NYLON

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At the 1939 World's Fair, fashion models (right) gave the public its first look at nylon stockings. When nylons first went on sale in New York on May 15, 1940 (above), customers lined up long before the stores opened. Four million pairs were sold in a few hours.

By Sally A. Kydd

Take a look at the label on your jacket. You may find that it is made of nylon. If it is, you are wearing one of the first and most successful synthetic fabrics. You can hardly get through a day without encountering nylon. Do you like to go camping? If so, your backpack, tent, and sleeping bag are probably made of nylon. Do you prefer to fish, sky dive, or sail? The fishing line that almost caught the big one, the parachute that carried you through the wild blue yonder, and the sail that helped your boat go faster were made of nylon.

Nylon is a synthetic fiber—a laboratory product manufactured by the trainload. It is made from chemicals that have their origins in coal, air, and water. Compared with natural fibers, nylon is stronger, lighter, and water resistant. Such is the magic of chemistry.

But nylon can't do everything. It is not used in sweaters because it doesn't form a soft bulky yarn; it is not used in shirts because it is not as wrinkle resistant as polyester. In the clothes you wear daily, the largest amount of nylon you might discover is 10% in your socks or thermal underwear. But where the properties of nylon are suitable for a particular application, it usually supersedes the traditional natural fibers.

Soft landing

Soon after airplanes flew into combat in World War I, there was a demand for parachutes. They were made from a natural fiber that was strong, thin, and light—silk. However, during World War II the United States was cut off from Japan, the major supplier of the fabric. The process for manufacturing nylon had just been developed by the E.I. du Pont de Nemours Co. in Wilmington, Delaware. Nylon parachutes were manufactured by

CAMPING EQUIPMENT COURTESY OF HUDSON TRAIL OUTFITTERS, LTD.

Nylon's durability, flexibility, and strength make it ideal for camping equipment. This camper's jacket, backpack, sleeping bag cover, and tent are made of nylon; her hiking shoes are partly made of nylon fabric.

the thousands and saved countless soldiers' lives. Once the process was proven successful, many plants were built in this country and abroad.

Nylon can be manufactured with a range of properties, making it useful for different applications. Parachutes require fibers with very high strength, or tenacity. Its strength also makes nylon suitable for making ropes that are lighter, easier to handle, and more resistant to mildew than those made from natural fibers. The nylon fibers used in clothing are not as strong, but have greater stretch or extensibility.

Extensibility is very useful for the manufacture of women's hose. After it is woven from minute fibers, the stocking is pulled over a specially shaped form and set with steam. The stockings continue to maintain this shape, to a great extent, during wear. The high elasticity of nylon ensures that the stockings will not bag at the knees or ankles after each movement but will recover their original shape. This shape retention also makes nylon suitable for women's garments and underwear. Permanent pleats and creases can be set in clothing, making it useful for skirts and pants.

Bristles, once made from hog's hair, are now made from nylon into brushes for teeth, hair, clothes, and bottles. The list of products seems endless: luggage, sails, fishing nets, reinforcing cords in airplane tires, and on and on.

Carpets made of nylon fibers can be wet-cleaned with water and soap to look like new, so they appeal to businesses with heavy traffic. Nylon carpeting lasts longer and is more economical than other natural and man-made fibers.

Playing with polymers

Nylon was discovered by a very creative chemist named Wallace H. Carothers. He worked at the Du Pont Company where he enjoyed the freedom to do as much basic research as he wanted. He produced many new materials that were not useful, but also some that were fabulously successful, such as nylon and neoprene (synthetic rubber).

In 1928 Carothers began to study the nature of polymers—long molecules composed of much shorter molecules—at a time when the subject was not popular with other chemists. He had no products in mind at the time, and it was not possible to predict where his pursuits might lead. Carothers knew that when an organic acid (with a –COOH group) is reacted with an alcohol (with an –OH group), the acid group would link with the alcohol group to eliminate water and form an ester (with a –COOC– group). Acetic acid, for example, reacts with ethyl alcohol to form ethyl acetate (an ester) and water:

$$\underset{\text{acetic acid}}{CH_3COOH} + \underset{\text{ethyl alcohol}}{C_2H_5OH} \longrightarrow \underset{\text{ethyl acetate}}{CH_3COOC_2H_5} + \underset{\text{water}}{H_2O}$$

