight loss and water permeability.

2. Materials and mixes

2.1. Cement and additive

The cement used was CEM II/A-M (V-L) 42.5R, Portland cement with additions (CEM II), mixed (M) with a 6–20% (A-M) of siliceous fly ash (V) and limestone (L), and a 0–5% of minor components, compressive resistance at 28 days of 42.5 MPa and high initial strength (R) (EN 197-1).

In order to maintain the target values in consistency, an additive was used; it was a naphthalene sulphonate condensate superplasticizer (Melcret 222).

2.2. Natural and mussel shell aggregates

In this study, natural and mussel shell aggregates were used. Both coarse and fine natural aggregate came from crushed limestone. The size fractions used were a natural sand (NS) with a 0–4 mm fraction, and two natural coarse gravels, with a 4–16 mm fraction (NG(4–16)), and a 10–20 mm fraction (NG(10–20)). Properties of the natural aggregates are shown in Table 1.

The mussel shells have been heat treated at 135 °C for 32 min, using the treatment required by European regulations for poultry feeding as a reference [23]. This procedure ensures the disinfection of the aggregates and warrants their safe handling and storage. This treatment resulted in mussel shell gravel (MG). From this mussel gravel, two mussel shell sands were obtained by crushing

Table 1
Natural fine and coarse aggregate properties.

		NS	NG(4–16)	NG(10–20)	EHE-08 limits [24]
Fineness modulus UNE-EN 933-1 [25]		3.71	6.20	7.37	
Fineness content UNE-EN 933-1 [25]	(%)	11.54	1.49	0.42	<10 (sand) <1.5 (coarse)
Particle density UNE-EN 1097-6 [25]	(kg/l)	2.67	2.61	2.66	
Water absorption UNE-EN 1097-6 [26]	(%)	2.22	2.20	1.33	<5
Sand equivalent UNE-EN 933-8 [27]	(%)	64	–	–	⩾80
Flakiness index UNE-EN 933-3 [28]	(%)	–	14.02	7.21	<35
Los Ángeles Coefficient UNE-EN 1097-2 [29]	(%)	–	–	23.10	<40

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