Microstructure and mechanical properties of the enameloid of pacu and piranha fishes: The role of different diets

Auteur : Müller, Laura
Promoteur(s) : Ruffoni, Davide
Faculté : Faculté des Sciences appliquées
Diplôme : Master en ingénieur civil biomédical, à finalité spécialisée
Année académique : 2020-2021
URI/URL : http://hdl.handle.net/2268.2/11649

Biomedical Engineering
Academic year 2020-2021

Microstructure and mechanical properties of the enameloid of pacu and piranha fishes: The role of different diets

Author: Laura MÜLLER

Supervisors: Davide RUFFONI, Philippe COMPÈRE and Yann DELAUNOIS

An understanding of the relationship between the structure, mechanical properties and functions of teeth is required regarding the development of effective and durable bio-inspired synthetic dental materials. Many studies have investigated this relationship in many species. However, few studies have been conducted on the teeth of Serrasalmidae fishes. The family of Serrasalmidae, though, offers an excellent opportunity to study this relationship because of the diversity of their diet.

The tooth consists of three distinct layers which are called (going from the center of the tooth to the outside): the pulp, the dentin and the enamel/enameloid. In some fishes, including those of the family Serrasalmidae, an additional superficial layer called the cuticle is also present.

The topic of the present thesis is to investigate structural and mechanical adaptation of the enameloid in two Serrasalmidae fishes having different diets: the carnivorous *Pygocentrus nattereri*, preferentially feeding on soft prey, and the herbivorous pacu *Piaractus brachypomus*, preferentially eating hard shells.

Enameloid microstructure is first characterized. Microscopic analysis of fractured teeth as well as surface etching performed on teeth sections allow identifying precisely the structure of the enameloid in the two species. Comparison between the structures found in the two species highlights that despite their different diets, no structural differences are observed between species with different feeding strategies (slicing vs. crushing). The enameloid of both fishes possesses a two-part organization. The inner enameloid is characterized by hydroxyapatite fiber bundles oriented and curved in a random manner forming a very sophisticated interlocking structure. The outer enameloid is organized with hydroxyapatite bundles aligned with each outer and oriented either parallel or perpendicular to the tooth surface, depending on the region analyzed.

Second, the potential correlation between microstructure and mechanical properties is investigated through the assessment of local fracture behavior. Indeed, fracture resistance is an essential feature allowing the enameloid and, in general, the tooth to avoid catastrophic failure when cracks nucleate on the other surface due to repeated cycles of chewing. High load indentation tests in combination with scanning microscopy are used to explore fracture properties of the different teeth. Although the difference is not significant, a quantitative evaluation of the fracture toughness as well as a qualitative observation of the cracks morphology demonstrates that inner enameloid possesses a higher resistance to crack initiation and propagation than the outer enameloid. Furthermore, indentation-based cracks invariably propagate along the internal interfaces, especially at the interface between the hydroxyapatite bundles, and that several extrinsic toughening mechanisms, such as crack deflection/curvature and un-cracked hydroxyapatite bundles are used by the enameloid to increase fracture resistance.

Novel addictive manufacturing routes such as freeze casting or magnetically assisted manufacturing may allow the fabrication of ceramic scaffolds replicating the structure seeing in the enameloid to improve fracture resistance of synthetic teeth.

Keywords: Enameloid, Serrasalmidae, Structure, Scanning microscopy, Indentation, Fracture toughness, Toughening mechanisms.

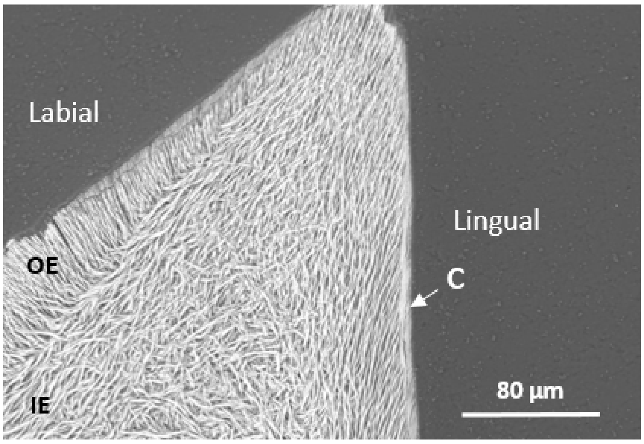

Figure 1: SEM−BSE images of the frontal section of an oral tooth of the carnivorous *P. nattereri* after HCl etching. *Abbreviations: OE, outer enameloid; IE, inner enameloid; c, cuticle.*

