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Development of a non-thermal plasma technology for imparting water repellency to nylon fibers

Abstract

Dr. Akitoshi Okino, Associate Professor of the Department of Energy Sciences at the Tokyo Institute of Technology Interdisciplinary Graduate School of Science and Engineering, and Sunline Co., Ltd. (Note 1) jointly developed a method for imparting water repellency to nylon fiber and for evaluating the water repellency of nylon fiber. These methods have potential applications in fiber materials including fishing line, for which there has been a demand for durable water repellency.

The present technology pertains to a plasma processing method to impart durable water repellency to nylon fibers. The surface of the fiber is functionalized to bond chemically with water repellent which is applied after the functionalization step.

Future prospects for the present technology include applications in surface modification of nylons, polyesters, polyolefins, and other general fibers, and for improving the surface adhesive properties of high performance fibers with high specific strength and modulus such as carbon and aramid, which are expected to save energy by reducing the weight of mobile units.

The present technology was supported by the Small and Medium-sized Enterprises Manufacturing Prototype Development Assistance Grant of the fiscal 2012 supplementary budget of the Small and Medium Enterprise Agency (Note 2).

（1）The significance of the present technology

Nylon fibers, with their softness, excellent abrasion resistance, and moderate strength, are used in a wide range of applications. They include clothing, industrial supplies such as airbags, and leisure and recreation products such as fishing line.

In fishing line applications, nylon fibers are coated with water repellent to make the line less prone to sinking. However, as the water repellent wears off after several hours of use, there was a demand for nylon fiber with durable water repellency.

The present technology is a plasma treatment method which enables the manufacture of nylon fiber with durable water repellency.

The present technology pertains to atmospheric pressure plasma treatment of fibers, and has the potential for application to a variety of industrial uses including but not limited to fibers, through its utilization on polyesters, acrylics, and polypropylenes in addition to nylons.

（2） Description of the present technology

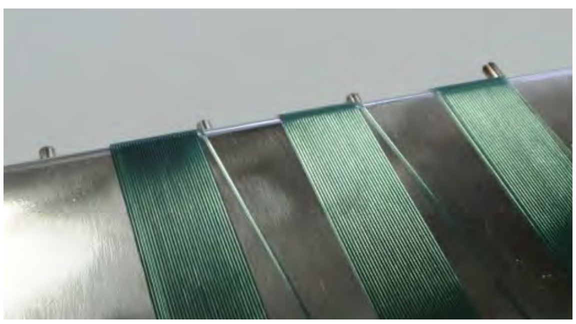
Explorations into plasma treatment of fibers mainly consisted of such methods as the spraying of plasma gas onto fiber surfaces, and were almost never put to practical industrial use.

Such plasma gas spray procedures costly to perform, as the long and thin configuration of fibers necessitated spraying from many directions to achieve uniform treatment of the entire fiber surface. In addition, there was a need for prolonged spraying on a fixed area to ensure the desired surface modification effect.

In the present technology, a method was developed whereby the fiber is passed through a uniform, high-density plasma gas for fast, continuous, uniform plasma treatment of the fiber surface.