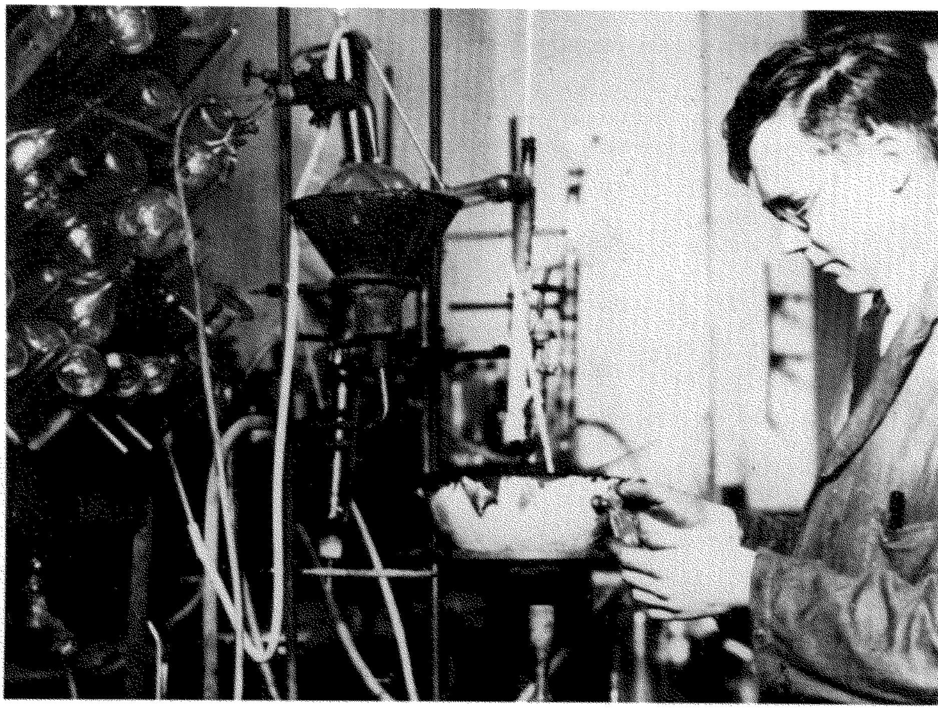

PHOTO DU PONT COMPANY

Wallace Carothers, inventor of nylon, in his laboratory at the Du Pont Company's Experimental Station at Wilmington, Delaware.

Extending this pattern, Carothers reacted the di-alcohol, hexamethylene glycol (which has an –OH on each end), with adipic acid (which has a –COOH group at each end) and again formed an ester.

$HO(CH_2)_6OH$ +
hexamethylene glycol

$HOOC(CH_2)_4COOH \longrightarrow$
adipic acid

$HO(CH_2)_6OOC(CH_2)_4COOH$ + H_2O
ester water

But because this ester has an alcohol group on one end and an acid group on the other, it can react with another molecule of the same kind and form yet another ester that is twice as long: $HO(CH_2)_6OOC(CH_2)_4COO(CH_2)_6OOC(CH_2)_4COOH$. Then two molecules of this ester can react to give a molecule that is twice as long again. . . and so on. By building on molecules that had reactive groups at each end, Carothers was able to form some very long molecules.

Carothers worked with these polymeric esters, or polyesters, but he found them to have no particularly useful properties. One day an assistant, whose name is unknown, dipped a glass rod into a molten mass of the polymer. He drew out some of the material that adhered to the rod. To his surprise, it stretched to form a long filament. Even after it was cold, the strand could be pulled by hand to several times its original length. Unlike rubber, it did not spring back to its former length, nor was the filament very strong.

The investigation might have stopped there but, with the rare insight of a gifted researcher, Carothers realized that the same approach that had yielded polyesters could also be used to make polyamides. So instead of the alcohol group, he turned to the amine group ($-NH_2$) and tried hexamethylene diamine, which has such a group on each end:

$NH_2(CH_2)_6NH_2$ +
hexamethylene diamine

$HOOC(CH_2)_4COOH \longrightarrow$
adipic acid

$NH_2(CH_2)_6NHCO(CH_2)_4COOH$ + H_2O
hexamethylene diamine adipate water

The result was hexamethylene diamine adipate, whose molecules could join with one another to form longer molecules. *These* molecules were very strong. They were the first nylon.

Weight control

The molecular weight of the nylon is crucial. It should be between 12,000 and 20,000 if the fiber is to be strong. The molecule can be stopped from growing at a particular point by a process known as "stabilization." If, instead of mixing exactly equivalent quantities of hexamethylene diamine and adipic acid, an excess of the latter is used, at a certain point all of the hexamethylene diamine will be used up and the reaction will stop. The ratio of 1 diamine to 1.02 diacid leads to a polymer with a molecular weight of 12,000, which is suitable for the production of nylon.

During the manufacturing process the polymerization takes about four hours at a temperature of 280 °C under an atmosphere of nitrogen. The molten polymer is then extruded through a slot to form a ribbon several inches wide. The hot material is quenched in cold water to prevent the growth of excessively large crystals that cannot be oriented lengthwise when the material is later stretched.

The ribbon is broken into chips and reheated. The molten nylon is pumped through a filter and extruded through tiny holes to form filaments. The filaments then pass through a cooling chamber, are wetted by steam, and are wound onto large bobbins. When the filaments are first produced, they are dull and not very strong. They are cold drawn—stretched to increase their length about 17%—to form strong, bright filaments. Stretching causes the randomly oriented molecules to align in the direction they are stretched, which adds strength to the nylon fiber. Finally, the fibers are dyed and woven to form the fabric for your jacket or knapsack.

The story of nylon is remarkable for several reasons: nylon is durable, water resistant, and strong. It is used successfully in so many products that we hardly notice it. And, after 50 years of commercial production, Wallace C. Carothers's invention is still the most widely used synthetic fiber.

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