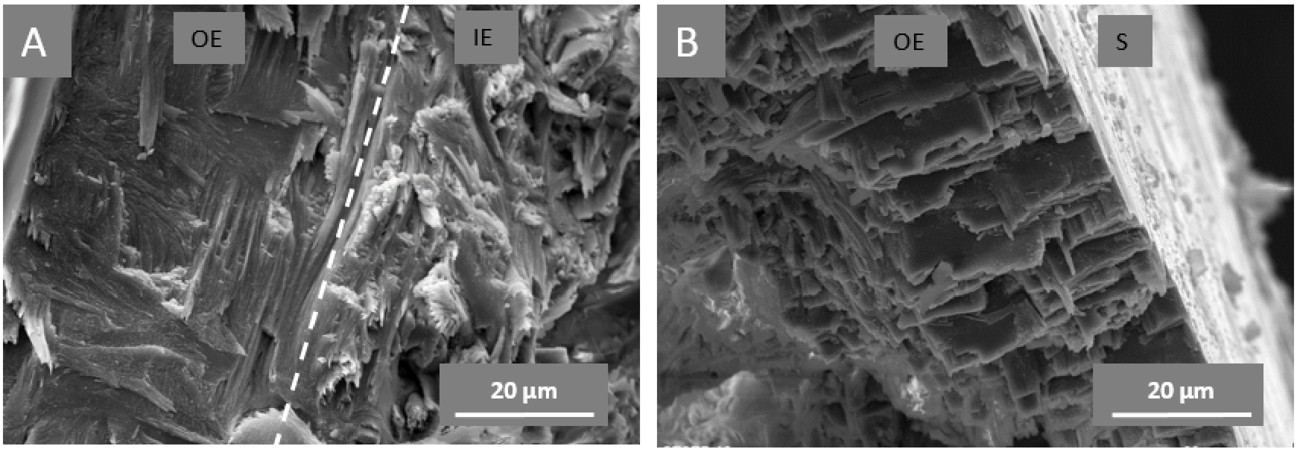

Figure 2: SEM−SE images of frontal section fractures of an oral tooth of the carnivorous *P. nattereri*. (A) shows the inner and the outer enameloid; (B) shows the outer enameloid. *Abbreviations: S, surface; OE, outer enameloid; IE, inner enameloid.*

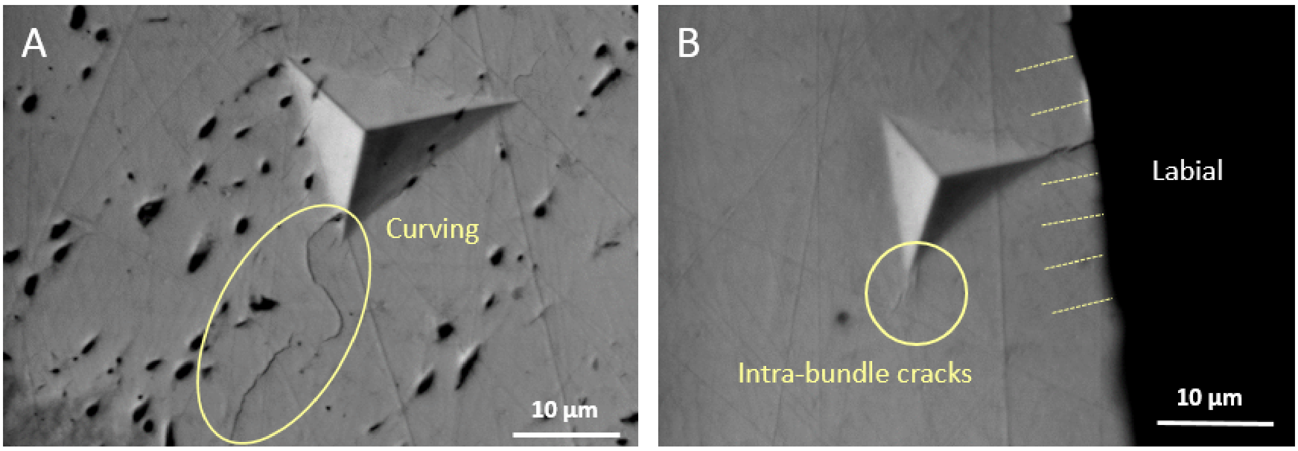

Figure 3: SEM−BSE images of the polished frontal section of (A) the inner enameloid and (B) the outer enameloid in the herbivorous *P. brachypomus* after indentation under (A) 1000 mN and (B) 400 mN load. The circled area in (A) shows crack curving. The circled region in (B) show intra-bundle cracks. The orientation of the bundles close to the indentation is denoted with yellow dotted lines in (B).