REINFORCING MATERIALS IN RUBBER PRODUCTS

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Summary

As described in the other modules of the VERT learning program, many elastomer types are too weak to be used without some reinforcing system. This means that most practical rubber products like tyres, hoses and different kinds of belts include the concept of reinforcing the elastomer matrix with some reinforcing agent. There are two main possible reinforcing principles: either the elastomer matrix is compounded with reinforcing fillers or the product is provided with some fibre consisting components applied in the product assembly phases.

The primary function of reinforcing filler is to improve the mechanical properties of the rubber compound, whereas the fibre based components have the extra purpose to give adequate functional properties to the product. In both cases it is crucially important, that the additional components of rubber compound and the product are well bonded to the elastomer segments of the matrix.

In this module of the Virtual Education for Rubber Technology (VERT) we tend to provide a general background and awareness of reinforcing fibres, and to give the rubber technologists an improved basic understanding of the uses, processes and potential problems associated with the use of fibre components in rubber products. The VERT module “The raw materials and compounds” handles the fundamentals of the topics of reinforcing additives and fillers.

The first part of this module covers the definitions and classification of the most common used textile fibres for example cotton, rayon, polyamide, polyester and aromatic polyamides. It includes as well the basic technologies of the processes like twisting, texturing, weaving, sizing and rubber/textile composite assembling by calendering or coating. In the context of the properties of reinforcing fibres, particular attention is given to the aspects of adhesion, heat setting, adhesive treatments and processing and the assessment of adhesion. The first part also presents different kinds of test methods, which are used in textile cord testing.

In the second part, the basic technologies of steel based fibres, steel cords, bead wires and the processes like calendering, extruding, cutting and splicing, which are used in preparing these components are handled. Again, attention is directed to the aspects of adhesion, to illustrate how the optimum reinforcement and performance for a particular application. Just like in the first part the in this part also different kinds of test methods for steel wire and cord testing are introduced.

The third part of this module sheds light to the principles of applying fibre reinforcement techniques in different rubber products. Short descriptions are presented on the use of reinforcing fibres and components in the tyre products as well as in industrial and consumer rubber good applications like belts, hoses and miscellaneous applications of reinforced rubber including inflatable and non-inflated structures.
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As described in chapter 3.2, different coating or spreading techniques can be used, when combining the textile and the rubber, especially in case of thin rubber coatings................................................................. 112

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Introduction

As described in the other modules of the VERT learning program, many elastomer types are too weak to be used without some reinforcing system. This means that most practical rubber products include the concept of reinforcing the elastomer matrix with some reinforcing agent.

There are two main possible reinforcing principles: either the elastomer matrix is compounded with reinforcing fillers or the product is provided with some fibre consisting components applied in the product assembly phases.

The primary function of a reinforcing filler is to improve the mechanical properties of the rubber compound, whereas the fibre based components have the extra purpose to give adequate functional properties to the product. In both cases it is crucially important, that the additional components of rubber compound and the product are well bonded to the elastomer segments of the matrix.

In this module of the Virtual Education for Rubber Technology (VERN) we tend to provide a general background and awareness of reinforcing fibres, and to give the rubber technologists an improved basic understanding of the uses, processes and potential problems associated with the use of fibre components in rubber products. The VERN module “The raw materials and compounds” handles the fundamentals of the topics of reinforcing additives and fillers.

The first part of this module covers the definitions, classification and basic technology of the processes used in preparing textile fibres. In the context of the properties of reinforcing fibres, particular attention is given to the aspects of adhesion, adhesive treatments and processing and the assessment of adhesion.

In the second part, the basic technology of steel based fibres and the processes used in preparing these components are handled. Again, attention is directed to the aspects of adhesion, to illustrate the way how the optimum reinforcement and performance for a particular application.

The third part of this module sheds light to the principles of applying fibre reinforcement techniques in different rubber products. Short descriptions are presented on the use of reinforcing fibres and components in the tyre products as well as in industrial and consumer rubber good applications.

History and background of rubber reinforcement

The earliest rubber products utilizing reinforcements were flat cotton composites like waterproof garments. The next development steps were the development of hoses, and later on, pneumatic tyres. The first tyres were based on a tube strapped to the wheel by means of rubberized fabric. Later, the inner tube with a separate outer tyre was evolved. The outer tyre was made from layers of square woven cotton canvas and rubber, with wire beads to hold it in place on the rim. In
the first decennia of nineteenth century, the canvas was replaced by cord fabrics, and during the same times carbon black was starting to be used in tyres, leading to doubled life of the tyres (mileage at that time being about 6000 km).

To further improve tyre performance, new artificial fibre, rayon, for the reinforcing plies of fabric was to be employed. When using cotton, there had been no problem in adhering the rubber to the textile inserts. The search to find a system to improve the adhesion led to the development of adhesive dips. These were originally based on natural latex and casein, but soon the casein system was replaced with a resorcinol/formaldehyde resin and later, especially when rayon and polyamide were introduced, ter-polymer lattices, containing e.g. vinyl pyridine as the third monomer, were developed to give improved adhesion.

With the introduction of polyester the standard RFL systems did not work. The first systems found to give good adhesion to polyester were based on very active isocyanates from solvent solution, and later, aqueous based process was achieved. In the 1970’s, the use of newly introduced aramid fibres necessitated the development of new adhesive systems.

The development history of fibres and their application (esp. tyres) are given in table 1.

Table 1.

<table>
<thead>
<tr>
<th>Fibre/cord</th>
<th>Introduced</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton (Square Woven)</td>
<td>1900</td>
<td>Staple fiber - No treatment needed</td>
</tr>
<tr>
<td>Cotton (Cord)</td>
<td>1920</td>
<td>Staple fiber - No treatment needed</td>
</tr>
<tr>
<td>Wire (Europe)</td>
<td>1937</td>
<td>Copper plating for adhesion</td>
</tr>
<tr>
<td>Rayon</td>
<td>1938</td>
<td>Stretch and adhesive RFL/NR</td>
</tr>
<tr>
<td>Nylon (Military)</td>
<td>1942</td>
<td>Stretch/heat set plus adhesive</td>
</tr>
<tr>
<td>RFL/VP: SBR</td>
<td>1947</td>
<td>Stretch/heat set plus adhesive</td>
</tr>
<tr>
<td>Nylon (Commercial)</td>
<td>1947</td>
<td>Stretch/heat set plus adhesive</td>
</tr>
<tr>
<td>Wire (USA)</td>
<td>1955</td>
<td>Copper plating for adhesion</td>
</tr>
<tr>
<td>Polyester</td>
<td>1962</td>
<td>Stretch/heat set plus adhesive RFL/ Blocked isocyanate</td>
</tr>
<tr>
<td>Fiberglass</td>
<td>1967</td>
<td>Adhesive - RFL</td>
</tr>
<tr>
<td>Polyester (Hi Modulus)</td>
<td>1982</td>
<td>Stretch/heat set plus adhesive RFL/ Blocked isocyanate.</td>
</tr>
</tbody>
</table>

In 1980’s and later the development of e.g. polyethylene naphthalate (PEN), polyvinyl alcohol (PVA), as well as liquid crystal polymer (LCP) fibres, glass, carbon and steel wire fibres has offered new opportunities to high performance rubber product development.

