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Mechanical behavior of concretes made with non-conventional organic origin calcareous aggregates

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HIGHLIGHTS

- Waste mussels' shells utilized as total/partial substitute of aggregate in concrete.
- Mussels' shells are good to be added to a concrete mix as aggregate.
- Compression and bending tests to analyze the behavior of this new concrete.
- Mussels' shells allow to obtain conglomerates having a good workability.
- Concrete samples with mussels' flakes showed a certain ductility of the behavior.

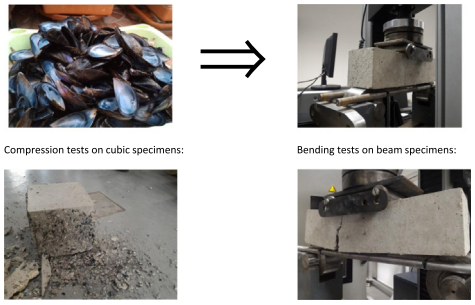
GRAPHICAL ABSTRACT

Waste mussels' shells utilized as total or partial substitute of aggregate in concrete.The mussels' shells, consisting essentially of limestone, a material similar to that of the other components of concrete, well adapt to be added to a concrete mix as aggregate.

The organic part on the shells has been totally removed with a cleaning process.

Most important: Reduction of waste.

The results showed: the shells of the mussels allow to obtain conglomerates having a good workability; even if no test has been carried out, the shells appear to have a good tensile strength; the compressive strength is reduced as the percentage of mussels' shells increases; the bending tests showed a higher peak for specimens with a higher percentage of mussels' flakes and a certain ductility of the behavior soon after the failure is reached; reduction of waste an improvement of the sustainability of the concrete.



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ABSTRACT

In this work the performance of plain concrete added with mussel shells of *Mytilus galloprovincialis* has been studied. In the Mediterranean Basin, this variety is among the most common wild and farming mussels. The type of mussel shell used comes from Italian shellfish farming, which generates 100,000 tons per year of mussel shell waste. The mussel waste has been cleaned with bleach and using different abrasives, then boiled in water for 15 min and finally dried in order to ensure to eliminate all the organic parts. The natural gravel in the concrete mix has been replaced with different percentages of crushed shells. The results have been analyzed and discussed in order to evaluate the possibility to utilize this waste material for concretes improving the sustainability of the environment.

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1. Introduction

Aquaculture, or farming of fish, shellfish and aquatic plants, is one of the world's fastest growing food sectors. Unlike most other aquatic species, wild mussel production is much smaller than cultured. The shellfish farming has increased substantially going from nearly 1 million tons in 1950 to about 14.6 million tons in 2010, especially in the Mediterranean area representing about 60% of the total production. Asia appears the main producer with 80% of the total production, Europe has approximately 16%, followed by America (4.1%) and Africa (0.3%) [1]. Within Europe, where mussels have been cultivated for centuries, Spain (209,000 tons, 2011) remains the industry leader, followed by France (85,000 tons) and Italy (32,000 tons) [2] where shellfish is the most productive sector of Italian aquaculture [3,4]. The most important marine bivalve mollusks in worldwide aquaculture are in the family *Arcidae*, *Cardiidae*, *Littorinidae*, *Mytilidae, Ostreidae* and *Pectinidae*. In the Mediterranean Basin, *Mytilus galloprovincialis*, a species belonging to the *Mytilus edulis complex* (blue mussels) in the *Mytilidae* family, is among the most common wild and cultured mussels.

This animal grows up to 140 mm in length. The shape of the shell is triangular and elongates with rounded edges. The shell is smooth with a sculpturing of thin lines of concentric growth, but no radiating ribs. The shells of these species are purple, blue or sometimes of brown color, occasionally with radial strips. The mussel shell is made up of two hinged halves or "valves". The valves are joined on the outside by a ligament, and are closed, when necessary, by strong internal muscles (anterior and posterior adductor muscles). Valves carry out a variety of functions, including support for soft tissues, protection from predators, and protection against desiccation. The shell is about 33% of the entire weight of the mussel and consists of three layers.

The outer surface (*Periostracum*) is composed primarily of a protein called conchin which, as eroded, exposes the middle layer composed by colored prismatic chalky crystals of calcium carbonate. The inner layer, known as nacre, is an organic-inorganic composite material highly rich in chitin and aragonite (a form of calcium carbonate).