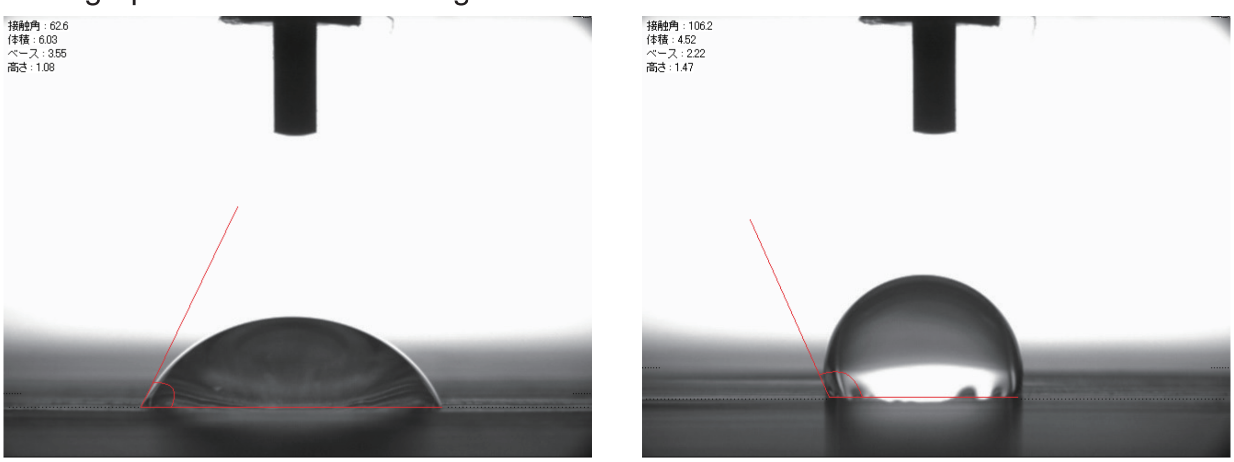
Furthermore, a method for evaluating water repellency was developed. Conventionally, there was no method for quantitative evaluation of the water repellency of fiber. As shown in Photograph 1, we developed a device whereby fiber is wrapped around a metal plate at a fixed tension in a parallel configuration to provide highly precise measurements of the fiber’ s water contact angle.

Photographs 2(a) and 2(b) show the water contact angle of nylon fiber. Photograph 2(a) shows untreated nylon fiber and 2(b) shows nylon fiber treated with the present technology of plasma surface modification.



Photograph 1: Fiber wrapped around in a parallel configuration

Photograph 2: Water contact angle of fiber



(a) Untreated nylon fiber
(water contact angle: 62°)

(b) Nylon fiber treated with the present technology
(water contact angle: 106°)

Conventional methods for imparting water repellency to nylon fibers consisted of coating the fiber surface with water repellent. In the present technology, plasma is used to functionalize the fiber surface to bond chemically with water repellent. Water repellent is then applied to obtain nylon fiber with durable water repellency.

In Figure 1, changes in the water contact angle of nylon fiber (0.220 mm diameter monofilament) are shown under saltwater fishing conditions in a comparison of nylon fiber uncoated with water repellent, coated with water repellent using conventional methods, and coated with water repellent after treatment with the present plasma technology.

As shown in the Figure, the application of water repellent greatly increased the water contact angle, even in nylon fiber without plasma treatment. However, after 10 hours of saltwater fishing, the water contact angle decreased to the same levels as uncoated fiber, indicating a loss of water repellency. By contrast, nylon fiber treated with the present plasma technology maintained a high water contact angle even after 10 hours of saltwater fishing.

