

# Polyesters: characteristics and applications



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Scrunch it, wash it – without any wear and wrinkles. That's what polyester became famous for. Polyester was the fabric of choice in a changing economy of speed, efficiency and convenience. If the food industry produced fries and coke, the textile industry supplemented it with Polyester – quick, cheap and easy.

It was W. H. Carothers who discovered that alcohols and carboxyl acids could be successfully mixed to create fibers. Carothers was working for duPont at the time and unfortunately when he discovered Nylon, polyester took a back seat.

## **PET & Terylene**

Carother's incomplete research had not advanced to investigating the polyester formed from mixing ethylene glycol and terephthalic acid. It was British scientists – Whinfield and Dickson who patented PET or PETE in 1941. Polyethylene terephthalate forms the basis for synthetic fibers like Dacron, Terylene and polyester.

Later that year, the first polyester fiber – Terylene – was created by Whinfield and Dickson along with Birtwhistle and Ritchie. Terylene was first manufactured by Imperial Chemical Industries or ICI.

## **DuPont's Role**

It was in 1946 that duPont bought all legal rights from ICI. In 1950, the Delaware property of duPont manufactured another polyester fiber, which they named Dacron. Mylar was introduced in 1952. Polyester was first introduced to the American public in 1951 as the magical fabric that needed

no ironing! PET and PEN are duPont trademarks that have turned the use and consumption of Polyester around.

## **Polyester Becomes Popular**

Subsequent to the development of Terylene and Dacron, Kodel was developed by Eastman Chemical Products, Inc in 1958.

The polyester market underwent rapid expansion and textile mills emerged everywhere. Many of the mills were located at small gas stations and produced cheap polyester apparel. The inexpensive and durable fiber became very popular and the industry expanded rapidly till the 1970s. Unfortunately, the infamous double-knit polyester image hit the industry and polyester soon came to be known as the uncomfortable fabric.

## **The Phoenix Rises**

Today, polyester is largely regarded as a cheap fabric that is rather uncomfortable for sensitive human skin to wear.

However, the emergence of luxury fibers like polyester microfiber and various polyester blends the industry is experiencing resurgence. The Tennessee Eastman Company and the Man-Made Fiber Producers' Association's (MMFPA) Polyester Fashion Council played a significant role in the revival of polyester. The Tennessee Eastman Company started a YES campaign for polYESTer and popularized it via radio and television. The idea was to focus on the wash and go properties of polyester rather than sell it as a cheap fabric.

Hoechst Fibers Industries also played a part. They conducted various studies from 1981 to 1983 and found that 89% of people could not distinguish between polyester and other natural fibers like cotton, wool and silk. Also, it was found that people were more interested in the appearance of the apparel than the fabric it was made of.

Today, the biggest contributor to the appeal of polyester is the discovery of microfibers. Microfibers give polyester the feel of silk and are rapidly becoming the choice of fabric. With an expensive tag to match, the cheap image of polyester seems to be on its way out. Here's to heralding a new era in the history of polyester!

Polyester is a term often defined as " long-chain polymers chemically composed of at least 85% by weight of an ester and a dihydric alcohol and a terephthalic acid". In other words, it means the linking of several esters within the fibers. Reaction of alcohol with carboxylic acid results in the formation of esters.

Polyester also refers to the various polymers in which the backbones are formed by the " esterification condensation of polyfunctional alcohols and acids".

Polyester can also be classified as saturated and unsaturated polyesters.

Saturated polyesters refer to that family of polyesters in which the polyester backbones are saturated. They are thus not as reactive as unsaturated polyesters. They consist of low molecular weight liquids used as plasticizers and as reactants in forming urethane polymers, and linear, high molecular

weight thermoplastics such as polyethylene terephthalate (Dacron and Mylar). Usual reactants for the saturated polyesters are a glycol and an acid or anhydride.

Unsaturated polyesters refer to that family of polyesters in which the backbone consists of alkyl thermosetting resins characterized by vinyl unsaturation. They are mostly used in reinforced plastics. These are the most widely used and economical family of resins.

## **Characteristics of polyester**

- Polyester fabrics and fibers are extremely strong.
- Polyester is very durable: resistant to most chemicals, stretching and shrinking, wrinkle resistant, mildew and abrasion resistant.
- Polyester is hydrophobic in nature and quick drying. It can be used for insulation by manufacturing hollow fibers.
- Polyester retains its shape and hence is good for making outdoor clothing for harsh climates.
- It is easily washed and dried.

## **Uses of Polyester**

The most popular and one of the earliest uses of polyester was to make polyester suits – all the rage in the 70s. Polyester clothes were very popular. Due to its strength and tenacity polyester was also used to make ropes in industries. PET bottles are today one of the most popular uses of polyester.

