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Bending Speed Dependence Properties of Stiffness of Anisotropic Viscoelastic Fin Containing Fiber Composite Dilatant Fluid

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Abstract

The stiffness of the elastic fin for underwater propulsion may need to change concerning its bending speed. In order to realize the bending speed dependence of stiffness in relation to the structure, we have developed an anisotropic viscoelastic fin containing fiber composite dilatant fluid. For the bending test of the fin to examine its stiffness, the top of the fin is fixed, while the base of the fin is rotated. The bending resistance force, as the apparent stiffness of the fin, was measured by the load cell connected to the top of the fin. Bending resistance of the fin containing dilatant fluid increased as the average angular velocity of bending increased. Furthermore, bending resistance of the fin increased according to the existence of fiber, especially the fin along the longitudinal direction of the fiber. This developed fin is a highly functional structure, which can adapt to the demands of changing optimum stiffness with regard to different directions of deformation speed.

Keywords: Bio-inspired Mechanism; Stiffness; Viscoelastic Fin; Dilatant Fluid; Fiber Composite Material

1 Introduction

Nowadays, the conventional screw propeller is widely used to propel boats and underwater vehicles. An aquatic propulsion mechanism using a bio-inspired oscillating elastic fin has advantages in resolving problems associated with the screw propeller, the entanglement of fishing nets or algae, the disturbance of mud that pollutes water, and the danger to aquatic animals from the high-speed rotation and intense churning of the propeller [1]. However, the optimum elasticity of the fin is not constant and changes based on oscillating speed. It is highly challenging to exchange fins of different stiffness while moving. To address this problem, we developed a variable stiffness fin with a variable effective length spring or torsional elastic rectangular plates for the propulsion

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of aquatic vehicles [2, 3]. From the results of the experiments, we found a tendency of better stiffness for the propulsion in water: higher stiffness for high-speed oscillation and lower stiffness for low-speed oscillation. To maintain the optimum rigidity concerning its changing oscillation speed without using variable stiffness mechanism, we also developed a viscoelastic fin containing fiber composite dilatant fluid [4]. We succeed to keep higher thrust force in water by changing the moving speed of the fin. This fin was focused on the development of the aquatic propulsion mechanism, but this also has a possibility as a novel smart structure, which adapts its better stiffness while changing the bending speed condition. Since this fin consists of dilatant fluid and fibers, it also has the feature of anisotropic bending speed dependence of stiffness. In this paper, we have made the anisotropic viscoelastic fin containing fiber composite dilatant fluid and examined the bending speed dependence of the fin's stiffness in the case of the changing orientation of fiber.

2 Viscoelastic Fin Containing Fiber Composite Dilatant Fluid

2.1 Concept of Bending Speed Dependence of the Fin's Stiffness

Dilatant fluid is one of the non-Newtonian fluids, whose viscosity increases as the shear rate is increased; it is also known as shear thickening fluid [5]. Fig. 1 presents the concept of a viscoelastic fin containing dilatant fluid. When the bending is applied to the fin, dilatant fluid flows inside the elastic bag and the shear rate of fluid also increases. As the bending applied to the fin becomes faster, the shear rate and viscosity of the dilatant fluid becomes greater, as does the resistance to the bending of the fin. This means that the apparent bending stiffness of the fin is increased. If the fibers are added to the dilatant and bending is applied to the fin (Fig. 2), fibers slide against each other and the increase of the shear rate and viscosity of the dilatant fluid is promoted by the increase in the shear gradient, which narrows the distance between each fiber. Generally, dilatant fluid is the suspension, while fibers act to maintain fluid and avoid the precipitation of particles in suspension. Fig. 3 presents the concept of two directions of the bending applied to the fin. When the bending is applied in the direction of fiber orientation (Bending A), the increase in stiffness is greater than that when the bending is applied perpendicular to the fiber orientation (Bending B). These characteristics will indicate the anisotropic bending speed dependence of stiffness. Furthermore, the bending speed dependence of stiffness can be controlled not only by the properties of dilatant fluid, but also the density of fiber. Some applications use non-Newtonian fluids for mechanical parts, but an external source of energy is required for the control [6]. Therefore, this fin is a novel smart structure, which does not need an outer energy to control stiffness.

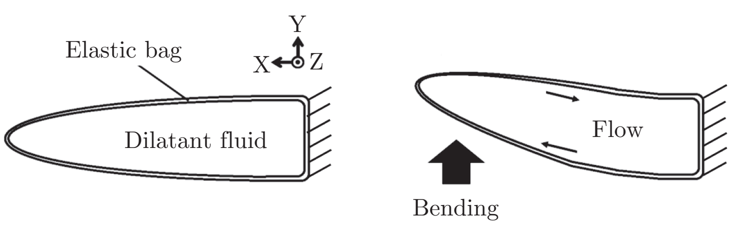

Fig. 1: Concept of a viscoelastic fin containing dilatant fluid