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Nylon (Chemistry, Properties and Uses)

Chemistry

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ABSTRACT

Nylon can be described as a ubiquitous polymer. It is a part of various applications which are paramount in our quotidian life. Hence it is important to study the chemistry and properties of nylon which are instrumental for its selection in various applications. The paper focusses on the chemistry of nylon and its different types. Maximum emphasis is placed on the synthesis of various nylons and their structure which influence its properties. The properties in turn widen the range of applications of this important entity. Possible additives if added to nylon could make it a better material for newer and more sophisticated applications are also discussed.

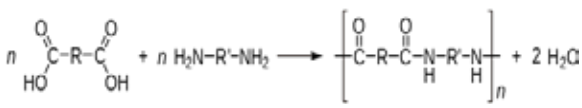
Introduction:

Before going to the synthesis and chemistry of nylon, one needs to study the various types of nylon and their application. The various types of nylon used in everyday life are Nylon-6, Nylon-6,6, Nylon-6,10, Nylon-6,12, Nylon-11, Nylon-12 and Nylon MXD6. Some common applications of these nylons are electrical connectors, gear, slide, cams, and bearings, cable ties and film packaging, fluid reservoirs, fishing line, brush bristles, automotive oil pans, fabric, carpeting, sportswear, sports and recreational equipment [1, 2].

Chemistry:

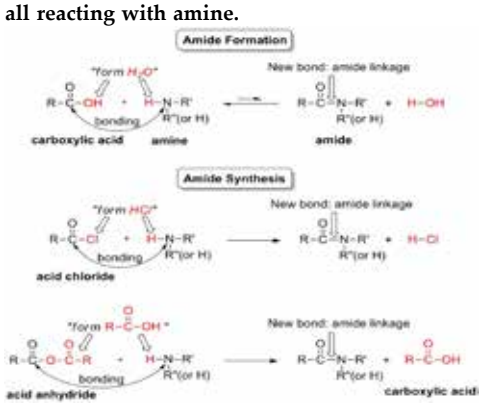
Nylons are basically included in the class of polyamides which also contains Kevlar [3]. Nylons, except for Nylon-6, are all formed by condensation polymerisation between dicarboxylic acids and diamines as shown in Figure 1. This is an example of nucleophilic addition- elimination reaction as shown in Figure2. [5]

Figure 1: Condensation polymerization reaction of Nylons.



But usually this conventional method of forming a nylon is replaced by a newer method. In the newer method, a carbonyl chloride group is used to form an amide linkage with an alcohol instead of a carboxylic acid group as shown in Figure 2. This method of forming an amide linkage is more effective than the conventional one. Sometimes acid anhydrides are also used instead of carboxylic acid groups as shown in figure 2. [4, 5]

Figure 2: Amide synthesis by three different compounds all reacting with amine.



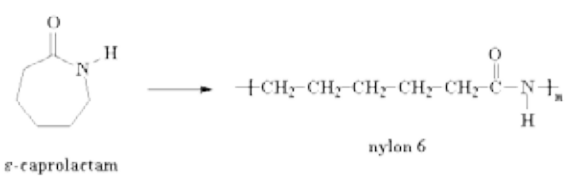
From figure 2, it is evident that these acyl and anhydride groups render the carbonyl carbon atom more electropositive for a nucleophilic addition of the amine group to take place.

The polymerization technique used for nylon is interfacial condensation. In this technique, polymerization is allowed to proceed at the interface between an aqueous and an organic medium.[6] Since the polymer formation at the interface is a diffusion controlled process, very high molecular weight polymers can be achieved by this technique.

Nylon-6:

Nylon-6, Nylon-11, Nylon-12 are all homopolymers. But Nylon-11 and Nylon-12 are formed by condensation polymerization because their monomers (11-aminoundecanoic acid and ω-aminolauric acid respectively) contain both amine and acid functionalities in a single molecule (monomer) itself. [7] Nylon-12 can also be produced by ring-opening polymerization of laurolactam at 260-300°C. [8] Nylon-6 however is only formed by ring opening polymerization of ε-Caprolactam [9] as shown in figure 3.

Figure 3 polymerization reaction of nylon-6



Structure and related properties:

As the separation of the amide groups increases (by adding more methyl groups) and the polarity of the amide groups is reduced, moisture absorbance is decreased. Resistance to thermal deformation is lowered due to more flexibility and mobility in the methyl unit sections of the chain. In the case of Nylon-6,6 and Nylon-6,12, one can clearly see this relationship. Nylon-6,12 has a lower modulus, higher elongation, lower strength, lower thermal distortion temperature, lower hardness, and lower melting point than Nylon-6,6. However, Nylon-6,12 absorbs half as much water on Nylon-6,6. Thus, even though the properties may not be as good as Nylon-6,6 in dry conditions; the properties of Nylon-6,12 will be much more consistent when it is used in applications in which water may be present. The absorption of water has a significant effect on the properties of nylon. [2]