With each new reinforcing agent, either synthetic polymer or metal wire/cord type introduced, special adhesive systems had to be developed, in order to obtain
the optimum performance from the rubber composite products. Today, composites are available which satisfy even the most stringent performance requirements met under the widely varying application fields of elastomer based products.

**Definitions**

In order to understand and use unambiguous terms relating to reinforcing fibre concepts, the following list of definitions is useful:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>Air at local atmospheric pressure with a relative humidity of 65% and temperature of 20°C. Standard atmosphere for physical testing is maintained within the following limits: relative humidity ± 2% and temperature ± 2°C.</td>
</tr>
<tr>
<td>Fibres</td>
<td>Linear macromolecules oriented along the length of the fibre axis.</td>
</tr>
<tr>
<td>Filament</td>
<td>The smallest continuous component in a textile or steel cord composing the strand or cord.</td>
</tr>
<tr>
<td>Yarn (Strand)</td>
<td>Filaments assembled so as to form a continuous strand.</td>
</tr>
<tr>
<td>Folded yarn (plied yarn)</td>
<td>A yarn in which two or more single yarns are combined by a single twisting.</td>
</tr>
<tr>
<td>Cord</td>
<td>A structure composed of two or more strands used as plied yarns or as the end product.</td>
</tr>
<tr>
<td>Dip</td>
<td>A chemical composition applied to a cord to improve its adhesion to rubber.</td>
</tr>
<tr>
<td>Warp</td>
<td>Cords that run lengthwise in a tire or other rubber product such as a conveyor belt.</td>
</tr>
<tr>
<td>Weft (Pick)</td>
<td>Cords in a fabric running crosswise to the direction of the warp.</td>
</tr>
<tr>
<td>Filling</td>
<td>The light threads that are placed at right angles to the warp cords; also referred to as the pick.</td>
</tr>
<tr>
<td>Rivet</td>
<td>Distance between cords in a fabric. A fabric with a low number of cord ends per width of fabric has high rivet.</td>
</tr>
<tr>
<td>Twist</td>
<td>The helical disposition of the components of a single, folded or cabled yarn. Twist is in the S (or Z) direction when spirals of the yarn held vertically slope in the same direction as the middle part of the letter S (or Z).</td>
</tr>
<tr>
<td>Wrap</td>
<td>A filament helically wound around a steel cord.</td>
</tr>
</tbody>
</table>
### Lay
Lay is the helical disposition of the components of a strand or cord.

<table>
<thead>
<tr>
<th><strong>Lenght of lay</strong></th>
<th>The axial distance required to make a 360 degrees revolution of any element in a strand or in a cord, expressed in millimetres.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Denier</strong></td>
<td>The mass per unit length of cord expressed in grams per 9000 m.</td>
</tr>
<tr>
<td><strong>Decitex</strong></td>
<td>Similar to denier but describes the mass of cord in grams/10 000 m.</td>
</tr>
<tr>
<td><strong>Tenacity</strong></td>
<td>Cord strength. Strength may also be defined by the term tenacity. It is a measure of the tensile strength of the cord and can be expressed in grams per denier (= Force divided by linear density).</td>
</tr>
<tr>
<td><strong>LASE</strong></td>
<td>Load applied to a cord for a specified elongation (load at specified elongation).</td>
</tr>
<tr>
<td><strong>Standard condition</strong></td>
<td>A sample is in a “standard condition” or “conditioned” for testing purposes when it has been kept in the atmosphere for testing until moisture equilibrium has been reached.</td>
</tr>
<tr>
<td><strong>Breaking force</strong></td>
<td>Maximum force applied to a test specimen carried to rupture during a tensile test.</td>
</tr>
<tr>
<td><strong>Shrinkage</strong></td>
<td>The decrease in length of test specimen caused by boiling water or hot air treatment, expressed as a percentage of the untreated test specimen.</td>
</tr>
<tr>
<td><strong>Tensile strength</strong></td>
<td>Strength per unit cross section (Pa)</td>
</tr>
</tbody>
</table>

*1 tex = 0.11 denier = 1x10^{-6} kg/m; 1 tex = weight in grams of 1000 meter filament

### Direction of lay

Lay is the helical disposition of the components of a strand or cord. The strand or cord has an "S" or lefthand lay if, when held vertically, the spiral around the central axis of the strand or cord conform in direction of slope to the central portion of the letter "S"; and "Z" or right-hand lay the spirals conform in direction of slope to the central portion of the letter "Z"(see figures below).
The lay of a strand or cord are designated according to the undermentioned general rules:

- strand used as an end product: S
- ordinary or regular lay cord:
  - Lang's lay cord (LL): strand and cord S strand S
  - Lang's lay cord (LL): strand and cord S cord Z
- spiral wrap: opposite to the direction of the cord lay
I. TEXTILE REINFORCEMENT

1. Production and properties of textile yarns

There are at present five main types of organic fibres used in reinforcements for rubbers. Cotton is still in use in many applications, but is more and more replaced by synthetic fibres. It is worth mentioning that in Europe, the term synthetic is used only when referring to fibres in which the fibre-forming polymer is not of natural origin. Thus in Europe, e.g. rayon, which is based on naturally occurring cellulose, is classified as man-made or artificial but is not considered to be a synthetic yarn. Rayon, the first of the successful artificial fibres, is chemically very similar to cotton, but the various processes introduce certain differences in properties between the two. The first truly synthetic fibres polyamides (both PA 6.6 and PA 6) offer certain advantages over the cellulosic fibres. On the other hand, polyester has the strength similar to nylon, but has a higher modulus. The aramids, with considerably higher strength and modulus, are the latest reinforcing yarns. They have relatively high cost, but e.g. their strength/cost ratio, comparable with steel wire has made their applications steadily increasing. A relatively new fibre family in rubber reinforcing field, PEN, is emerging to the market in the applications where good heavy duty properties are required.

1.1 Production methods of textile fibres

1.1.1 Cotton

In order to bring about cotton fibres, starting from the harvesting state (about 600 kg/ha), many different stages have to be carried out. Just to mention the main measures, the phases to produce cotton fibres to be used as reinforcing component in elastomer products are

- picking and separating of seeds and fibres with gin (special machine)
- baling
- spinning with a mill
  Bale Breaking
  Opening and Cleaning
  Carding
  Drafting
  Spinning: in the final stage, the required level of twist is achieved

Properties of Cotton

Cotton is a 100 % natural cellulose (structure, see figure 1) fibre. Cotton absorbs humidity from air (approximately 8 %) and swells in water, but the wet strength of the yarn can improve up to 20 % from that in the dry state. When drying, the properties revert to the original.
Cotton has generally good resistance to heat up to 150 °C, but on prolonged exposure between 100 °C and 150 °C and above 150 °C, it will lose strength. The decomposition starts at around 230 °C. Cotton burns readily, but in low oxygen concentration it will chars and leaves a carbon skeleton.

