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Physical and Morphological Properties of Snail (*Achatina Fulica*) Shells for Beneficiation into Biocomposite Materials

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Abstract
In this study, microhardness and flow strength (tensile) of a shell of an African Giant snail (*Achatina Fulica*) were studied as a function of indentation load. The influence of loading direction on the hardness of the nacreous and prismatic structure of the shell material was analyzed. The results revealed that microhardness measured on the shell was dependent on the load on the nacreous and prismatic structures. Indentation loading between 50 and 500 kN induced tensile strengths that ranged between 675–1050 and 390–810 MPa on the prismatic and nacreous layers, respectively. In addition, the morphology of the shell surface exhibited an interlocking structure with a large surface for binding to the organic matrix. The observed reinforcement of the shell explained the hardness property of the shell. The improved hardness of the shell implies that it can be beneficiated into filler that may be used to improve the mechanical properties of polymeric composite materials.

Keywords Snail shell · Microhardness · Tensile strength · Indentation loading · Microstructure

1 Introduction

Snail shells are a ubiquitous waste in the environment. Many of them are generated after the processing and consumption of snails, e.g., by snail merchants, food, and cosmetics industries [1]. Accumulation of waste shells in the environment constitutes a serious threat to human health and sometimes causes blockage of waterways [2, 3]. A study by Arias and Fernández [4] on shells, bone, and teeth classified them as ceramic biocomposites consisting of layered assemblies of microscopic amounts of macromolecules with well-ordered inorganic structures rich in calcium that provides a material with unique morphologies and properties. Microstructural features such as organized, layered organic/inorganic assemblies and the existence of spongy and fibrous elements in many biological components have become an inspiration for the development of biocomposite materials.

Furthermore, the existence of organic and inorganic structural networks at molecular and micro-levels often form synergistic effects that significantly improve the mechanical properties of advanced nano-laminates and other composite materials made from them [5, 6]. Several studies have demonstrated the addition of these biological materials, in micro-particle size form, to polymeric materials and this resulted in improved composite materials. Also, a combination of two or more of these naturally sourced materials has been developed to produce advance materials with desired properties [7–9]. However, there is a dearth of information on the fundamental properties of the materials that can be exploited for the manufacture of biocomposites. This may be due to the size of the biological materials—shells, in particular, do not have adequate size/space required to produce a standard specimen for measurement of mechanical properties.

Despite this, valuable information on mechanical responses of the shell, such as tensile, may be obtained by conducting nano and micro-indentation (Vickers hardness test) studies on shell samples. Material hardness may not always be a fundamental property of a material; however, mechanical properties such as yield strength, work hardening, and true tensile strength of a material may be

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determined through nano and micro-indentations on the material under loading conditions.

Furthermore, material hardness is directly linked to numerous properties including resistance to plastic deformation, resistance to scratch, indentation, deformation, friction, wear, and abrasion [10, 11]. Correlation connection between hardness and tensile strength usually depends on the microstructure of the material [12, 13], and resistance to deformation depends on its modulus of elasticity [14, 15]. Vickers hardness testing technique is widely used to determine the resistance to indentation of ceramic materials but has not been reported for biological or inorganic composites such as *Achatina Fulica* snail shells although nano-indentation of the shell structure on a micro-scale has been reported [16–18]. In this regard, this study provides information on microhardness, and its correlation to tensile strength, for *Achatina Fulica* snail shells. *Achatina Fulica* or African land snail is one of the largest species of snails in the world and can grow up to 20 cm. The snail is widely consumed in Africa; hence, the snail shells are widely available.

2 Experimental Details

2.1 Materials and Method

Shells of the *Achatina fulica* snail were collected from the University of KwaZulu-Natal, Westville campus soccer pitch. They were washed in a soap solution, rinsed with running tap water to remove dirt, and then dried under room conditions for 7 days before testing.

