AFI-2019
November 6-8, 2019, Sendai, Miyagi, Japan

CRF-J2

Multiphase Flow and Interfacial Transport Phenomena at Phase and Material Boundaries

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ABSTRACT

Interfacial and boundary phenomena, such as boundary layer flow, interfacial electrokinetic one, mass transport and adsorption, are analyzed to clarify their multiscale mechanisms. Some important applications where boundary and interface are essential factors are studied here, which include drag reduction by laminarized wing, electricity generation from flowing water and graphene interface, and characterization of phase transition at hydrogen-metal material interfaces.

1. Introduction

Boundaries between different materials or phases are of critical importance for fluid science and technology. Various interfacial and boundary phenomena arising from heterogeneous structures, such as boundary layer flow, interfacial electrokinetic one, mass transport and adsorption, are analyzed in this study and their multiscale mechanisms are clarified. Some important applications are studied here, which include aircraft drag reduction by laminarized wing, electricity generation from flowing water and graphene interface, and characterization of phase transition at hydrogen-metal material interfaces which are related to low drag airplane, energy harvesting, and hydrogen energy equipment, respectively.

2. Aircraft drag reduction by laminarized wing

The ultimate optimum design of any aerospace vehicle will be finally achieved by reducing the viscous drag on the surface. About half of the total drag of the aircraft in flight is due to the viscous drag of the air. If the laminar state is maintained around an aircraft wing to reduce the viscous drag, we can expect the significant energy saving effect. Recent improvements in computer aided engineering, and, the practical surface processing techniques have increased the feasibility of drag reduction by such a modern laminarized wing. That is drawing more attention from the aircraft industry and airlines around the world. As a joint project of Tohoku University, JAXA, and Mitsubishi Heavy Industries, we are researching to find a way to delay transition by using a supercomputer.

As the Tohoku University part, we have investigated 'receptivity' to cause a transition around an attachment line of a swept wing, by direct numerical simulation (DNS) of compressible Navier-Stokes equations. Up to now, two optimal instability modes have been found (Fig. 1). We will verify the dependence of the wing shape on these growth rates. We are also trying to delay turbulence transition by ultra-fine roughness coating. In the past, Dr. Tani mentioned (1989), and there is an example of experiments by Oguri & Kohama (1996), however, the control mechanism has not been elucidated. As the first step, we have investigated the effect of wall surface roughness on two-dimensional Tollmien-Schlichting instability. It has been found that the background pressure gradient near the wall is modified by the distributed surface roughness, which is much smaller than the TS vortex. The boundary layer thickness is kept suppressed with the larger wavelength roughness (Fig. 2).

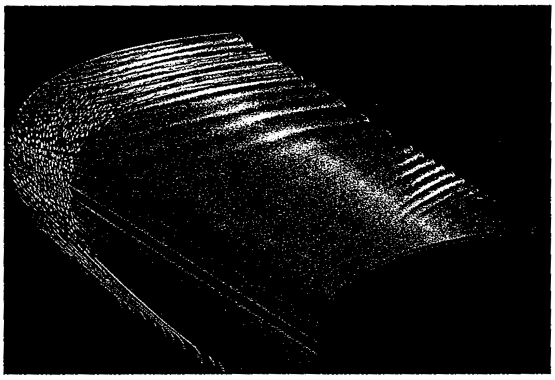

Fig. 1 Receptivity analysis to cause a transition around an attachment line of a swept wing, by direct numerical simulation; iso-surfaces are the second invariant of deformation tensor, colored with the spanwise velocity.

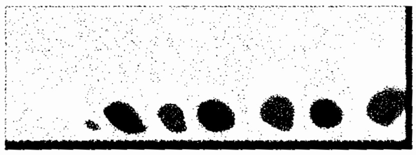

Fig. 2. Investigation of wall surface-roughness effect on two-dimensional Tollmien-Schlichting instability to cause transition; contour represents the wall-normal velocity.