Chemical and Physical properties:

- Acid: Nylon 6, 6 is attacked by mineral acids is disintegrated or dissolved almost. But is inert to dilute

acetate acid and formic acids even of the boil. It is dissolved in the concentrated formic acid. Nylon 6 is attacked by mineral acid but resistant to dilute boiling organic acid. [6,7]

- Bleaches: Not attacked by oxidizing and reducing bleaches but may be harmed by chlorine and strong oxidizing bleaches. [10,11]
- Alkali: Nylon is substantially inert to alkalis. [11]
- Organic solvent: Most of the solvent have little or no effect on nylon. Phenol metacressol and formic acid dissolve the fibre but solvents used in stain removal and dry cleaning do not damage it. [12,13]
- Light: No discoloration. Nylon 6 gradually loss of strength on prolonged extension.[6,10,11]
- Biological: Neither micro organism nor moth, larvae attack nylon. [6]
- Electrical: High insulating properties leads to static charges on the fibre.
- Flammability: Burns slowly. [6]

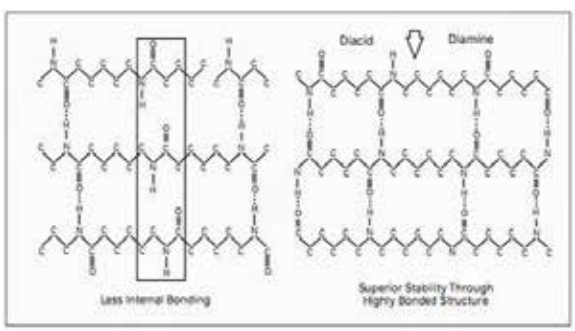


Figure 4: The molecular structure of Nylon-6 versus Nylon-6, 6 yields enhanced properties.

Nylon-6, 6 shows greater strength as compared to Nylon-6 because of the greater hydrogen bonding shown in Nylon-6, 6 as shown in figure 4.

Melting point and crystallinity increase because of this greater hydrogen bonding between adjacent chains. But this effect is not a regular one. The increase in melting point also depends on whether the number of -CH_2 groups present in between the CONH groups is even or odd. The odd number of -CH_2 groups between the amide groups in Nylon-6 allows complete hydrogen bonding when the amides in the adjacent chains have an opposed or an antiparallel orientation but not when they have the same or parallel orientation(as shown in the figure 4). Changing from a parallel to an antiparallel array requires inverting the entire molecular chain in the odd numbered case. But only a segment lateral movement is needed if there is an even number of -CH_2 groups, as in the case of Nylon-6, 6 with its intervening number of 4 and 6 -CH_2 groups. It is this odd-even feature that accounts for the lower melting point and percent crystallinity of Nylon-6 versus Nylon-6, 6. It is this reason in general why Nylon-odd and Nylon-odd-even have lower melting points than comparable or similar Nylon-even-even. [7]

Thus the crystalline behaviour of nylon is directly related to its structure.

Increasing crystallinity increases

- Stiffness
- Density
- Tensile and yield stress
- Chemical and abrasion resistance
- Better dimensional properties.

However increasing crystallinity decreases

- Elongation
- Impact resistance
- Thermal expansion
- and Permeability.

Water absorption as discussed earlier is characteristic of nylons. Unless compensated for by increased crystallinity, a higher proportion of amide groups leads to higher water absorption. Increased water content has an effect analogous to that of increased temperature, i.e., enhanced segmental mobility with concomitant loss in stiffness and tensile strength, gain in toughness and growth in dimensions (elongation).

At very low temperature, however, water stiffens the nylon. Thus the brittleness temperature (ASTM D746) of Nylon-6, 6 is-80°c if dry and - 65°c if conditioned to 50% relative humidity. Properties are frequently reported in the "dry", as- molded condition corresponding to about 0.2% water or less, and after equilibration to a specified relative humidity such as 50 or 65% and occasionally to 100%.

Also nylons with fewer CONH groups and lower water absorption have a lower dry Tg, but shows less change of Tg with relative humidity. [7] Thus we see that the mechanical properties of nylon depend greatly on the crystallinity and water absorption.

Applications:

1. Nylon is a high strength fibre. It is used for making fishing nets, ropes, parachutes and type cords. [6, 14]

2. It is used for making fabrics in textile industry. Nylon creates draperies, flame-resistant products, and clothes. It is often used for carpets. [15, 16]

3. Crinkled nylon fibres are used for making elastic hosiery. Most stockings for women are made from nylon. Used to make and design clothing. [6, 15]

4. Nylon is widely used as plastic for making machine parts. [15]

5. It is blended with wool to increase the strength. [14]

6. Military applications such as parachutes, flak vests, and tires for vehicles.

7. Nylon threads are used for surgical suture, dresses, under garments, ties, tapestry. [16]



Figure 5: Applications of Nylon-6, 6

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