As to the chemical resistance of cotton, even traces of acid, not properly washed out, can lead to a severe loss of strength. Cotton will dissolve in some mineral acids, e.g., 70 % sulphuric acid, and this is usually accompanied by chemical decomposition. Cotton is resistant to alkali, but will swell. If cotton yarns are stretched in fairly concentrated alkali, the fibres swell, introducing certain re-orientation of the molecular structure, which results in an improved strength and a more glossy appearance (mercerisation process). Cotton is not affected by usual hydrocarbons, aromatic or chlorinated solvents.

**General properties of cotton:**

- Density of cotton $1.54 \text{ g/cm}^3$
- Strand $0.1 – 0.2 \text{ tex}$
- Advantage: inexpensive, wet strength, heat resistant, good adhesion
- Disadvantage: weak, soft, mildew, hygroscopic (7 %), fatigue, quality variations

### 1.1.2 Rayon

Rayon is a modified, regenerated cellulose fibre. The cellulose raw material can originate from cotton, or more usually, wood pulp. During the viscose rayon process there is some degradation of the polymer, giving lower molecular weight (approximately 200 – 300 repeating units, compared with some 2000 units in cellulose).

In the production starting from the wood pulp, the pulp is boiled with caustic soda, to give soda cellulose. In the next stage, this sheet is crumbed and treated with carbon disulphide, with which it reacts to give sodium cellulose xanthate. This is then dissolved in dilute caustic soda to give the spinning solution.
At the spinning stage, the solution is filtered and pumped through spinnerets (usually made of highly corrosion resistant material, e.g. platinum) into the coagulant bath. This extruding process of polymer solution into a coagulation bath, is known as a wet spinning process. The coagulant bath for the standard rayons consists of approximately 10 % sulphuric acid. The wet spinning process, which is used for rayon, is also used with e.g. aramides. The wet spinning contains the main steps described in figure 2. General spinning alternatives are shown in figure 3.

After spinning, the yarn is washed and dried, and wound up onto delivery packages to the converters.

Instead of the original batch process, the viscose rayon process today is typically a high speed continuous process, giving a very consistent product.

The majority of all rayon at reinforcement is used as continuous filament, but there is still some use of spun staple rayon.
Figure 3. Schematic of the three principal types of fibre spinning: (a) melt spinning; (b) dry spinning; (c) wet spinning. [After Carraher, C. E., Jr. 2002. Polymer News, 27, 3, 91]

General properties of Rayon

Similarly to cotton, rayon swells in water, but the wet strength of rayon is some 30% – 40% lower than the dry fibre. The tensile properties of regular and wet rayon and cotton are shown in figure 4 (Obs. Polynosic rayon yarn, having higher tenacity and lower swell than standard viscose rayon, through modification of the spinning process). As with cotton the strength is reversible on drying, if the yarn is not allowed to shrink. Standard moisture regain of rayon is 13%.

Rayon is generally heat resistant up to about 150 °C, but loses strength on prolonged exposure and more rapidly at higher temperatures. It starts to decompose at around 210 °C. Rayon burns readily but as with cotton, rayon will char in oxygen starved atmosphere and leave a carbon residue.

The susceptibility of rayon to acids is very similar to that of cotton. The same is true with reaction of rayon to alkali, but rayon will lose some strength on swelling in concentrated alkali.

Rayon is susceptible to microbiological attack, but the absence of the small amounts of naturally occurring proteins found in cotton, and the presence of traces of chemicals from the manufacture, render rayon slightly more resistant than cotton.

Identification: Rayon burns readily with the characteristic burnt paper smell; with Shirlastain A, gives a pink colour in the cold and purple on boiling.
- Density 1.52 g/cm³
- Strand 0.17 – 0.18 tex
- Yarn 122, 184, 244 tex
- Advantage: renewable, good dimension stability (at elevated temperatures)
- Disadvantage: mechanically weak, hygroscopic (11%)

**Figure 4. Stress–strain curves of a) regular rayon types and cotton after process conditioning and b) wet rayon and cotton.** [Regenerated Cellulose Fibers, Richard Kotek, in Handbook of Fiber Chemistry Third Edition, Edited by Menachem Lewin]

**Special Rayons**

As for all synthetic fibres, also many special types of Rayon have been developed. Especially for tyre reinforcement purposes there is e.g. a special type of cellulose-based filament (Lyocell), which is announced to have high dry/wet strength, good dimensional stability and physical properties even in high temperature, and adhesive force over the rubber. The recommended applications are Ultra High Performance Tire and Run Flat Tire [http://pi.hyosung.com/pi_eng/tire/tire_cord/tirecord_04.jsp].

**1.1.3 Polyamides (PA, Nylon)**

Nylon is the generic name for the linear aliphatic polyamides. There are two main types of PA’s, PA 6 and PA 6.6, used as fibre form. The polyamide 6 is derived from caprolactam, which contains 6 carbon atoms, hence giving the designation nylon 6, with formula $-[\text{NH}(\text{CH}_2)_6\text{CO}]_n^-$. Nylon 6.6 is obtained from the polycondensation of hexamethylene diamine and adipic acid, each monomer containing six carbon atoms, so giving the designation of nylon 6.6, $-[\text{NH}(\text{CH}_2)_6\text{NHCO}(\text{CH}_2)_4\text{CO}]_n^-$. 

15
**Nylon 6**

After the polymerization, thermoplastic Nylon 6, as well as Nylon 6.6, can be melt spun and drawn to make the fibre.

In addition to multifilament yarns, using many fine holes in the spinneret, monofilaments with diameters up to 2.5 mm are produced. The thinner monofilaments are used in the production of industrial fabrics, particularly for filtration fabrics. The heavier diameters are used e.g. for stringing tennis and squash rackets.

**Nylon 6.6**

Nylons are thermoplastic, and so melt spinning technique can be used to produce fibres from the synthesized polyamide. The polymer is melted and forced through the fine holes of a spinneret. The fibre is formed on cooling. When emerging from the spinneret, the polymer starts to solidify immediately. At this stage the filaments are pulled away and stretched by between four to six times their original length. This drawing stage brings about considerable orientation and alignment of the polymer molecules, resulting in the formation of crystallites, which crystalline structure significantly affects the final properties of the yarn. By control and adjustment of the degree of stretch at this stage, and by selection of the molecular weight distribution, it is possible to vary considerably the main properties of the yarn, such as strength, modulus and thermal shrinkage.

The principle of melt spinning process, which is used in addition to introduce polyamide fibres, eg with polyesters, is described in Figure 5. The melt spinning process is described in Figure 6.

![Figure 5. The phases of melt spinning to produce raw (flat) fibre](image-url)
Properties of PA6 and PA 6.6

The chemical properties of both PA 6 and PA 6.6 are very similar.

Polyamide fibres are not significantly affected by water. A slight drop in tenacity when immersing in water is fully reversible on drying. The standard regain of nylon is 4.5 % of water.

Nylon is generally quite resistant to heat up to temperatures of 180 °C (unless exposed for prolonged periods). Nylon 6.6 melts at 250 °C and nylon 6 at 225 °C.

