Research of release characteristics of ship attached fouling

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Abstract. Marine fouling increases navigation resistance and restricts the performance of hulls. Based on the fluid-structure coupling theory, the release characteristics of fouling barnacles attached to the silicone coating were studied by a numerical analysis method according to the antifouling performance parameters, such as coating thickness and elastic modulus. The simulation results show that the influence of coating thickness and elastic modulus on barnacle release is far less than that of composite variable \((E/T)^{0.5}\). For the hull coating with a small \((E/T)^{0.5}\) value, the barnacle more easily peels off under small external forces. This provides a reference for the selection of silicone antifouling coatings for ships.

1. Introduction

The ship will be attached with a large amount of marine fouling with a long time in the marine environment. Marine fouling seriously affects the normal operation of ship equipment, increases the surface roughness and friction of the ship, damages the surface protective coating of the ship, and speeds up the corrosion of the ship. The Marine fouling also increases the navigation resistance, slows down the navigation speed, weakens the flexibility of the ship, causes unnecessary fuel consumption, and shortens the life of the ship[1]. Barnacles are hermaphrodites with hard calcareous shell plates, strong adaptability, fast growth speed, wide distribution, which are extremely difficult to remove[2]. Chung[3] established different fouling adhesion models, experimentally studied the relationship between the elastic modulus, thickness and fouling release of organic silicone coatings, and analysed its mechanism. Kim et al.[4] studied the release mechanism of false barnacles and living barnacles and their relationship with coating thickness, elastic modulus and shear rate.

Based on the fluid-structure coupling theory, a numerical simulation method is used to analyse the mechanical shear characteristics of barnacles attached to a non-toxic silicone antifouling coating on a ship surface. The variation trend of the shear stress of barnacles under the influence of coating thickness, elastic modulus and speed is studied. The release characteristics of fouling are analysed, which provides a reference for decontamination, drag reduction and energy consumption reduction, and the selection of ship surface coating.

2. Barnacle attachment model

Barnacles' attachment is the larval nauplius in the planktonic life stage, which continuously secretes glue from temporary adhesion to permanent adhesion and develops into adults[5].


Considering the realisation of simulation of the release of shear stress by the size of the barnacle organism, and combining with the literature\textsuperscript{[6]}, a single adult barnacle attached to the ship's surface was selected as the research object to establish the barnacle attachment model, as shown in Figure 1. The upper ellipse model (set as area A) is used to simulate barnacle adults with the long axis and the short axis of 5 mm and 4 mm respectively. The position below the ellipse (set as area B) is used to simulate barnacle glue secreted by barnacles, which can be crosslinked and polymerised underwater. It is represented in the form of a liquid bridge with a transverse dimension of 3.4 mm and a vertical dimension of 1.8 mm. The position of middle sheet (set as zone C) is used to simulate the coating thickness of the non-toxic organic silicones, which is set to 300 μm, 400 μm, 500 μm, 600 μm and 700 μm respectively. Figure 1 shows the thickness of 300 μm. The zone of D represents the underwater ship attached by the barnacle, and the geometric size of which is 20 mm x 20 mm x 3 mm.

3. Adhesion mechanics analysis of barnacle

The barnacle attachment model is set a certain speed (1 m/s), and the fluid calculation domain is constructed based on the barnacle attachment model. The flow field model is shown in Figure 2. The use of user-defined material property of area A is set according to reference\textsuperscript{[6]}. The material of area B is selected from the material database Viscoelastic material model. The elastic modulus of area C is set as 0.2 MPa, 0.4 MPa, 0.8 MPa, 1 MPa, 1.3 MPa. The material of area D is structural steel. The main material parameters of areas A, B, C and D are shown in Table 1.

