A NOVEL DRAG-REDUCING COATING MATERIAL : FDR-SPC (FRICTIONAL DRAG REDUCTION SELF-POLISHING COPOLYMER)

Inwon Lee, Hyun Park, Ho Hwan Chun
Global Core Research Center for Ships and Offshore Plants, Pusan National University,
Busan 609-735, Korea

INTRODUCTION

The reduction of frictional drag of turbulent boundary layer is of great importance for the fuel economy of ship. Along with the development of hull form optimization technique, the wavemaking resistance has become less than 20% of the total drag of most modern ships. Therefore, the advantage from the reduction of the remaining frictional drag would be enormous. The fuel consumption of global ocean shipping in 2003 was estimated 2.1 billion barrel/year [1], which corresponds to approximately 200 billion US$/year. Thus, 10% reduction of frictional drag would lead to saving of 16 billion US$/year. The skin frictional drag is closely associated with the coherent structures, e.g. hairpin vortices in the turbulent boundary layer flow. Various control strategies toward the attenuation of the drag-inducing flow structure have been proposed during several decades. One of the most effective drag reduction strategies is the polymer injection, which was first introduced by Toms (1949). Toms (1949) found that addition of few ppm of a high molecular weight polymer to a turbulent water flow can result in large (up to 80%) reduction of skin friction drag. Added long chain polymer molecule extracts the turbulent energy out of the adjacent flow by coiling its chain structures and then releases the energy by becoming stretched back in the shear flow. The turbulent energy transfer between the freestream and the near-wall flow is thus interfered, leading to a significant skin friction reduction. This is named Toms effect after who discovered it. The polymer injection has been put into practice for the pipeline transportation of petroleum, demonstrating one of the most effective examples of drag reduction.

It has been suggested that the polymer injection be applied to the frictional drag reduction for ships. There have been various researches to exemplifying the drag reduction efficiency of polymer injection in turbulent boundary layer [3-4]. From the aspect of implementation, however, the polymer injection is impractical for ship application. This is because it necessarily requires the injection holes to be installed onto the hull surface, which would cause significant structural strength issues. As a feasible alternative to the polymer injection method, Yang et al. [5] proposed a PEO-containing AF paint. They reported the release of PEO, the well-documented drag reducing agent leading to Toms effect, from the surface of coating. It was found that the PEO-mixed paint exhibited significant drag reduction efficiency in excess of 10% from various lab tests. In their paint, however, the PEO powders were physically mixed with the paint matrix, thereby giving rise to an increase in surface roughness and rapid release associated with the solubility of PEO in water. These factors may be detrimental to the longevity of drag reduction performance.

SYNTHESIS OF FDR-SPC

With a view to overcoming the drawbacks of the PEO-mixed paint in the previous research, a novel FDR-SPC is first synthesized in this study. The drag reducing functional radical such as PEGMA (Poly(ethylene) glycol methacrylate) has been utilized to participate in the synthesis process of the SPC. Figure 1 illustrates the release mechanism of PEO from the hydrolysis reaction between the FDR-SPC and seawater. The types of the baseline SPC monomers, the molecular weight and the mole fraction of PEGMA were varied in the synthesis process. The resulting SPCs were coated to the substrate plates for the subsequent hydrodynamic test for skin friction measurement. In a low-Reynolds number flow measurement using PIV (Particle Image Velocimeter), a significant reduction in Reynolds stress was observed in a range of specimen, with the maximum drag reduction being 15.9% relative to the smooth surface for PRD3-1, as shown in Table 1. Figure 2 shows the profiles of the streamwise turbulent intensity and the Reynolds stress. It is obvious that those turbulent quantities significantly decreased in the case of PRD3-1, corroborating the presence of Toms effect from the present FDR-SPC.

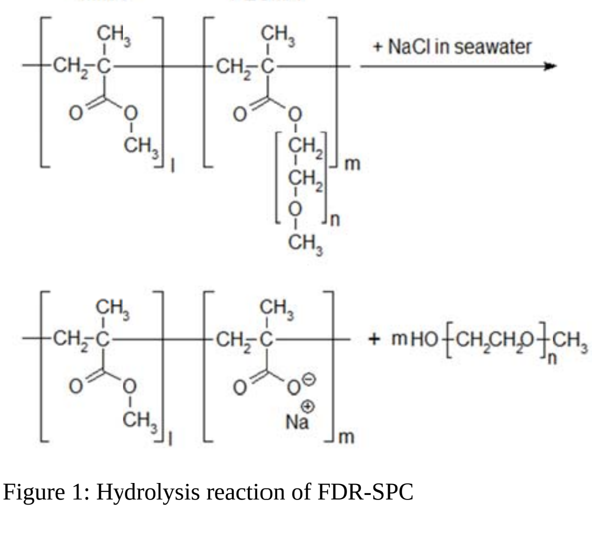


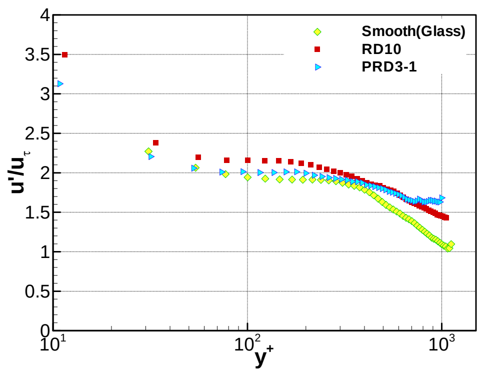
Figure 1: Hydrolysis reaction of FDR-SPC