On burning, nyons burn less readily than cotton and rayon and tend to melt away from the flame. Nylon fibres have a tendency to be self-extinguishing. However, in bulk, a molten mass will burn fairly readily. On burning, nylon has a characteristic celery-like odour.

Nylon has good general resistance to acids, but will disintegrate on heating with concentrated acids. Nylon is soluble in boiling 80% acetic acid and in formic acid at room temperature. Nylon is resistant to alkali.

Nylon is not affected by the standard hydrocarbon, aromatic or chlorinated solvents. Nylon is soluble in phenols, especially in-cresol.
Nylon 6.6 and 6 can be differentiated by their reaction to boiling dimethylformamide; nylon 6.6 is soluble while nylon 6 is insoluble.

In Shirlastain A (typical recognition method for polymers) it gives a dull yellow colour in the cold, which deepens to orange on boiling.

**General properties of melt spun Nylons:**

- Density $1.14 \text{ g/cm}^3$
- Strand 0.7 tex
- Yarn 47, 70, 94, 140, 188, 210 tex
- Advantage: strong, good fatigue and high temperature resistance, stiffness, water resistant
- Disadvantage: bad dimension stability at elevated temperatures, creep, bad adhesion

As in the case of most polymer fibres, the processing parameters influence quite drastically on the end-use properties of the fibres. For instance the spinning speed and draw ratio in fibre processing affect strongly on the properties of achieved fibres. The figure 7 below shows an example of polyamide spinning two phase spinning, Figure iii describes the influence of drawing ratio in the spinning process of PA 6.


Linear aliphatic polyamides are partially crystalline materials. Therefore they are characterized by both an unordered amorphous state and an ordered crystalline state. The crystalline phase may exhibit polymorphism, i.e. it can have several crystal structures. The extent of each state or specific modification depends, for a given chemical structure, considerably on processing conditions and treatment operations. It affects the properties of the shaped polyamide product. Thus the
corresponding structure parameters are of importance for optimizing fibre processes as well as for assessing the performance of fibre products in particular applications.

Together with the crystallinity degree the degree of orientation (which on the other hand is strongly dependent on crystallinity) plays an important role in polyamide fibres as well as in all polymeric fibres and yarns.

Table 2. Typical Properties of Nylon 6 and Nylon 6,6 Fibers [Polyamide Fibers, H.H. Yang, in Handbook of Fiber Chemistry Third Edition, Edited by Menachem Lewin]

<table>
<thead>
<tr>
<th>Polymer type</th>
<th>Nylon-6</th>
<th>Nylon-6,6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Staple</td>
<td>Regular</td>
</tr>
<tr>
<td>Molecular weight (g/mol)</td>
<td>20000–30000</td>
<td>12000–20000</td>
</tr>
<tr>
<td>Glass transition temperature (°C)</td>
<td>65–75</td>
<td>65–80</td>
</tr>
<tr>
<td>Melt temperature (°C)</td>
<td>210–230</td>
<td>255–265</td>
</tr>
<tr>
<td>Ignition temperature (°C)</td>
<td>530</td>
<td>530</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Moisture regain (%)</td>
<td>4.0–5.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Tenacity (GPa)</td>
<td>4.2–5.9</td>
<td>4.9–5.7</td>
</tr>
<tr>
<td>Wet</td>
<td>3.5–5.0</td>
<td>4.8–5.3</td>
</tr>
<tr>
<td>Wet/dry tenacity ratio (%)</td>
<td>81–90</td>
<td>90–95</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>84–92</td>
<td>85–90</td>
</tr>
<tr>
<td>Dry</td>
<td>38–50</td>
<td>24–40</td>
</tr>
<tr>
<td>Wet</td>
<td>40–53</td>
<td>24–40</td>
</tr>
<tr>
<td>Recovery at 3% elongation (%)</td>
<td>95–100</td>
<td>95–100</td>
</tr>
<tr>
<td>Initial modulus (GPa/m²)</td>
<td>0.91–2.45</td>
<td>3.86–4.38</td>
</tr>
</tbody>
</table>

1.1.4 Polyester (PET)

There are two main methods for the polymerizing of polyester polymers for textile applications. Widely used route, especially in Europe is an ester interchange via dimethyl terephthalate (Figure 8a), while especially in the USA, the direct esterification of the acid with ethylene glycol is the more favoured method (Figure 8b).

![Ethylene glycol](image1) ![Polyethylene terephthalate](image2)

**Figure 8. Polyester preparation via Ester interchange (a) and direct esterification (b).**

After polymerisation, the polymer passes through melt spinning and drawing stages, as for the polyamides.
A considerable proportion of the polyester is used as spun, but because of problems with adhesion, there is also a requirement for pretreated yarns. For these, the filaments are treated at the spinning stage to modify the surface of the polyester, e.g. with epoxy derivatives. The epoxy pretreated fibre surface creates adhesion with standard RFL dips, as used for nylon. In context of the surface treatment of polyester, also heat treatment can be carried out, to reduce the normal shrinkage level of 10% – 12%, to values between 2% and 4%, which offers advantages in many processes.

**Typical PET processes**

The end-use properties of polyester fibres and yarns depend strongly on the spinning process applied, as well as on the spinning speed and surface finishing of the cord and yarns. The following three pictures illustrate typical PET processes and the influences of processing on the fiber properties. In Figure 9 the melt spinning process and finished yarn take-up are described. In Figure 10 the morphology development in PET melt spinning, and in Figure 11 morphology development as a function of key spinning parameters are illustrated. The figures 10 and 11 demonstrate the wide range of fibre structures and properties available through the adjusting of fibre process parameters.

*Figure 9. Key elements of polyester filament yarn melt-spinning machine. [Handbook of Fiber Chemistry Third Edition, Edited by Menachem Lewin]*
Properties of Melt Spun Polyesters

Polyester is generally far more stable and less reactive than would be expected in view of the presence of ester groups, the PET ester groups being much less reactive than the simple aliphatic esters.

Polyester is quite water resistant. It is losing a few per cent of its tenacity when immersed in water at ambient temperatures, but returning to its original properties on drying. The standard regain of polyester is 0.5 % water. Boiling water and steam will cause polyester to shrink and can also cause some slight permanent loss of strength, due to hydrolysis.

Polyester is not greatly affected by (dry) temperatures of up to 180 °C, except on prolonged exposure. The melting point of polyester is 250 °C.
On burning, its melt tends away from the flame and burns with a smoky flame with a slightly sweet odour.

Polyesters are resistant to the standard hydrocarbon, aromatic and chlorinated solvents. It is soluble in phenols and in other solvents at their boiling points including cyclohexanone, benzyl alcohol, nitrobenzene and dimethyl phthalate. Polyester will dissolve in boiling concentrated alkali and boiling ethylene glycol, although in these cases, solution is due to de-polymerisation rather than to true solvent action.

Polyester is not susceptible to microbiological attack and gives slight fluorescence under ultraviolet light.