The shellfish farming generates 100,000 tons per year of mussel shell waste in Italy and over 1 million tons per year worldwide. This implies a significant environmental and health problem on the global waste. In fact, bivalve mollusks are generally recognized as a potential vehicle for many human diseases. The most common form is hepatitis A caused by hepatitis A virus (HAV). At global level, hepatitis infections are estimated to reach a few tens of millions [5]. So, the recycling of mussel waste over to reducing global waste can decrease the risks connected to circulation of some toxic bacteria in ecosystems [6].

Physical and chemical characterization and leaching tests performed according to UNE-EN 12457-4 [7] on non-crushed *M. galloprovincialis* mussels and crushed ones have recently established that the first could be classified directly as inert waste, while the second ones as non-hazardous waste for the greater amounts released of chloride and sulfate when the material is shattered to the size of gravel or sand [1]. Generally, the shellfish waste is suitable to be used as aggregates in concrete because the main component of the shells are calcium carbonate, approximately with a percentage of 95%. On the other hand, aggregates for concrete are generally mined or quarried from more than 9000 pits and quarries across the country with not always low costs [8]. The use of recycled aggregate is one way to potentially extend the life of natural resources by supplementing their supply, reduce the environmental impact of material extraction, as well as the impact of construction demolition in landfills [8,9]. New options in the recycled aggregate market are constantly introduced by industry. The most pronounced presence in the aggregate arena for amounts are the post-consumer glass, fiberglass pellets [10], plastics [11,12], even old tires [13]. In this scenery, the mussel shell waste represents a very interesting alternative to these aggregates. Waste can be added in the mix also in the shape of fibers too as proposed in [14–16]. Unlike the other recycled aggregates, documentation of oyster shells (family *Ostreidae*) as aggregate in concrete, also known as shellcrete, dates back several hundred years ago and crosses many countries [17]. It was realized in Spanish Texas and became very popular as building home material in the mid-1800s, then later as pavement (mid-1960s). In Florida, crushed oyster shells were used as a main ingredient in highway paving for many years until the mid-80s, when legislation called for its halt due to the detrimental nature of dredging [17]. In recent years, some studies have been developed using periwinkle shells (*Littorinidae*), but also cockle (*Cardiida*), scallop (*Pectinidae*) and mussel shells as natural course [1,18–23], fine aggregates [1,17,22,24–28] and sand [17,29]. All 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.

The cleaning of mussels is important for getting a commercial by-product with security guarantees. Few authors have used waste shells without any cleaning [18,21,23]. From the literature various cleaning treatments of mussel shells are proposed; some shells were cleaned with bleach, white vinegar solution, baking soda and using different abrasives [17], others were washed and air dried at room temperature [19]; recently they have been treated thermally at 105–300 °C for variable interval periods. The cleaning of the mussel waste with the removal of the organic matter is an important process for the properties of concretes incorporating crushed shells and it should be simple, low cost and secure. The present study evaluates the potential of the Mytilus galloprovincialis shells as a recycled aggregate, as well as it seeks to develop a ductile concrete mixture that is also a sustainable building material. Tests have been performed on specimens made with different mixes that include different percentages of crushed shells of mussels. The results have been discussed considering also as a final aim to create as little environmental impact as possible. The objective of this research is also to create an easy mix design, which may be of particular use to individuals and small-scale constructions.

2. Materials and mixes

The aggregates that can be used for concrete production in Europe need to fulfil strict limits in several physicochemical parameters in order to warrant the quality and ensure the durability of the produced concrete. Concerning this, the mussel shell was carefully characterized in a recent study. It was found that aggregate derivatives meet the Spanish and European normative criteria except for the contents of chloride, total sulphate and organic matter (visual) [1]. Chlorides could produce the rapid corrosion of the steel. Therefore, the use of shell aggregates in reinforced or prestressed concrete is prevented or severely limited. Sulphates in concrete must be <1% to prevent the expansive reaction in the hardened concrete. These effects are greater in sand fractions than in gravel fractions due to the high specific surface of sand particles. The organic matter causes an increase of the entrapped air of concrete, in the range from 3 to 9% in samples containing shattered shells. Consequently, the mechanical properties of this concrete are lower than the concrete made of natural aggregates, although they remain quite satisfactory and acceptable [1,23]. In addition, the incorporation of crushed shells causes an increase of the