Table 1: Synthesis parameters and drag reduction effects for various SPCs

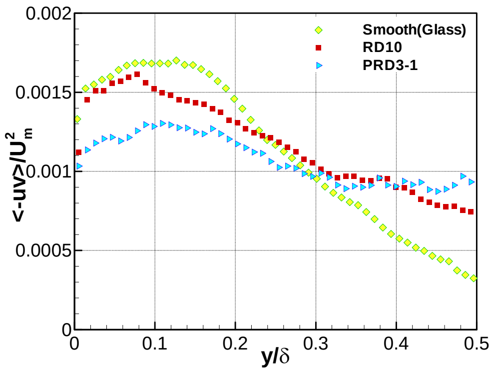
Substrates	PEGMA M.W.	PEGMA mol%	Drag Reduction (%)
SPC 13	-	0	**1.291**
PRD1-1	A	X	**1.741**
PRD1-2	A	Y	**2.557**
PRD1-3	A	Z	**0.117**
SPC 10	-	0	**5.49**
PRD2-1	A	X	**8.54**
PRD2-2	A	Y	**12.82**
PRD2-3	A	Z	**15.42**
PRD3-1	B	X	**15.94**
PRD3-2	B	Y	**14.44**
PRD3-3	B	Z	**10.06**

HYDRODYNAMIC PERFORMANCE OF FDR-SPC

In the high-Reynolds number flow measurement with a flush-mounted balance and a LDV (Laser Doppler Velocimeter), the skin friction of the present FDR-SPC is found to be smaller than that of smooth plate in the entire Reynolds number range, with the average drag reduction efficiency being 13.5% over the smooth plate. These results strongly support that the present FDR-SPC gives rise to the Toms effect based on chemical reaction at the surface of the coating. The FDR-AF (Anti-Fouling) coating manufactured from the present FDR-SPC exhibits drag reduction efficiency of about 20% over the conventional AF coatings, as shown in Fig. 3

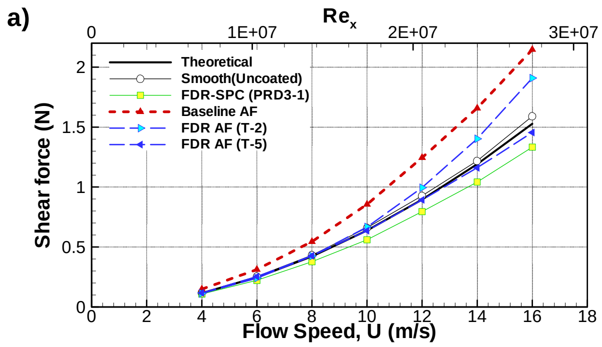


(a) Streamwise turbulence intensity

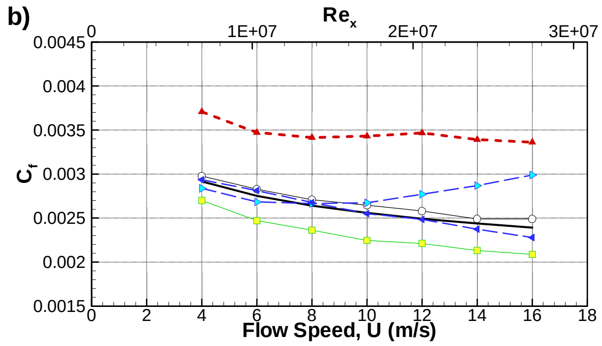


(b) Reynolds stress

Figure 2: Comparison of turbulent quantities in low-Reynolds number flow for FDR-SPC



(a) Streamwise turbulence intensity



(b) Reynolds stress

Figure 3: Comparison of frictional drag in high Reynolds number flow for FDR-SPC and FDR AF coatings

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) through GCRC-SOP(No. 2011-0030013) and Industrial Strategic Technology Development Program (Grant No. 10038606) funded by MOTIE, Korea.

REFERENCES

[1] Corbett, J. J. and Koehler, H. W., 2003, Updated emissions from ocean shipping, *J. Geophysical Research*, vol. 108, no. D20, pp. ACH 9-1 ~ 9.13

[2] Toms, B., 1948, Observation on the flow of linear polymer solutions through straight tubes at large Reynolds numbers, *Proc. Intl Rheol. Congr.* vol. 2, pp.135–141.

[3] Brasseur, J. G., Robert, A., Collins, L. R. and Vaithianathan, T., 2005, Fundamental Physics Underlying Polymer Drag Reduction, from Homogeneous DNS Turbulence with the FENE-P Model, *2nd Inernational Symposium on Seawater Drag Reduction*, Busan, Korea, 23-26 May 2005, pp.477-487

[4] Somandepalli, V. S. R., Hou, Y. X. and Mungal, M. G., 2010, Concentration flux measurements in a polymer drag-reduced turbulent boundary layer, *Journal of Fluid Mechanics*, vol. 644, pp.281-319

[5] Yang, J. W., Park, H., Chun, H. H., Ceccio, S. L., Perlin, M. and Lee, I., 2014, Development and performance at high Reynolds number of a skin-friction reducing marine paint using polymer additives, *Ocean Engineering*, vol. 84, pp.183-193