Procedures used in testing of ceramic materials were used to prepare cross-sections of shell samples for testing. This involved cold casting in resin at room temperature, polishing by using silicon carbide particles, and lubrication. Relatively flat shell specimens were cold cast under 29 KN force, baked for 12 min at 50 °C and then cooled for 3 min. Hardness indentations were performed on casted specimens particularly on the outer and the inner surfaces of the shell. Vickers hardness tests commonly used for determining microhardness of ceramics or single crystal materials were adopted for this study (ASTM A370). This hardness testing technique is typically a load-dependent procedure with a corresponding increase in applied load [19–21]. Microhardness values of the shell were determined as a function of the indentation load at the cross-sectional area of both the inner and outer layers of the shell. To ensure stable mounting, the shell samples were cut using a saw blade and shaped with a file to 25 mm by 10 mm dimensions.

Vickers hardness measurements were conducted using a Leco (model M-400-H) Vickers hardness tester. The hardness was measured at different indentation loads of 50 N, 100 N, 200 N, 300 N, and 500 N at 15 s loading durations. Ten indentations values were randomly taken for each load on all the specimens, and the mean values taken were reported. Microhardness values were converted to tensile strength using the ceramic hardness unit's commonly used conversion table (11).

Microstructural studies were conducted on a ZEISS EVO LS 15 scanning electron microscope (SEM) to examine the structural formation of the shell.

3 Results and Discussions

3.1 Morphological Structure of *Achatina Fulica* Shell

The microstructure of broken-off piece *Achatina Fulica* shell was examined using a scanning electron microscope at 99X magnifications to ascertain the route of its hardness property. A typical SEM image is shown in Fig. 1.

The examination indicated that the shell was composed of a unique structure, which may possibly be classified as crossed-lamellar, which served as inner reinforcement

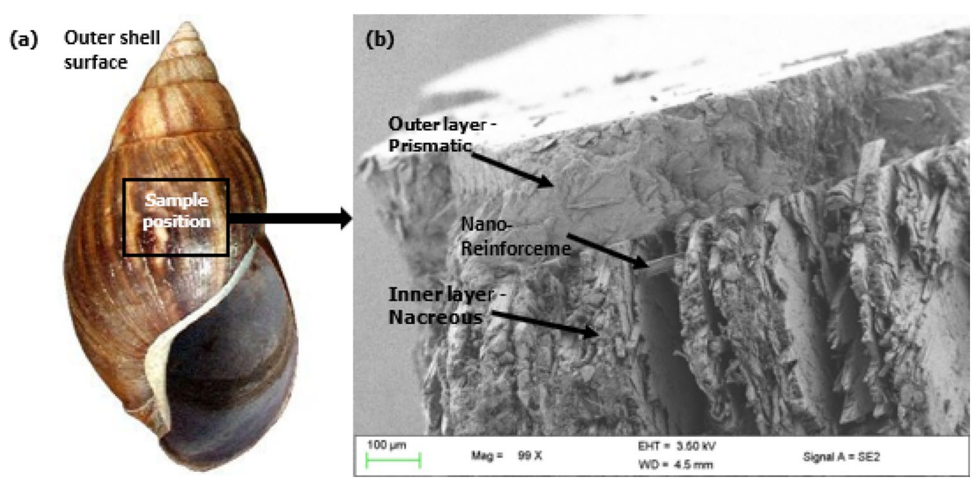

Fig. 1 Image **a** view of the outer section of the *Achatina Fulica* shell and the position where a sample was cut and **b** SEM image of the cross-section of the removed piece cross-sectional surface (99 magnification)

supporting the uppermost layer (prismatic layer), and homogenously foliated with the nacreous (inner layer) as shown in Fig. 1b. This confirmed that the snail shell had a distinctive structure comprised of biological tissue components with numerous linkages and distribution of soft and hard components. This is consistent with a study conducted by Tomislav et al. [21], who reported on the microstructure of mollusk seashell.

