The Amazing Strength and Structure of Woodpecker's Tongue

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Introduction

Nature evolution after millions of years has produced listless of biomaterials that exhibit unusual mechanical properties. Bone, teeth and nacre are nanocomposites of protein and mineral, but give a significantly higher strength than either the protein or the mineral [1]. Nephila spider dragline silk gives a surprising strength as high as 1.3GPa, a breaking elongation of 40%, and a toughness of 160kJ/kg [2]. For an artificial composite material, the interface connection strength is always the issue that we met now. However, for the interfaces of biomaterial material connections, such as the connections between the teeth roots and tissue and those between the bone and tendon, the interfacial strength is even stronger than the biomaterials to be connected. In fact, what has been found is only a small corner in the nature. Here we report that the tongue of a woodpecker exhibits an amazing strength and flexibility due to its special composite micro/nanostructure. The tongue consists of a flexible cartilage-and-bone skeleton covered with a thin layer tissue of high strength and elasticity. At the interface of the cartilage-and-bone skeleton and the tissue layer, there is a nano-hierarchical fiber-typed structure connection. It is this special design of the tongue with its amazing tensile length that makes the woodpeckers efficient in catching the insects inside trees. The special micro/nanostructures of the woodpecker's tongue shows us a very good idea how to enhance the interface connection strength between the fibers and the matrix material for an artificial composite material.

In the nature, different kinds of animals have their own special skills to escape from predators or to search for food. Woodpeckers have certain unique and interesting features adapted to drilling holes in trees to search for insects and other prey [3-6]. One of the most fascinating adaptations is the tongue of woodpeckers.

Experimental

The woodpecker investigated here is a female gray-faced one living in the Northern China. The length of the woodpecker's tongue is 171mm, which is about 2.8 times the length of its mouth (~60mm), and is even longer than its body length (~165mm, measured from the mouth tip to the buttock). The cartilage-and-bone skeleton supporting the woodpecker's tongue is called the hyoid apparatus, a Y-shaped structure as shown in the inset of Fig.1a. The fork in the "Y" shape sits in the front of the throat, and goes below the base of the jaw. It is amazing that the fork wraps round the skull and extends into the right nostril of the woodpecker. A typical stress-strain curve is demonstrated in Fig.1a at the marked position 2 of the inset. The tongue has a tensile strength of about 92±5MPa with an initial elastic modulus of 3.72GPa at this position. This high strength is comparable with that of aluminum. The thin tissue layer covering the cartilage-and-bone skeleton of the tongue has a thickness of about 15μm and an amazing strength of about 300MPa, while the covered skeleton at the corresponding position gives the strength of about 55MPa. We found that the tensile strength of the tongue is stronger at the rear part than that at the top part (tongue tip). The tensile strength at position 3 is 131±5MPa, while the tensile strength at position 1 is 76±8MPa.

The microstructure of the cartilage-and-bone skeleton is shown in Fig.1b. In the center, there is a microhole with the diameter of about 11 mm. The skeleton exhibits a grain-like microstructure around the hole, but a fiber-like microstructure with the increase of the radius. The fine fiber diameter is in the order of nanometer scale. The interface between the skeleton and thin tissue layer is shown in Fig.1c, exhibiting a fiber-like hierarchically structural connection. The thin tissue layer gives a fiber structure oriented mainly in the axial direction. Certainly, this interesting interface plays a key role in determining the mechanical response of the

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composite structure consisting of a flexible cartilage-and-bone skeleton covered with a thin tissue layer. The tissue layer shows a typically hierarchical fiber structure (see Fig.1d) producing a high strength and elasticity.

Conclusions

Here we report that the woodpecker's tongue exhibits an amazingly high strength and flexibility due to its special composite micro/nanostructure. The tongue consists of a flexible cartilage-and-bone skeleton covered with a thin layer tissue of high strength and elasticity. At the interface between the cartilage-and-bone skeleton and tissue layer, there is a hierarchical fiber-typed connection. It is the special design of the tongue that makes the woodpeckers efficient in catching the insects inside trees. The special micro/nanostructures of the woodpecker's tongue show us a potential way how to enhance the interfacial connection between soft and hard material layers for bio-inspired composite system designs.

References

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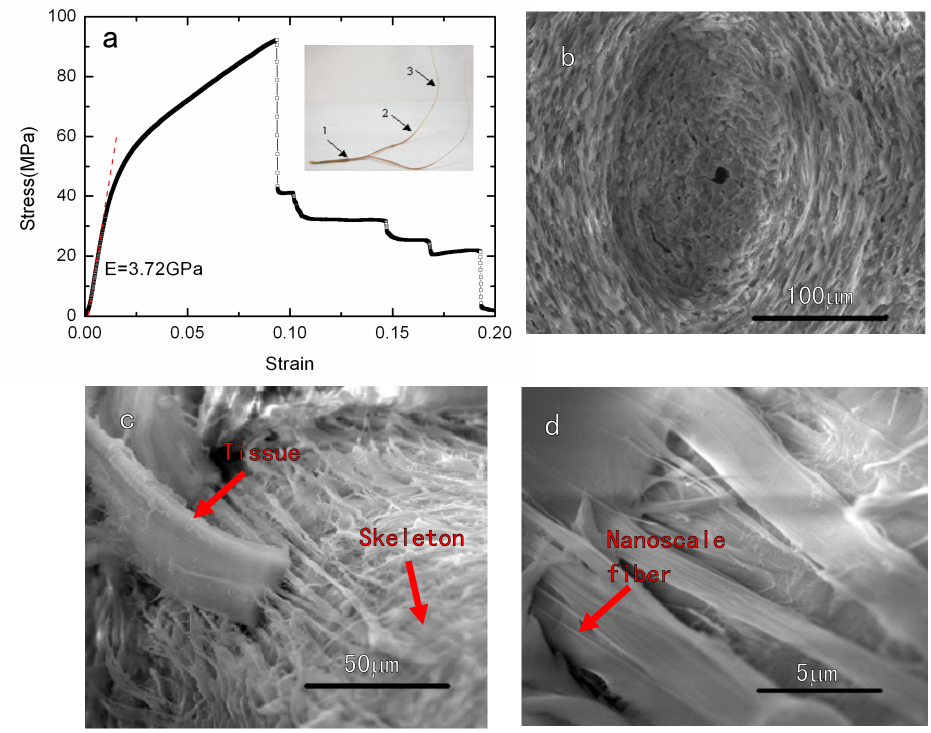

Figure 1. Mechanical property of the woodpecker's tongue: (a) a typical stress-strain curve of the tongue; (b) the microstructure of the cartilage-and-bone skeleton; (c) the interface between the skeleton and thin tissue layer, exhibiting a fiber-typed hierarchical structure; (d) the fiber-typed hierarchical structure of the tissue layer.

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