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A new composite designed to resist wear

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ABSTRACT

Nacre is known for its superior mechanical properties due to its uniquely interlocked-layered structures. In this study, a new composite containing nacre in an Al matrix was fabricated. The composite was produced using powder metallurgy method followed by a heat treatment. Mechanical properties were tested using SEM, micro hardness tester and profilometer. Results showed that the hardness of the composites increased as the concentration of nacre increased in the composite. The hardness of a composite containing 20 wt% of nacre increased by 40% compared to pure Al. Tribological evaluation indicates that samples with 1 wt% and 5 wt% of nacre exhibited the best wear resistance. The wear mechanism changed from adhesive to abrasive wear with varying concentration of nacre. This research demonstrates that the design of mechanical properties and the control of wear mechanisms is possible through the optimization of hybrid configuration. This approach can be adapted to most conventional materials.

1. Introduction

Biological organisms developed unique structures through millions of years of evolution. Hard shells from biomineralization are the choice of many vulnerable creatures with soft and weak body. Nacre, or mother-of-pearl, is a material widely found in the shells of mollusks-like oysters and abalones. Nacre is composed of 95% of aragonite, a mineral formed from calcium carbonate ($CaCO_3$), and 5% of organics, protein like chitin. Compared to pure aragonite, nacre is one fold higher in tensile strength and 1000-fold tougher in fracture toughness [1,2]. The supreme mechanical properties of nacre are attributed to the particular arrangement of this organic–inorganic composite [3–5]. The platelet-shaped aragonite forms a layered structure and the protein between these inorganic layers serves as an organic adhesive [6,7]. This ordered "bricks-and-mortar" arrangement optimizes the strength of the aragonite platelet and the viscoelasticity of the protein [8]. This type of structure generates a zigzag path making it harder for a crack to grow [9,10]. As a matter of fact a single aragonite plate has been proven to be resistant to crack propagation [11]. The stretching of the protein molecules under tension greatly increases the tensile strength of nacre [12]. Various toughening mechanisms, including interlocking [13], mineral bridging [14] and deformation twinning [15], have been reported to contribute to the increased fracture toughness.

Biomimetics is a branch of science aiming at understanding the mechanism of superior properties of biological materials and developing new materials by mimicking nature. Inspired by the unique structure of nacre, various composites with improved mechanical properties have been developed. Cheng et al. [16] developed an artificial nacre by grafting 10,12-pentacosadiyn-1-ol (PCDO) on graphite oxide surface. The toughness and tensile strength of the man-made composite are increased to 1.49 MJ m^{-3} and 111.2 MPa as compared to 0.37 MJ m^{-3} and 95.4 MPa for pure graphite oxide. A layer nanocomposite of polymer/montmorillonite was produced by means of electrophoretic deposition by Long et al. [17]. Hardness and Young's modulus of the composite are 0.95 GPa and 16.92 GPa, which are 4-fold higher than those of the main constituent. A poly(vinyl alcohol)/graphene oxide composite was developed by Li et al. [18]. This nacre composite showed excellent biocompatible properties besides the improved tensile strength and Young's modulus.

Despite the efforts in making nacre-contained materials, the report on using the same to enhance structural materials has not been reported. This research aims to develop new composites using nacre to enhance aluminum alloys by means of particle-reinforcement [19–23]. For the first time, we explore to develop new nacre reinforced aluminum composites. Nacre from eastern oyster was mixed with pure aluminum powder followed by sintering. The mechanical properties of samples were tested.