The barnacle attachment model was meshed with the Structured grid and unstructured grid, as shown in Figure 3. The model was Fully constrained through Inertia Relief. During the static analysis of the ship body by Inertia Release operation, a virtual support should be set in the ship structure, that is, a constraint of 6 degrees of freedom imposed on a node of the ship structure to achieve the equilibrium state.

| Table 1. Main material parameters in regions A, B, C and D |
|----------------------------------|
| A   | B           | C           | D           |
| density/(kg/m\textsuperscript{3}) | 5000    | 1190    | 1070    | 7850    |
| elasticity modulus/MPa           | 100     | 3       | 0.2-1.3 | 200     |
| Poisson's ratio                   | 0.3     | 0.1     | 0.3     | 0.33    |

Figure 1. Attachment model of barnacles

Figure 2. Marine environment of the hull attached to a barnacle

Figure 3. Meshing figure of the hull surface
4. Release characteristic analysis

4.1. Relationship between shear stress, deformation, coating thickness, and elastic modulus

Figure 4 shows the curve of shear stress and deformation of barnacle fouling on the surface of the ship with the change of coating thickness $T$ and elastic modulus $E$ under the action of ocean water with the speed of 1 m/s. Figure 5 and Figure 6 show the shear deformation diagram of the barnacle when the elastic modulus is 0.2 MPa and 5 MPa respectively under the condition of the same external force (1 m/s) and the same thickness of the coating ($T=300$ μm).

(a) Relationship between coating thickness, elastic modulus and shear stress.
(b) Relationship between coating thickness, elastic modulus and deformation.

It can be seen from Figure 4 that when the ship is sailing at a certain speed, for the non-toxic organic silicone with the same elastic modulus, the barnacle fouling on the ship with a thicker coating is subject to greater shear stress, greater deformation, and it is easier to be released. For coating of the same thickness, the barnacle contamination attached to the hull coated with less elastic modulus coating is subjected to greater shear stress, greater deformation, and easier release.

It can be seen from Figure 5 and Figure 6 that the change of external force is more obvious for the coating with smaller elastic modulus when subjected to the same external force, and the adhesion release behaviour of barnacle contamination is more inclined to the peeling failure mode. In contrast, for the coating with a large elastic modulus, it has a strong resistance to the external force and is not easy to deform, so the release of barnacle fouling can only depend on the shear action of water.
4.2. Relationship between shear stress, deformation and $(E/T)^{0.5}$ at the same speed

The relationship between $(E/T)^{0.5}$, shear stress and deformation is studied with the data of $T$ (300 $\mu$m ~ 700 $\mu$m) and $E$ (0.2 MPa ~ 1.3 MPa) obtained, as shown in Figure 7. With the same external force, the shear stress caused by barnacle fouling on the surface of the ship body coated with a non-toxic silicone coating with a smaller value of $(E/T)^{0.5}$ is bigger and easier to release. Because the antifouling coating with low surface energy makes it difficult for marine organisms to adhere and grow, even if they adhere to the coating film's surface, they are washed down by the seawater flow due to the weak adhesion between the fouling organisms and the coating film.

![Figure 7. Relationship between shear stress, deformation and $(E/T)^{0.5}$](image)

(a) The relation between shear stress and $(E/T)^{0.5}$  (b) The relation between deformation and $(E/T)^{0.5}$

4.3. Relationship between shear stress, deformation, and $(E/T)^{0.5}$ at different speeds

Figure 8 shows the relationship of shear stress, deformation, and $(E/T)^{0.5}$ at different speeds. The conclusion in Figure 7 is still valid for different speeds, and the relationship between shear stress, deformation and $(E/T)^{0.5}$ becomes more evident with speed increasing. The influence of the change of the $(E/T)^{0.5}$ value of the coating on the shear stress and deformation of barnacle fouling resistance to external forces increases with the increase of ship speed.

![Figure 8. Relationship between speed, $(E/T)^{0.5}$, shear stress, and deformation](image)

(a) Relationship between speed, $(E/T)^{0.5}$, and shear stress  (b) Relationship between speed, $(E/T)^{0.5}$, and deformation

The $(E/T)^{0.5}$ value of the coating has a greater influence on the barnacle fouling release behaviour at high speed than at low speed. Therefore, the relationship between the elastic modulus $E$ and the thickness $T$ of the coating $(E/T)^{0.5}$ should be given more attention for high-speed ships.
5. Conclusions
(1) The coating thickness and elastic modulus have specific effects on the release of barnacles, but the effect of a single variable is less significant than that of the composite variable of elastic modulus and coating thickness \((E/T)^{0.5}\).

(2) For the coating with a small value of \((E/T)^{0.5}\), due to the weak adhesion between the fouling and the coating, marine fouling can be released under a small external force, and the higher the speed is, the faster release.

(3) At the same speed and the same coating thickness, the release behaviour of barnacles tends to peel off at a low elastic modulus and depends on the shear mode at a high elastic modulus.

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