## **Polyester care tips**

- Taking care of polyester clothing is really easy and very time efficient.

- Polyester clothing can be machine washed and dried. Adding a fabric softener generally helps. Dry the fabric at low temperatures to get maximum usage from the clothing.
- Though polyester does not require much ironing, if you must then iron warm.
- Polyester can be dry-cleaned with no hassles.
- Polyester is the choice of fiber and fabric for many industries. It can be applied to a wide variety of useful purposes.

## **Use of polyester in garments**

Polyester is used in the manufacturing of all kinds of clothes and home furnishings like bedspreads, sheets, pillows, furniture, carpets and even curtains. The disco clothing of the 70s with all its jazz and flash was made of polyester.

Hydrophobic nature: High tenacity and good durability makes polyester the choice of fabric for high stress outdoors use. Polyester is also a strong fiber that is hydrophobic in nature. It is thus ideal for clothing to be used in wet and damp environments. The fabric is also coated with a water-resistant finish and further intensifies the hydrophobic nature.

Being the most heavily recycled polymer worldwide, it is also used by climbers. Climbing suits, parkas, sleeping bags and other outdoor gear are using the new insulating polyester fiberfill products. One can also do winter windsurfing wearing dry suits lined with polyester fleece.

Creating insulation: By creating hollow fibers it is also possible to build insulation into the polyester fiber. Air is trapped inside the fiber, which is

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then warmed by the heat of the body. This keeps the body warm in cold weather. Another method to build insulation is to use crimped polyester in a fiberfill. The crimp helps keep the warm air in. Polyester is an ideal fabric for this kind of insulation because it retains its shape. Cotton and wool tend to flatten over a period of time and lose the warming effect.

Wrinkle resistant: Polyester is also wrinkle resistant and is used very often in everyday clothing like pants, shirts, tops, skirts and suits. Used either by itself or as a blend, it is also stain resistant and hence very popular.

## **Industrial uses of polyester**

While clothing used to be the most popular use of polyester and which made it a household name worldwide, there are many other uses polyester is put to.

PET: The most common use of polyester today is to make the plastic bottles that store our much beloved beverages. Shatterproof and cheap these bottles are an absolute boon to the beverages industry.

Mylar: An unusual and little known use of polyester is in the manufacturing of balloons. Not the rubber kind that you use for water balloons but the really pretty decorated ones that are gifted on special occasions. These are made of Mylar – a kind of polyester film manufactured by DuPont. The balloons are made of a composite of Mylar and aluminum foil.

Miscellaneous: Polyester is also used to manufacture high strength ropes, thread, hoses, sails, floppy disk liners, power belting and much more in industries.

Thus, polyester has many uses for homes and industries as well.

The process of manufacturing polyester is fascinating. It is an artificial man-made fiber. Polyesters are generally manufactured from petroleum from which the constituent acids and alcohols are derived.

There are three steps in the synthesizing of polyester.

**Condensation Polymerization:** When acid and alcohol are reacted in a vacuum at high temperatures it results in condensation polymerization. Once the polymerization has occurred the material is extruded onto a casting trough in the form of a ribbon. Once cool, the ribbon hardens and is cut into chips.

**Melt-spun Fiber:** The chips are dried completely. Hopper reservoirs are then used to melt the chips. A unique feature of polyester is that it is melt-spun fiber. The chips are heated, extruded through spinnerets and cools upon hitting the air. It is then loosely wound around cylinders.

**Drawing:** The fibers consequently formed are hot stretched to about five times their original length. This helps to reduce the fiber width. This fiber is now ready and would into cones as filaments. It can also be crimped and cut into staple lengths as per requirements.

## **Different Types Of Polyester**

There are several processes that can be carried out on the base polyester fiber. These processes add dimension to the polyester fiber as required for various end uses.



Polyester is a bright fiber by nature. However, it can be made dull or semi-dull by adding a delusterant. By changing the shape of the spinneret also, the hand and the strength of the fiber can be changed. Most spinnerets are circular. However, square, oval and bean-shaped fibers are also produced sometimes. Hollow fibers can also be created.

Polyester fiber is generally drawn to about five times its original length. However, drawing it out further makes it thinner. This is how the latest microfibers are being manufactured. Dyeing can give desired colors of polyester fiber. Normal polyester fiber is long and smooth. Crimping it can give the fiber more bulk and texture and increase its insulation capabilities.

## **Using Polyester**

Once the polyester fiber is ready it is used to make filament and spun yarns. The yarns can be blended with other fibers to make various blended fabrics.