**General properties of PET:**

- **Density** 1.33 g/cm$^3$ (amorphous, undrawn), 1.39 g/cm$^3$ (crystalline drawn fiber)
- **Strand** 0.6 tex
- **Yarn** 110, 144, 167, 220 tex
- **Advantage:** strength, stiffness, dimension stability at high temperatures, water resistant
- **Disadvantage:** weak adhesion, aminolysis

**Height-perfprmance polyester fiber: polyethylene naphtalate – PEN**

The polyester derived from ethylene glycol and naphthalene-2,6-dicarboxylic acid (polyethylene naphtalate) has a much higher T$_g$ than PET and gives strong, high-modulus fibers. The development work of e.g. ICI, Honeywell, Amoco, High Performance Fibers Inc and Hyosung has aimed especially at good cord qualities for lightweight tyres with more advanced driving properties. These PEN fibres feature heat resistance, low elongation and shrinkage, dimensional stability, and high tenacity. The mentioned features give them additional value also in designing high speed flexing mechanical belts, transmission belts in new generation automobiles, special hoses, and conveyor belts.

In the picture (Fig. 12) below the properties of ordinary polyester fibres and PEN fibres have been compared [Hyosung].
There are specially treated PEN qualities where the fibre is modified to be adhesion friendly with an adhesive top coat [High Performance Fibers Inc]. New more advanced stable-type (High Modulus Low Shrinkage) polyester tire cord called HSP polyester has been developed, too. The development trends can be seen in figure 13 below [Hyosung].

### 1.1.5 Aromatic Polyamides: Aramids

The aramids are closely related to the aliphatic polyamides. The substitution of the aliphatic carbon backbone by aromatic groups brings about considerable changes in the properties of the resultant fibres.

The first commercial fibre of this class was Nomex from DuPont. This yarn is of only medium tenacity, but is non-flammable and widely used for the production of fireproof clothing, etc.
After launching of Nomex very high strength yarns were developed, under the trade names of Kevlar (from DuPont) and Twaron (from Akzo Nobel Fibres). The principally simple polymerization routes of the polyaramids are shown in Figure 14.

![Figure 14 Polymerization of aramids](image)

The major problem to be overcome in the production of the aramid yarns, was to find out the right solvent systems for polymerisation and for spinning, because aramids cannot be melt spun. In order to develop the optimum fibre properties, the yarns spun from the solvent required considerable after-treatment.

The spinning processes applied at present utilise combined dry jet and wet spinning system [E.I. DuPont de Nemours & Co Inc., GB Patent 393011, 1971], where the spinning solution is extruded through the spinneret just above the coagulant bath. As a result of this, the as-spun yarns are superior to the yarns by previous processes, and after-treatments are not necessary. Some special high modulus aramid yarns give higher strength with lower weight than standard glass reinforced polymer products.

**Properties of aramids**

The aromatic polyamides are remarkably more inert than the aliphatic nylons.

There is no significant effect on the properties of aramid on immersion in water. The standard regain of aramid is 2.0%.

Aramid is practically not affected by temperatures up to at least 250 °C. Aramid does not burn but starts to decompose on heating at temperatures of around 500 °C.

Aramids are resistant to normal acids and alkalis, but will dissolve in boiling concentrated sulphuric acid.

The exceptionally inert aramids will dissolve in boiling concentrated sulphuric acid and in certain mixed solvent systems based on amides and alkali chlorides.

Aramid loses progressively strength by ultraviolet light exposure and needs so chemical protection.
Two commercially available aramids, Kevlar (from DuPont) and Twaron (from Akzo Nobel Fibres), are yellow in colour, they do not burn and are not stained by Shirlastain A.

**General properties of aramids:**

- **Density** 1.4 g/cm$^3$
- **Filament** 0.1-0.38 tex
- **Advantage:** high strength, stiffness, dimension stability
- **Disadvantage:** high density, weak adhesion, low fatigue resistance

Comparison of two commercial aramid grades with other polymer fibres, glass fibres, steel wires and high tenacity carbon is shown in Table 3 [Technical Information/Kevlar/DuPont].

![Table 3. Comparative Properties of KEVLAR® vs. Other Yarns](image)

1.1.6 Physical properties of textile fibres

The main physical properties of the textile fibres and for comparison, glass and steel are given in Table 4.

The major differences between the textile fibres and the inorganic materials lie in

- specific gravities (those of the textiles lying between 1.0 and 1.5 g/cm$^3$, whereas glass density is 2.5 g/cm$^3$ and steel at 7.85 g/cm$^3$)
• tensile strength, (the organic fibres are much weaker than glass or steel, with the exception of aramids)
• the tenacity of nylon and polyester is similar to glass, tenacity of steel lying between cotton and rayon
• the modulus values of the inorganic materials, with the exception of aramid, are higher than the modulus of organic fibres.

The stress-strain curves of the fibres are given in Figure 15.

Table 4. Physical properties of textile fibres, compared with glass, steel and carbon fibre [RAPRA, Nokia Tekninen kumi: Elastomeerein mahdollisuus]

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Polyamide</th>
<th>Cotton*</th>
<th>Rayon (Polynosic)</th>
<th>Nylon 6</th>
<th>Nylon 6.6</th>
<th>Carbon Fibre</th>
<th>Polyester</th>
<th>Aramid</th>
<th>Glass</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.54</td>
<td>1.52</td>
<td>1.14</td>
<td>1.14</td>
<td>1.80</td>
<td>1.38</td>
<td>1.44</td>
<td>2.54</td>
<td>7.85</td>
<td></td>
</tr>
<tr>
<td>Mean filament diameter (µm)</td>
<td>15</td>
<td>8</td>
<td>25</td>
<td>25</td>
<td>-</td>
<td>25</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mean decitex per filament</td>
<td>1.6</td>
<td>1.8</td>
<td>6.7</td>
<td>6.7</td>
<td>-</td>
<td>5.7</td>
<td>1.7</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>230</td>
<td>685(850)</td>
<td>850</td>
<td>950</td>
<td>3400</td>
<td>1100</td>
<td>2750</td>
<td>2250</td>
<td>2750</td>
<td></td>
</tr>
<tr>
<td>Tenacity (cN/Tex)</td>
<td>15</td>
<td>40 (50)</td>
<td>80</td>
<td>85</td>
<td>190</td>
<td>80</td>
<td>190</td>
<td>85</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>8</td>
<td>10(6)</td>
<td>19</td>
<td>16</td>
<td>1.4</td>
<td>13</td>
<td>4</td>
<td>5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Initial modulus' (cN/Tex)</td>
<td>225</td>
<td>600(800)</td>
<td>300</td>
<td>500</td>
<td>-</td>
<td>850</td>
<td>4000</td>
<td>2150</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>Shrinkage at 150 °C (%)</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>11</td>
<td>0.2</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
2. Yarn and Cord Processing

As a rule, it is a necessity to modify the yarn, in order to obtain the optimum benefit from their incorporation as reinforcement in elastomeric composites.

Depending on the product to be reinforced, either single-end yarns or cords (several twisted yarns twisted together) are the preferred form, or in some cases (particularly in tyres) cord-fabric form, where the cords have been assembled together into a woven cord-fabric. For most other applications, woven fabrics constructions are applied, and it is generally necessary to modify the yarn, rather than using them in as-produced form.