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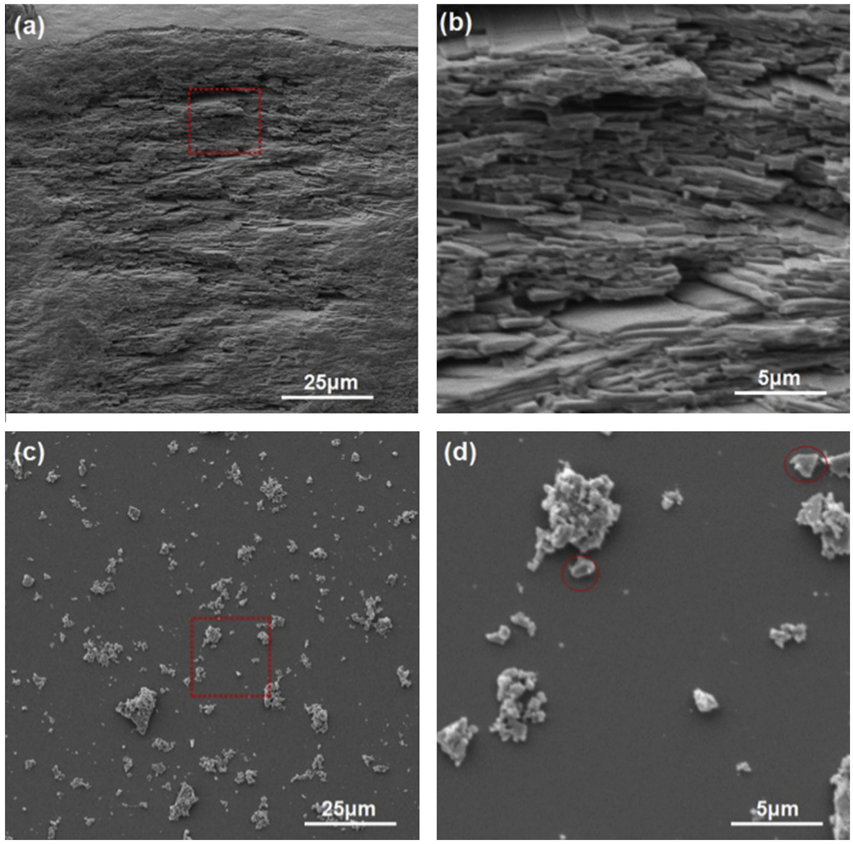

Fig. 1. SEM images of layered structure of nacre (a and b) and crashed nacre powder (c and d).

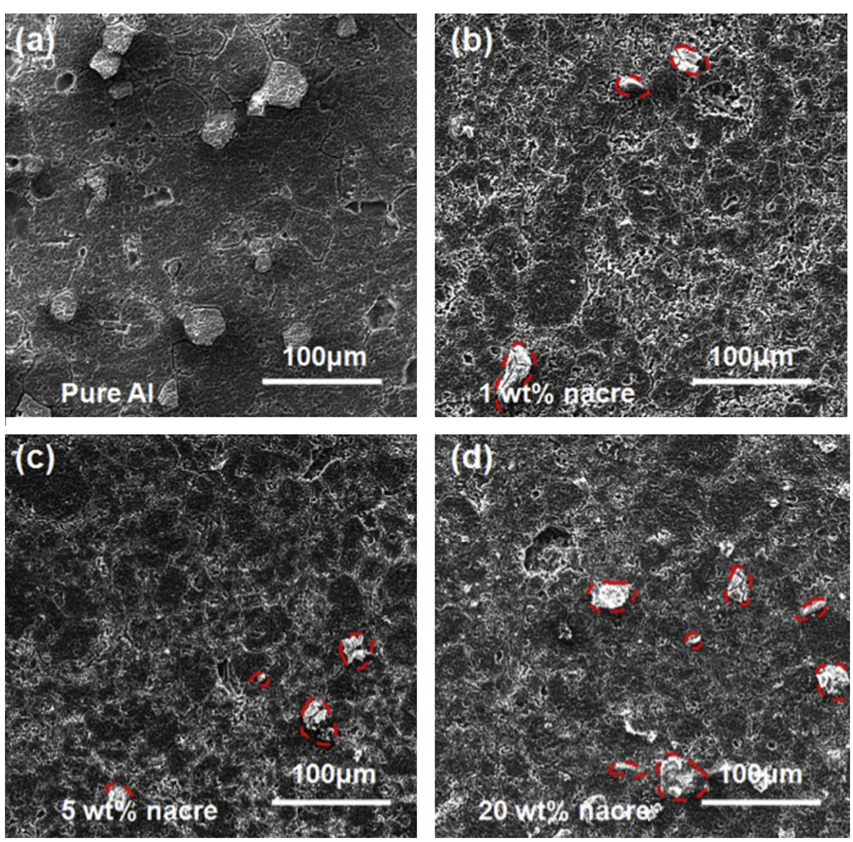

Fig. 2. SEM images of sample surfaces (a, pure Al, b, 1 wt% nacre in Al matrix, c, 5 wt% nacre in Al matrix and d, 20 wt% nacre in Al matrix. The nacre aggregates are labeled with dashed lines.).