Polyester and cotton are a popular combination. Wool and rayon are also blended with polyester to make fabrics.

Polyesters are long chain synthetic polymers that have ester linkages.

Polyester materials are used as fibers, plastics, and films; in composites and elastomers; and as coatings. They are truly versatile materials.

In the late 1920s American chemist Wallace Carothers and his research group at DuPont began to investigate the formation of polymers from the reaction of aliphatic di acids (having two acid groups) with diols (having two alcohol groups), in search of materials that would give them fibers. At first they were able to form only syrupy mixtures. But the Carothers group did

make polyester fibers. They investigated a wide array of dialcohols, diacids, and  $\omega$ -hydroxy acids for use as starting points. Some of the polyesters that they achieved were solids, but they had rather low melting points and thus were not useful as fiber materials. The lack of success was due to the fact that the researchers had used only aliphatic diacids. In order to form long polymer chains, the reactive groups of the reactants must be present in approximately equal amounts. This is easily achieved via the use of amines and the subsequent formation of amine salts. (Diols do not easily form salts.) Carothers's group understood the principle of "driving" an equilibrium reaction and so sought to remove water from their amine salt mixtures, thus forcing the reaction toward ester formation. For this they developed a so-called molecular still, which involved heating the mixture and applying a vacuum coupled with a "cold-finger" that allowed evacuated water to condense and be removed from the reaction system. Even with this understanding and lots of hard work, they achieved polymer chains with fewer than 100 repeat units. (See Figure 2.)

The DuPont research team turned from the synthesis of polyesters to tackle, more successfully, the synthesis of polyamides. The experience with polyesters was put to use in the making of polyamides.

Initial polyester formation actually occurred much earlier and is attributed to Gay Lussac and Théophile-Jules Pelouze in 1833 and Jöns Jakob Berzelius in 1847. They did not realize what they had discovered, however, and so moved on to other work.

Glyptal polyesters were first produced in 1901 by heating glycerol and phthalic anhydride. (See Figure 3.) Because the secondary hydroxyl is less active than the terminal, primary hydroxyl in glycerol, the initial product formed is a linear polyester. A cross-linked product is produced by further heating through reaction the third alcohol.

Related compounds, alkyds, were synthesized by Kienle in the 1920s from trifunctional alcohols and dicarboxylic acids. Unsaturated oils (alcohols and anhydrides containing double bonds) were also reacted with phthalic anhydride, yielding polyesters that contained a double bond, which could be further reacted to produce cross-linked products. The extent of cross-linking or “drying” depends on the amount of unsaturated oil present.

Today, the term alkyd is often used to describe all polyesters produced from the reaction of a diacid or anhydride and a diol or triol resulting in a product that contains a double bond that can be further reacted, giving a cross-linked product. (See Figure 4.) These polyesters are called unsaturated polyesters. They are mainly used in the production of reinforced plastics (composites) and nonreinforced filled products for the marine, automotive, and other industries.

These glyptal and alkyd polyesters are useful as coating materials but not for fiber or plastic production. The first commercially available polyesters were made by GE in the 1920s. Called Glyptals™, they were used as sealing waxes. Out of the Glyptal™ research came alkyd paints. Although these reactions had low fractional conversions, they formed high molecular weight

materials because they had functionalities (i. e., a number of reactive groups on a single reactant) greater than 2, resulting in cross-linking.

The heat resistance of Carothers's polyesters was not sufficient to withstand the temperature of the hot ironing process. Expanding on the work of Carothers and his coworkers on polyesters, Whinfield and Dickson, in England, overcame the problems of the Carothers group by using aromatic acids, especially terephthalic. This classic reaction, which produces plastics and fibers that are sold under a variety of tradenames, including Dacron, Fortrel, Trevira, and Terylene, and films sold under a variety of trade names that includes Mylar, is shown in Figure 5. All new plants now use pure acid for this reaction.

Methyl alcohol, or methanol, is lower boiling than water (65 ° C compared with 100 ° C) and is thus more easily removed, allowing the reaction to be forced toward polymer formation more easily. Although this poly(aryl ester), produced by Whinfield and Dickson, poly(ethylene terephthalate) or PET, met the specifications for a useful synthetic fiber, because of inferior molding machines and inadequate plastic technology, it was not possible to use it in injection molds. Until more recently PET was not a widely used plastic or film material.

