Prototype of a Self-controlled, Self-actuated Surface Roughness Mechanism

Sean Leverance, CSU Northridge
Dr. George Youssef, CSU Northridge
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Executive Summary

The behavior of external flow is dependent on wall-surface conditions such as surface roughness as well as working fluid physical properties and flow velocity. In general, the surface roughness is controlled during the manufacturing process but not easily changed after product deployment. The surface roughness of water and wind turbine blades, for examples, affects the power generation efficiency due to parasitic drag. The objective of this project was to study the scientific feasibility of using electro-elasticity coupling of active material to change the surface roughness and thus its effect on flow characteristics. The approach to accomplish the objective of the study was to fabricate piezoelectric thin-film using sol-gel spin coating technique. Piezoelectric materials, e.g. Lead-Zirconate-Titinate (Pb(Zr,Ti)O3), have direct and converse coupling between electrical field and deformation. The sol-gel process was selected for two reasons: 1) it is an open-air process, which does not require specialized vacuum equipment; and 2) the ease of scaling up the process to objects with complex geometries. A PZT precursor solution was prepared by mixing lead acetate trihydrate, zirconium propoxide, titanium isopropoxide, and glacial acetic acid. The solution was then spin-coated on Pt-coated Si wafers. Prior to coating, the wafers were cleaned by boiling in distilled water for 10 minutes, ultrasonically rinsed in methanol solution for 15 minutes, cleaned once again with distilled water, and nitrogen-dried. The deep cleaning process was used to improve surface wettability. The contact angle before cleaning was 74°, which was reduced to 48° after cleaning. Reduction in contact angle indicated an increase in wettability. The film was fired at 350 °C for 15 minutes to become amorphous then annealed at 600 °C for 6 hours to cause the structure to change from amorphous to perovskite. Qualitatively, crack-free films were fabricated with approximate thickness of 1-10 μm.
**Project Objectives**

According to the International Energy Agency, “energy efficiency is the world’s most important fuel”. This is because high energy efficiency means using less energy to accomplish the same task. One approach to increasing energy efficiency is by reducing drag. Parasitic drag is a type of drag that includes form drag and skin friction drag. Form drag is caused by a pressure difference along a body. It can be reduced by changing surface roughness to delay flow separation.

Skin friction drag, on the other hand, is created by shear forces as a fluid flows over a body. Reduction in skin friction drag has been seen using riblet technology. The dimensions of the riblet geometries are given by $h^+ = h \frac{u}{v}$ and $s^+ = s \frac{u}{v}$ where $h^+$ and $s^+$ are experimentally determined values, $u$ is flow velocity, and $v$ is kinematic viscosity.

It can be seen that the ideal level of roughness and the riblet dimensions vary depending on the flow velocity and fluid properties. Passive and active surface control mechanisms have been investigated a prior. On the one hand, active surface control adds complexity to the design as well as weight due to additional on-board components. Furthermore, active control requires a continuous power supply, which may not be available in remote locations of installation. On the other hand, passive surface roughness is set during the manufacturing process and cannot be controlled thereafter.

Using the piezoelectric effect, it may be feasible to dynamically change the surface characteristics. Piezoelectric materials, e.g. Lead-Zirconate-Titinate (Pb(ZrxTi1-x)O3), have direct and converse coupling between electrical field and deformation. The objective of this project is to study the scientific feasibility of using electro-elasticity coupling of active material to change the surface roughness and thus its effect on flow characteristics.
Project Approach

The methodology used for this project is shown in the flow diagrams below. First, the PZT precursor solution was made. Then, a silicon wafer was prepared so that the solution could be deposited onto it. Using a spin coater, the PZT precursor solution was deposited onto the silicon wafer. If the surface tension between the silicon wafer and PZT precursor solution was low enough, then the sample would be heat treated, turning the organic solution into an inorganic perovskite structure. Finally, the sample was poled to induce the piezoelectric effect within the material.
Project Outcomes

The contact angle before cleaning was 74°, which was reduced to 48° after cleaning. Reduction in contact angle indicated an increase in wettability. The film was fired at 350 °C for 15 minutes to become amorphous then annealed at 600 °C for 6 hours to cause the structure to change from amorphous to perovskite. Qualitatively, crack-free films were fabricated with approximate thickness of 1-10 μm.
Conclusions

Film quality depended on the precursor solution chemical ratios, cleaning methods, spin coating speed, and heat treatment. Challenges were encountered during the entire fabrication of the PZT thin-films including: PZT precursor solution mixing, substrate cleaning, spin coating, firing and annealing, and characterization. Thin film deposition techniques generally require precise equipment and clean-room quality laboratory settings, which were not available during this project. Future steps for the project would be to: produce higher quality PZT thin-films and characterize their electrical and mechanical properties, fabricate thin films on ITO-coated glass as substrate using the surface of the substrate as the bottom electrode, and perform tests in a wind or water tunnel while varying the applied voltage, and thus the surface wall conditions, to see the effect on the drag coefficient. Once the relationship between the drag coefficient and the surface properties of the substrate can be determined, then this technology could be applied to wind and water turbines, increasing energy efficiency and reducing greenhouse gas emissions.
References


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