2.1 Yarn Preparation

The single yarns from the production stage exist as individual, coherent threads, containing many individual filaments or fibres. The most common methods of obtaining the required structure of yarn are twisting and texturing. For some fabrics, a chemical modification in the form of sizing is employed for the warp yarns (weaving: interlacing of two sets of yarns, warp and weft).
2.1.1 Twisting

The twisting of yarns and the doubling of them together is to give plied yarns, are usually performed on ring-doublers (see Figure 16 a and b).

*Figure 16 a) Twisting of textile yarns to give 2-ply cord. Remark also the twist directions [Acron course at Nokian Tyres Plc]. b) twisting and weaving up machine, twister cabler [Hyosung].*

Purpose of twisting:

- to prevent filament breakage
- filaments are more firmly held, which gives greater resistance to damage from abrasion
- improved compactness and coherence of yarns
- to improve fatigue resistance
- to improve weaving workability

The standard unit of twist is turns per metre (tpm).

It is possible to assemble several single yarns together, into a plied coherent yarn, by feeding these together to the twisting frame. Such yarns enable the incorporation of a higher volume of yarn into the final structure. Only a certain number of single yarns can be placed side by side, but by increasing the number of singles in each yarn, it is possible to increase the number of single yarns in the same width.

The different forms of yarn, singles, as produced (flat) and twisted, and plied constructions are illustrated in Figure 17 [Matador book].
In the figure 17, the individual filaments of the single flat yarn (uppermost picture) do not significantly bind into the yarn and are therefore liable to be caught and damaged. The twisted single yarn (centre picture) shows the effect of twist in producing a more compact and coherent yarn, holding individual filaments together in the final thread. In plied yarn (lowest part of the picture), several individual single plied flat twisted yarns, give a coherent and compact structure. Individual single yarns can be also twisted in one direction and then twisted together in the opposite sense in the cable, introducing a yarn, in which the tendency to twist up on itself is minimized.

It is possible to prepare twisted cords in two or one phase. The difference between these methods are shown in Figure 18 [Acron]. In this picture, also the designation of the resulting cords are shown, as an example.

Typical applications for twisted and plied yarns are
- basic components of woven fabrics
- large-bore hoses
- V-belts
- tyres

To bring about heavier cords, the cabling operation can be applied to already plied and twisted yarns. With cabled cords, higher levels of twist can be used, in order to obtain good resistance to dynamic fatigue, and in dense, circular cross-section cords. In order to achieve a properly balanced cord, a fundamental principle to get adequate helix angle is given by the formula

$$Twist \ (\text{turns/meter}) \times \sqrt{\text{Linear Density}} = \text{Constant}$$

The linear density should be based on weight per unit length, such as decitex.
In the plying of single yarns, there is usually some loss of strength, that is, a two-fold yarn will not have the same strength as two single yarns. The level of this loss of strength is called, the conversion efficiency of the doubling. In addition to tensile strength and elongation at break, also other properties are altered by doubling. In principle, the higher the twist, the lower the conversion efficiency. This is due to the effective increase in linear density, arising from the twisting operation which results in a drop in tenacity, greater than the corresponding loss in absolute strength.

Apart from fatigue resistance requirements, also other factors influence on the correct levels of twist for any specific application. In yarns used for fabrics, low levels of twist are most usual, the twist serving mainly to hold the single or plied yarns together. For the cabled constructions with higher twist, there is the need to balance the twist in the successive operations, so that the final cord does not twist up on itself.

As to the direction of twist, at low levels of twist, the direction of twist has little effect. However, when dealing with high-twist and cabled cords, the selection of twist direction is very important. In order to obtain a balanced cabled cord construction, it is essential that the twist directions in each successive throw be reversed, otherwise if the same direction were used, the resultant cord would be very lively and difficult to handle. Generally, there is no rule, other than conventional practice, as to the direction of twist to be selected.

It is often desirable to combine together fibres of different types, to obtain certain specific properties. There are three main alternatives to carry out the combining:
1. Mixing together different staple yarns at the beginning of the spinning process, e.g. polyester/cotton blends
2. Combining together of a high strength continuous filament yarn with a weaker but bulkier spun yarn (e.g. combined doubling of cotton with nylon).
3. Two dissimilar fibres can be fed together at the spinning stage, the continuous filament yarn (e.g. polyester) being fed forward and the other, staple portion (e.g. cotton) is drafted down and spun around the continuous filament core.

Some special procedures have been developed, for instance, a system in which the single yarns are wrapped with a light helically laid binder yarn by feeding through a hollow spindle and bound together into a coherent form. By using this kind of system, very heavy yarns with good strength characteristics, can be produced.

2.1.2 Texturing

In the texturing procedure the continuous filaments of the yarns are tangled and looped together, giving a bulky and coherent yarn.

There are two main systems used for texturing yarns for industrial applications, air texturing and false-twist texturing.

The texturing processes modify the properties of the yarn significantly, not just in bulk and linear density, but also reducing tensile strength, increasing elongation and increasing the inter-yarn frictional properties. The drop e.g. in tensile strength is quite significant, but this is generally acceptable, as the other benefits of texturing outweigh this. Frequently also textured synthetic yarns are used as a replacement for spun staple yarns, such as cotton, and the resultant strength is still higher than with the natural fibre yarn.

2.1.3 Weaving and sizing

For many industrial reinforcement applications, it is desirable to assemble the yarns together into a coherent form using various weaving or knitting techniques and designs.

The majority of rubber reinforcements are based on weaved fabrics, although e.g. knitting or non-woven systems can offer certain advantages for special applications.

The main operating principle of – even modern weaving machines – is to achieve the interlacing of two sets of yarns (warp and weft) at right angles to one another, to produce a fabric.

For certain applications, it is desirable to apply a size to the yarns to facilitate the weaving process. The size (e.g. starch derived product or a synthetic polymer, such as polyvinyl acid), protects yarns from abrasion and assist to hold the filaments together during weaving.
Design of woven fabrics

In selecting a fabric for a specific application, three main questions have to be answered:

1. What are the physical property requirements? Are there any special requirements?
2. Which fibre type and grade should be used?
3. Which kind of fabric construction should be selected?

Physical properties of woven fabrics

Generally, the most important property of woven reinforcement is strength, which is strongly dependent on the application. For example, conveyor belting is usually designed to operate at 10% of the nominal breaking strength, while for hoses the operating level is typically 15 – 20%. When more than one layer or ply of textile is applied, each ply will only contribute approximately 70 – 80% of its stand-alone strength.

For instance, elongation, flexibility, fatigue resistance, tear strength, heat resistance can be extra selection criteria in addition to strength properties.

Fibre type

A wide selection of fibre materials is available, so that a very wide range of physical properties of fabrics can be achieved. In the first stage, the general strength and elongation requirements frequently restrict the choice of materials. The final selection of the fabric applied is frequently governed by the special requirements of the final product, such as the need for heat resistance or chemical resistance. As a rule, the economic considerations influence in the selection, too.