The Interlocking of the biological component with a relatively smooth surface was observed on the prismatic layer. The smooth surface could be a result of polishing done on the cut shell sample. A layer of aragonite platelet that could be referred to as reinforcement was also observed in the inner layer of the shell. This cross-sectional structure formation is advantageous for external force resistance. Figures 2 and 3 indicate that this structure is the main functional mechanism for high resistance to indentation, resulting in relatively high microhardness and tensile strength properties shown in the figures.

3.2 Hardness Property

The relationships between the microhardness of the outer and inner shell surfaces structure with different indentation loads are shown in Fig. 2.

As expected, the outer structure (prismatic layer) showed better resistance to indentation than the inner structure (nacreous layer) irrespective of the applied force. However,

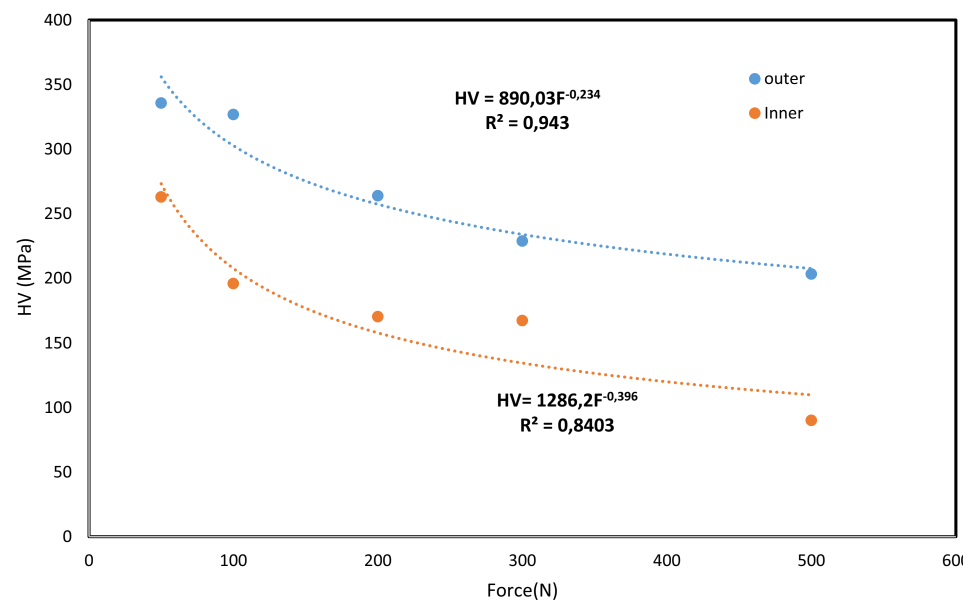

Fig. 2 Graph showing the relationship between microhardness and the applied load

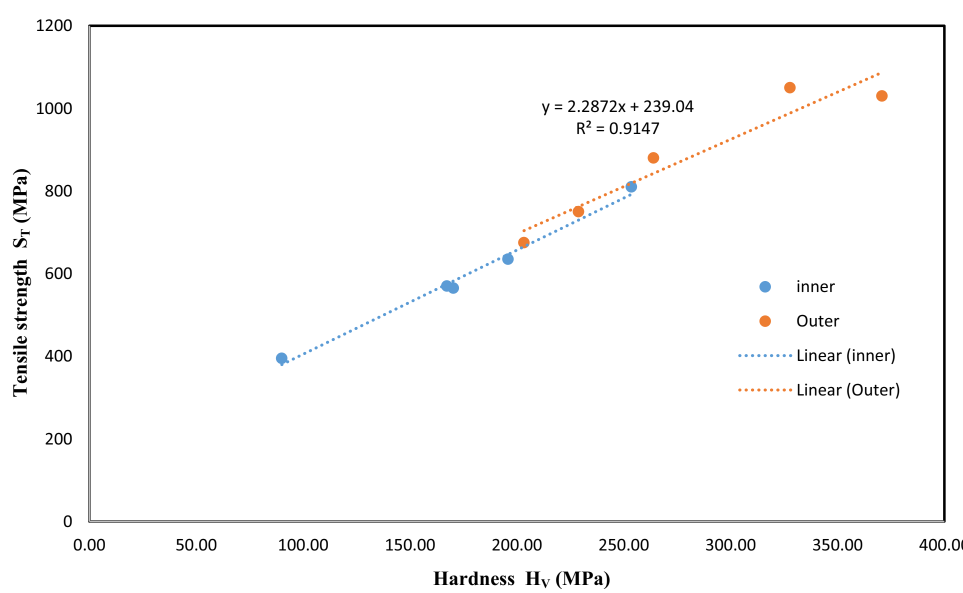

Fig. 3 Graph presenting the correlation of hardness and strength of *Achatina Fulica* shell

the coefficients of correlation for both the inner and outer structures were relatively high. The applied force had a significant effect on shell microhardness; the microhardness increased with a corresponding increase in indentation test load for both inner and outer structures, which is in accordance with the power law.

The shell is an outer skeleton or exoskeleton, which is crucial for protection against the elements and provides protection for snails [2, 22]. The microhardness values are evidence of high hardness property, which enables resistance to the aforementioned external forces. The lower hardness properties of the inner structure (nacreous) provide better comfort for the flesh of the animal. The hardness property of the shell makes it a suitable material that may be used as a nano-filler to reinforce polymer materials for the development of composites or biocomposites.

3.3 Correlation Between Hardness and Strength

Figure 3 presents the hardness and strength correlation of the outer and inner structure of the shell. A significant linear correlation coefficient was observed and the prismatic layer exhibited higher strength than the nacreous layer.