3. Electricity generation from flowing water and graphene interface [1,2]

Owing to the rapidly increasing of global energy demands, energy harvesting from the environment has

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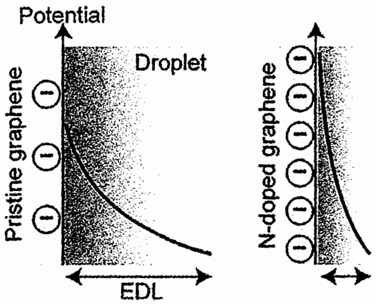

Fig. 3 Schematic image of reduction of EDL thickness by surface charging effect.

received much attention. Among them, electricity generation from the interface between graphene and flowing water has advantages in terms of variety of natural bodies of water, such as rain, ocean, river, and so on. We have investigated the mechanism of the electricity generation from flowing water (droplets) and graphene by tuning surface condition of graphene by doping techniques.

We have found that surface potential of the doped-graphene plays a role. When nitrogen is doped in graphene, the surface is changed to negatively charged potential due to an electron donor nature of nitrogen. In addition, the thickness of the electrical double layer (EDL) in the water is reduced, then the EDL creates a steep potential as shown in Fig. 3. The enhanced electric field accompanies the flowing water and results in a higher voltage generation. In the optimum condition, we have found that the valid generated voltage is proportional to the doping concentration, which indicates the role of nitrogen as dopant in graphene enhancing the output voltage and yielding more than 2 times higher voltage. The maximum enhancement of output power is approximately 1.5 times compared with pristine graphene.

4. Characterization of phase transition at hydrogen-metal material interfaces [3]

Hydrogen embrittlement (HE) is one of key issues for design and maintenance of the hydrogen stations. Concerning the HE of austenitic stainless steels which widely used as materials for hydrogen components, it has been reported that there is a correlation between their stabilities of austenite phases and susceptibilities to HE. However, the detailed mechanism of HE of austenitic stainless steels have not been fully understood in a view of phase transition so far.

In this study, eddy current testing (ECT) is focused on as an evaluation method of the phase transition of hydrogen charged austenitic stainless steels, and the effect of phase transition on hydrogen embrittlement is discussed.

Each specimen made of type 304 austenitic stainless steel plates was put in a high-pressure hydrogen container

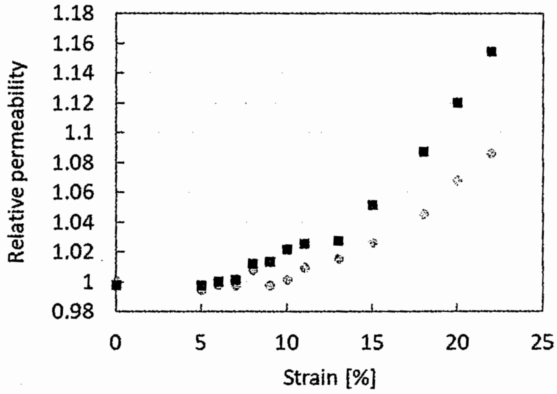

Fig. 4 Relative permeability as function of residual strain.

for 300 hours that was kept at a temperature of 270°C and a pressure of 100 MPa. The tensile tests were performed on the specimens with the strain rate of 5.0×10^{-5} s^{-1}. The hydrogen charged specimen was ruptured at the strain of 25% which is less than half of the uncharged specimen and the HE is confirmed.

Eddy current testing was carried out using an experimental setup consists of a lock-in amplifier, a function generator, a bipolar amplifier, and the probe. A transmitter-receiver (TR) type probe was used in this study. Figure 4 shows relative permeability as a function of strain. The relative permeability was estimated through the comparison of the numerical and the experimental signals. In both cases with and without hydrogen charged, relative permeability increased with the increase of applied plastic strain. This result suggested that the amount of the magnetic (α') phase increased by applying strain regardless the hydrogen charging. In the high strain region over 10%, the increments of relative permeability of hydrogen charged specimens was larger than that of uncharged ones. The mechanism of this difference will be discussed according to the microstructural analysis.

Acknowledgement

This work has been supported by Collaborative Research Project at Institute of Fluid Science, Tohoku University.

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