In order to assist the fibre material selection, designation systems have been devised. In these systems, both fibre types used and the strength rating are denoted in the fabric designation system (example, see Table 5, obs. abbreviations based on the German names). The nomenclature is used especially in conveyor belt design.

When starting the selecting of fibre, the most frequently used criteria is the ultimate strength. Typically however, the strength requirements can be met with a number of fibre types or combinations. In such case, e.g. the required modulus or elongation characteristics, adhesion properties, or heat and chemical resistance will indicate the correct fibres to be used.

Due to the processing of the fabrics to make rubberized laminates, there may be significant changes during processing, e.g. loss of width, and consequently influencing in strength. The influence of processing circumstances on the properties of woven fabrics and components made of these makes the rational selection of the fabric system quite complicated.
Table 5. Fabric designation system

<table>
<thead>
<tr>
<th>(A) Designation of fibre type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
</tr>
<tr>
<td>Z</td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(B) Code letters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>First capital: major component of warp yarn</td>
</tr>
<tr>
<td>Second capital: major component of weft yarn</td>
</tr>
<tr>
<td>Lowercase letters: secondary yarn components in warp/weft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(C) Strength designation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>First number: minimum warp strength (kN/m)</td>
</tr>
<tr>
<td>Second number: minimum weft strength (kN/m)</td>
</tr>
</tbody>
</table>

Selection of fabric construction

After having decided the required properties and the type of fibre, the fabric structure design has to be considered, i.e., the interlacing patterns of the threads. In this course module we do not inspect the numerous alternatives for fabric constructions, but just to indicate the number of alternatives, the most general types are mentioned:

- **Plain weave**

Simplest construction, where both warp and weft pass alternately above and below the threads in the other direction and out of phase with the adjacent yarns on either side, running in the same direction. Most ply belting and coating fabrics are plain weave.

- **Matt weave**

Modified plain weave to meet more strict strength requirements

- **Twill**

Warp and weft threads pass alternately over two and under two.

- **Leno weave**

In Leno weave, the warp ends are arranged in pairs, which are interlacing with the weft, and they also cross over each other. One of the pair always crosses over the top of the weft and the other under the weft. The major advantage of this weave is that the structure is very stable, with both warp and weft threads held firmly, allowing much more open fabrics to be produced. These fabrics possess good tear strength, and are often used as breakers, as an additional layer of fabric reinforcement, close to the
surface of the final composite, to impart improved tear and cut resistance to the final product.

- **Stress warp fabric structures**

For very high strength fabrics, e.g. for single- or two-ply reinforcement of belting,

- **Solid-woven fabric structures**

Solid-Woven Fabric Structures are weaved, when very thick and heavy fabrics are been produced.

- **Triaxial woven fabric structures**

Triaxial woven structures belong to the recent development in fabric constructions.

### 3. Rubber/textile composite assembly (Fabrication)

It is important to avert any contamination of the surfaces of the rubber compound or the textile on assembly of the composite. Contamination can seriously reduce the obtained adhesion. Direct calendering or spread coating is the best method to use, to ensure intimate and clean contact between the rubber and the textile surface.

All the precautions are required to avoid the migration to the surface, or blooming, of any of the ingredients, or any other surface deposits interfering with adhesion.

It is also important to avert any entrapment of air or volatile materials during the assembly. A spiked roller is often used to allow egress of air or profiled compaction roller, with a slight bow in the center, is used to push air to the outside of the composite which is assembled.

The most common volatile material is moisture. To eliminate any moisture absorbed by the textile materials containing cotton or rayon, must be dried before rubberising or assembly. The regain of nylon and polyester is normally sufficiently low for the moisture to cause any problem.

If nylon has been held under high temperature and very high humidity, a drying stage may be required before using the material.

It is important that all solvent, if solvents are used, is allowed to evaporate off before assembling the composite. Any surface treatment which are applied during prior processes to avoid the sticking together of sheeted rubbers, must be removed.
Coating and calendering are the two most important processes used to combine textiles and rubber.

### 3.1 Calendering

A simple three-bowl calender is shown in picture 19. Rubber compound is pre-warmed and then fed to the top nip, to give a rolling bank in the nip, with a sheet of rubber running around the bowl. The fabric to be calendered is fed into the lower nip, which presses the with the running rubber sheet. Cotton and rayon fabrics, and sometimes nylon fabrics must be dried before entering into the nip. This is normally done by passing the fabric over a set of heated rollers, at temperatures of around 100 – 120 °C.

The surfaces of the rollers must be clean to prevent any contamination of the fabric. Rollers should not be damaged, although only relatively low temperatures are used. Differential shrinkages may occur, if the fabric is not uniformly in contact with the heated surface, due to buckled roller etc. That might give loose stripes in the fabric, which could lead to wrinkling and compressing of the fabric in the calender nip.

Calendering can be done in two ways, frictioning and topping. If the centre bowl runs at a higher surface speed than the top and bottom bowls, it is called frictioning. Frictioning gives high heat build-up of rubber and a smooth, soft and thin layer of rubber running round the bowl. The speed different between the centre bowl with the rubber and the lower bowl and fabric forces the rubber to penetrate into the structure of fabric. One side frictioning gives usually satisfactory strike with synthetic fabrics. Both sides frictioning is needed with cotton fabrics to make sure adequate adhesion in the composite. If all the rolls of the calender run at the same surface speed, it is called topping. The rubber sheet is pressed onto the top of the fabric under the pressure of the nip.

Usually the rubber compound is topped onto both faces of the fabric. With three-bowl calender this means two passes or two of that kind in line. Two calender line requires a complicated threading system for the fabric to present the other side of the fabric to the latter calender. Nowadays 4-bowl calendars with different set-ups are mainly used for both side topping. Both sides of the fabric can be topped on one pass with modern 4-bowl calenders.
There are several parameters to be controlled during calendering. The behavior of the applied compound is the most important. The scorch and plasticity of the compound should be suitable for processing. The feed from warm-up mills must equal the rate at which the compound is being applied to the fabric. Too high feed rate increases rolling bank at the nip and too feed rate low gives inferior results with uneven thickness, uncovered areas and blemishes.

Calender bowl temperature must be controlled to give homogeneous coverage and surface smoothness. The tension of the fabric in the calender nip must be right. It is usually 2-3 % of the maximum strength of the fabric. Too low tension can lead to sagging of the fabric and that might cause folding or creasing. Too high tension can lead to uneven coverage or tight edges, which might cause sagging and creasing in center of the fabric and also bad quality line of the fabric.

Thickness of the rubber applied is probably the most critical parameter. High pressures are generated when passing rubber through the nip. These pressures cause the bowls to deflect. Bowls are set parallel when unloaded. Under pressure this deflection gives a rubber sheet, which is thicker in the middle. This deflection depends on plasticity of the compound, the processing width and the design of the calender. Most calender bowls are profiled to avoid overusage of the compound and to achieve as homogenous sheet as possible. That means that bowls are ground with a convex contour. Contour is a compromise solution and allows increased thickness in the middle. There are two ways to solve this problem. The first one is cross axial adjustment, which means that axis of one roll is rotated in the horizontal plane in relation to the other. That increases separation of the rolls at the outer ends and due to the bowl deflection decreases thickness in the center. The second one is roll bending, which means in the vertical plane the bearings of the bowl are tilted having an opposite deflection.
With old calendaring lines it requires skill to achieve a uniform covering of rubber on one or both sides of the textile. With the modern systems, which use thickness monitoring etc. it is much more easier.