Although aromatic polyesters had been successfully synthesized from the reaction of ethylene glycol with various aromatic diacids (almost always terephthalic acid or its ester), commercialization of polyester synthesis awaited an inexpensive source of aromatic diacids. In 1953 an inexpensive process for the separation of the various xylene isomers by crystallization

was discovered. The availability of inexpensive xylene isomers enabled the formation of terephthalic acid through the air oxidation of the p-xylene isomer. Du Pont, in 1953, produced polyester fibers from melt spinning, but it was not until the 1970s that these polyester fibers became commercially available.

John Travolta and Karen Lynn Gorney in the 1970s hit film Saturday Night Fever. Polyester was a popular fabric used in clothing in the 1970s.

In 2000 about 3, 900 million pounds of polyester fiber were used in the United States, making it the largest single fiber group material. As with nylon, polyester fibers are comparable to and/or surpass common natural fibers such as cotton and wool in heat stability, wash-and-wear properties, and wrinkle resistance. Textiles blended from polyester, cotton, and wool (in varying combinations) can also be made to be “ permanent press” and wrinkle resistant. The fibers are typically formed from melt or solvent spinning. Chemical and physical modification can generate fibers of differing fiber appearances from the same basic fiber material. Self-crimping textiles are made by combining materials that have differing shrinkage properties. Different shaped dyes produce materials with varying contours and properties, including hollow fibers.

Along with the famous polyester suits and slacks, polyester fibers are widely used in undergarments, permanent press shirts, tire cord, and felts.

Because the ease of processing and fabricating polyesters is related to the number of methylene groups (-CH<sub>2</sub>-) in the repeat units, scientists turned to the use of diols with additional methylene units. Whereas PET is difficult to

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polyester mold because of its high melting point,  $T_m$  240° C, poly(butylene terephthalate), or PBT, because of its two additional methylene units in the diol-derived portion, is lower melting with a  $T_g$  of about 170° C. PET also crystallizes relatively slowly, so extra care must be exercised to insure that PET molded products become fully crystallized. Otherwise, the partially crystallized portions will be preferred sites for cracking, crazing, shrinkage, and so on.

By comparison, PBT melts at a lower temperature (as noted above), crystallizes more rapidly, and is often employed as a molding compound. PBT has properties that represent a balance between those of nylons and acetals. It is characterized by low moisture absorption, good fatigue resistance, good solvent resistance, extremely good self-lubrication, and good maintenance of its physical properties even at relatively high use temperatures. Fiber-reinforced PBT molding compound is sold under the trade-name Celanex. Another PBT molding compound was first sold under the trade name Valox. Today, there are many PBT molding compounds available.

In 2000 worldwide production of PET was 30 million tons. The manufacture of PET textiles is increasing at 5 percent a year, of PET bottles at 10 percent a year. China produces the most polyesters. PET is now used extensively as bottling material for soft drinks instead of glass because it is shatterproof and lightweight. Carbon dioxide permeability decreases with increasing film thickness and crystallinity. Glass has better CO<sub>2</sub> impermeability than PET in these respects. Therefore, to achieve optimal crystallinity, partially crystalline PET is employed in the stretch blow molding process, carried out to promote further crystalline formation. It is also used for molded automobile parts.

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Over 500, 000 tons of polyester engineering plastics are produced annually in the United States.

Polymers are the origin of polyesters

Classification of polymers:-

Based on characteristics , intended use and performances of the finished product, polyesters are divided into three main categories:-

Plastics, fibres, elastomers.

Plastics are widely variety of polymers-based composite materials which possess appreciable mechanical strength (they have stiff chains at room temperature) and are characterised by plasticity, they can be formed or moulded into useful shapes by application of heat and pressure. Materials which possess plasticity at some stage during their formation are also included in this category.

Based on their thermal behaviour, plastics have been subdivided into thermoplastics (that soften and flow on heating) and thermosetting or thermohardening plastics (that set or harden on heating)

A fibre is any material whose minimum length is 100 times its average diameter which should be less than . 25 mm. fibres are natural (cotton, silk, wool) or artificially prepared long chain polymers with average molecular weight of 15000 or more. Fibre forming materials are characterised by high softening or melting points, a high degree of resistance to chemicals and solvents, high tensile strength and very high rigidity

They however undergo irreversible deformation.

Elastomers or rubbers are polyesters characterised by a very high degree of reversible or elastic deformation. They can be stretched to several times their original length but regain their previous shape or dimensions when the stretching force is removed. The molecular chains of elastomers can exist in randomly coiled state and their elastic behaviour can be compared to that of the spring of a chest expander which uncoils and recoils on application and removal respectively, of an elongated force. The glass-transition temperatures of elastomers are very much below their use temperature.