This trend corresponding to the hardness regression is illustrated in Fig. 2. Furthermore, this suggested that the prismatic layer had better resistance to plastic deformation than the nacreous layer. A noteworthy increase in strength with a corresponding increase in hardness values was observed. This is evidence that the hardness properties of both layers correlated well with tensile strength. Hardness has been directly linked to numerous properties which include resistance to plastic deformation, resistance to scratch, indentation, and abrasion [10]. The resistance to indentation and plastic deformation confirmed the link between hardness and tensile strength. Furthermore, the better quality of mechanical properties identified in this shell makes it suitable for use as micro- or nano-filler reinforcement for polymer composites. The dispersion of the shell particles in a matrix may lead to the production of composite materials with excellent mechanical properties.

4 Conclusions

This study was an evaluation of the potential for beneficiation of waste *Achantina Fulica* snail shells to reduce the accumulation of waste shells in the environment after consumption of the snails. The properties and characteristics of that were studied included the following:

- Indentation
- Microhardness
- Morphological characteristics, and
- Tensile strength.

The results showed that:

- Satisfactory hardness values with high correlation coefficients were ascertained.
- The outer prismatic layer of the shell exhibited higher resistance to indentations loading than the inner layer.
- Resistance to indentation decreased with a corresponding increase in loading.
- A linear correlation of hardness and tensile strength was observed
- The prismatic layer exhibited higher strength compared to the nacreous layer of the shell.
- SEM images of the nacreous layer exhibited an aragonite platelet layer structure that presumably serves as reinforcement that supports the prismatic layer, which reduced plastic deformation of the shell resulting in relatively high resistance to indentation and plastic deformation.

These results suggest that the snail shells could be used as a filler material (micro- or nano-size) for reinforcement of polymer materials in the development of composites or biocomposites. The structural formation of *Achatina Fulica* shell could be a mimic for design synthetic processes to fabricate new bioinspired composites or nanocomposites with enhanced properties.

5 Future Research

The completion of this research brought forth certain boundaries and consequently provides opportunities for more research work. The size of the *Achatina Fulica* shell is the main drawback. Therefore, the optimization of processes for synthesizing micro- or nanoparticle from *Achatina Fulica* shell is a potential area to be explored. The imitating of *Achatina Fulica* shell morphology for design synthetic processes to fabricate new bioinspired composites or nanocomposite with required properties may also be another area for future research.

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