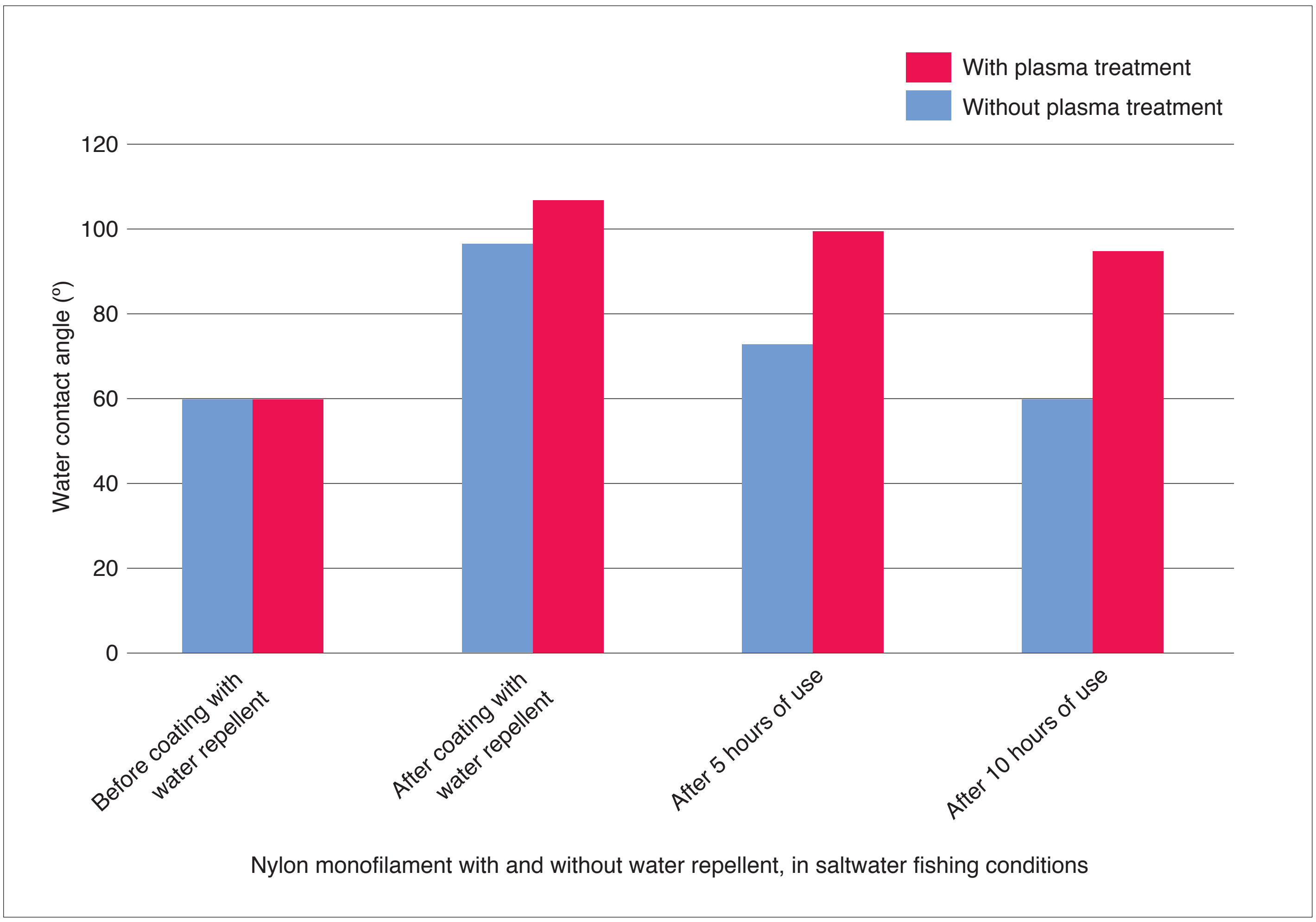


Figure1: Changes in water repellency of nylon monofilament

Photographs 3(a) and 3(b) are high speed camera photographs of nylon fiber pulled up momentarily after being floated on the water surface. Photograph 3(a) shows water repellent nylon fiber treated with the present technology, and 3(b) shows conventional nylon fiber. Compared to the untreated fiber of Photograph 3(b), the fiber treated with the present technology (Photograph 3(a)) shows good separation from the water, demonstrating the manageability required in a fishing line.

Photograph 3(a): Plasma treated nylon fiber (the arrow indicates the direction of the pull)

Photograph 3(b): Conventional nylon fiber

（3）Future prospects

The present technology pertains to atmospheric pressure plasma treatment for imparting water repellency to nylon fibers, with the additional capability of continuous treatment on long lengths of fibrous material.

Future prospects for the present technology include applications in surface modification of nylons, polyesters, polyolefins, fluorocarbons, and other other all-purpose fibers, and for improving the surface properties (hydrophilicity control, better adhesiveness, better dyefastness) of high performance fibers with high specific strength and modulus such as carbon and aramid.

In particular, high performance fibers are the focus of attention in recent years as weight-reducing, energy-saving materials for mobile units such as aircraft and automobiles. As the structural strength of composite materials made of these fibers is greatly influenced by the adhesiveness of the fiber and the matrix, there is a strong demand for improvement in adhesiveness. The present technology holds promise in this area.

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(Note 2)
"Small and Medium-sized Enterprises Manufacturing Prototype Development Assistance Grant"
A grant, created as a part of the national government's package of emergency economic measures (fiscal 2012 supplementary budget), for supporting the manufacturing efforts of small and medium-sized enterprises by providing assistance for the development of prototypes (including trial marketing).

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