Preparation of polymers:-

Bulk polymerization:- a free radical catalyst or initiator is dissolved in the monomer which is then heated and stirred in a suitable vessel. The polymerization is exothermic and dissipation of heat through cooling may be required. As the reaction progresses, the system becomes viscous making stirring difficult. The method is economical and the product is of high purity. The technique is used for preparing polyvinyl chloride (PVC) polystyrene (PS) polymethylmethacrylate (PMMA).

Solution polymerization:- the monomer and catalyst (free radical, cationic and anionic) are dissolved in a suitable inert solvent. The resulting solution is heated and stirred. The presence of solvent helps in heat dissipation and in controlling viscosity. The solvent may interact and reduce the molecular weight of the product whose isolation from the solution is uneconomical unless it is insoluble. The technique is employed where the polymer is to be

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used in solution form such that as in case of adhesives and surface coatings. Polyacrylonitrile, polyisobutylene and certain block copolymers are produced by this method.

**Suspension polymerization:-** a solution of the catalyst in the monomer is dispersed as fine droplets in an inert solvent, usually water. To stabilize the suspension, water soluble protective colloids such as polyvinyl alcohol, methyl cellulose or starch are added and the mixture is kept stirring continuously. The problems of heat dissipation and viscosity increase are absent. The method gives a fairly high molecular weight product in the form of easily separable beads that can be filtered or centrifuged and water washed to remove the protective colloids. The technique is employed for the production of PVC, PS and styrene-divinylbenzene copolymer (used for making ion-exchange resins).

**Emulsion polymerisation:-** the particle size of the monomer is reduced to colloidal dimensions by more vigorous stirring and use of synthetic surfactants (anionic, cationic or non-ionic) in place of protective colloids used in suspension polymerisation. Usually water soluble catalysts such as persulphate, hydrogen peroxide are used. Thermal dissipation and viscosity problems are absent. Both the rate of polymerisation and the molecular weight of the product formed are very high. The product which is in the form of fine particles dispersed in water (called latex) can be used directly as adhesive or an emulsion paint, or it can be isolated by coagulating with an electrolyte. The technique is employed for the industrial production of PVC, PCP, polybutadiene, polyacrylates, polymethyl methacrylate.

**Melt polycondensation:-**

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The reactants are heated together in exact stoichiometry above the melting point of the product, at which temperature the starting materials and product must be thermally stable. Oxygen has to be excluded from the reaction chamber to avoid oxidation at high temperature. Increase in viscosity makes removal of the by-product extremely difficult towards the end (unless high vacuum is applied) which may prevent formation of high molecular weight product. The molten polymer is usually sent directly for spinning, extrusion etc. The technique is usually applied for the preparation of polyesters and polyamides.

Interfacial polymerization:-

The reaction takes place at the interface of between solutions of the reactants in immiscible solvents. Increasing the interface by thorough agitation of two solutions substantially the rate of polymerisation. Exact stoichiometry is not necessary and a high molecular weight product can be easily formed. Being very simple the method is widely used for the production of polyamides, polyesters, polyurethanes, polysulphonamides. Difference in the reactivity of materials can be utilized to prepare ordered copolymers which otherwise are very difficult to produce. The technique is however limited to reactants having highly reactive functional groups that can readily react at the ambient temperatures.

Testing and characterization of polymers:-

Testing and characterization of polymeric materials is essential for determining their suitability for a particular application. The manufacturers and processors need it for quality control such as maintaining product

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uniformity and for accessing the performance of new material in relation to the existing ones. processors and users wanting to better understand the polymeric behaviors. Under various conditions are naturally interested in knowing their chemical nature.

Polymeric materials are very complex in nature. their high molecular weights in homogeneity and their chemical inertness often present difficulties in their identification which therefore requires specific techniques and the use of advanced methods of analysis. The problem of characterstic is further complicated by the market availability of an extermely wide range of materials and the presence of compounding materials such as plastic stablizers and filers (which change the physical propeties of the product) and thus

Complete identification of polymeric materials may not always be possible. It is howeveere possible to make a positive identification as to the class of polymers (polyeolefine, polyesters, polyamine) to which a given sample belongs. By carrying out some simple test and correlating their results:

Application of these tests to the identification of to common polymeric materials is described as:-

Physical test:-

- Physical examination of polymeric materials includes the observation of their color,, solubility, density etc

Flootation test:-

- The test is based on Archimedes principal from which it follows that a material will float in liquid of same or high density .
- Combustion test:-holding the pair of tweezers or tongs insert a small piece of the sample into flame of Bunsen burner and observe the ease of ignition, flammability of the sample in and out of flame
- Ph paper test:-take a small amount of powdered sample in a test tube or ignition tube and place at its open end a piece of moist ph paper holding tube with a clip heat it with Bunsen burner at low heat.