The fabric is often cut on the bias after calendaring. It is normally cut at 45 angle and the portion is then turned 45 to align with previous section. The tack of the rubber holds sections together, it's called the butt joint. The bias fabric is often slit into narrowed widths for many applications.

### 3.2 Coating

Solvent coating or spreading is one method of combining the textile and the rubber. This is normally used for thin rubber coatings or applying an adhesive layer, other than RFL system.

Knife coating, using a dough, and lick roller coating are two basic systems of coating fabrics. In knife coating the rubber is chopped into small pieces and dissolved in specific solvent system. This viscous dough is applied to fabric and a knife controls thickness. There are three kinds of knife systems, knife on blanket, knife on air and knife on roller. It is also possible to control the degree of penetration of the coating into the fabric by modifying the knife. Acute and narrow knife is for thin, non-penetrating coating and wide and round knife is to increase penetration into fabric for thick coating. Only thin layer of rubber can be used in one pass. If thicker layer is needed, it is necessary to pass the fabric through the machine several times. In lick roller coating the rubber is less viscous than in knife coating. Rubber is applied indirectly by transfer from a roller immersed in the coating solution.

The solvent is always removed before further processing. Because of the environment and health issues the solvent cannot escape to the atmosphere.

### 4. Heat-Setting and Adhesive Treatments

Before the fibres can be used for elastomer reinforcement some treatments are often needed. If using cotton only drying to reduce moisture as pre-treatment is needed. If using rayon additional treatment is needed drying as well as drying.

Shrinkage causes some problems while using synthetics fibres. Moisture is not normally a problem with these, but special adhesive treatments are still needed.

Last stage in textile manufacturing is combined heat-setting and adhesive treatment. Nowadays there are sophisticated machines for single-end cords and for fabrics as well. Those machines adjust all the needed adhesive and physical properties for textile very accurately.
4.1 Heat-setting machinery

Many of the machinery process fabrics with several ends at the same time. Single-end machinery is mainly used only with trials.

In single-end machines the yarn or cord are in a maganized creel, which automatically changes the package when yarn or cord ends giving uninterrupted running. From the creel yarn is lead into driven entry nip to advance uniform tension to the impregnation and hold-back system. There two kinds of systems, but so-called snub system have largely been replaced by the pull-roll system. Main reason for replacing is that snub systems consist of snub roll and other two rolls, which generates high pressure between snub roll and the other rolls. After that a circular cross-section may become oval although in the snub arrangement this squeeze system controls the level of dip pick-up, while separate squeeze rollers are needed to control the level of dip pick-up in a pull roll system. Pull roll system can double as the immersion point, with one roller passing into a bath containing the relevant adhesive dip.

From these rollers in the immersion point cord is passed over a grooved roller, which guides and controls the cords. Then cords are feed into double pass oven with elevated temperature to dry (if dipped) and heat-set. Double pass means that cords return into oven by reversing rollers.

Some of the machines have two ovens with independent control of the tension and temperature applying two different dips before entering into ovens. This makes possible to use of two-stage adhesive systems, which are needed for example some of the polyester and aramid treatments.

After the oven the cords pass several rollers to give stretch. Those rolls have different speed than hold back rolls. After that cords are allowed to cool ambient air temperature before rewounded at the winder.

Similar principles than are used for single cords are used for fabric treatment as well. Two basic types of fabric machines are normally used. When the fabric is supported at the edges on pins or in clips on continuous chains and weft and the finished width are controlled, it is called stenter type.

The stenters are used to treat the light fabrics, giving improved flexibility, which also allows open constructions reducing the loss of width during processing. There is also an advantage when as similar warp and weft is needed, for example for hose. If there is no control of the width fabric, it is called tyre-cord machine.

Those tyre-cord machines apply tension to the warp to adjust the elongation and modulus of the fabric in the longitudinal direction. The right width is achieved by using correct design of the loomstate fabric, which allows free shrinkage of the weft yarns. The tyre-cord machines are suitable for the heavy, high-strength fabrics with high tension to the warp to achieve the required modulus and with nylon to reduce creep and growth.
Basically stenters and tyre-cord machines are complementary, but there is overlapping of capability. Fabrics with 100-200-kN/m warp strength can be processed on either type of machine.

The fabric is let off from the roll and fed by rollers to the impregnation bath in stenter machine. Surplus dip is removed by squeeze rolls, suction or air jets. Then fabric passes feed rollers, where the fabric is gripped and guided into the oven for heat treatment for heat setting or baking the dip. The fabric is still held by the pins or clips after the oven. Then it passes the unpinning roller where restraints are removed and finally it is rewinded in the rewind unit.

Depending on the construction and weight of fabric, it is held on pins or by clips. The hardened steel pins staggered in two rows and incline away from the centre of the machine. They are mounted in brass blocks, attached to the endless chains of the machine. If the shrinkage force of the fabric is great, it can be torn, but the pins leave small holes in the edge of the fabric always.

Clips are opened by a cam mechanism to allow the edge of the fabric to enter. When the cap is released, it closes onto the edge of the fabric and the increase of tension pulls the clip tighter. The holding force is spread wider distance than with pins. So there is less damage to the edge of the fabric and small longitudinal movement is possible reducing the distortion.

The fabric is pulled off from a continuous running twin let-off stand by the entry nip with tyre-cord machines. After that it is fed to the reserve. There is a floating carriage in the upper position, giving the maximum length of fabric in suspension. The entry nip stops, when one feed roll ends and next one from the second let-off stand is attached to the trailing end of the previous roll giving uninterrupted running. The floating carriage of the reserve falls and allows the fabric to feed. After jointing the fabrics the entry nip starts to run above the line speed until the reserve rises up.

The fabric passes rollers applying the tension for the first treatment zone. Then it passes the first impregnation tank and after that it is guided into the first zone drying and baking ovens.

Then there is master tension stack of rolls to give the required tension or stretch before second zone with an impregnation tank and ovens to the pull-out roller stack. From here, the fabric enters the exit reserve with the floating carriage at the bottom, so that the running of the machine is not interrupted. And finally it is rewinded in the rewind unit.

Normally the machines are mounted on transducer assemblies and measure directly the tension in the fabric web. Signals are processed electronically to give the required speed differential for the hold-hack or pull-out stack drives. With highly sophisticated machines fabric treatment tension can be applied bi-axially unit through pull-rolls, in the warp direction, and with heavy duty clip chains in the weft direction allowing very accurate control, for example in elongation.
4.2 Heat-setting

Synthetic yarns like nylon and polyester have a high shrinkage. Some changes in physical properties happen also if the yarns are exposed high temperature, especially in modulus and elongation.

Textile is treated at elevated temperatures under tension during manufacturing, this process is known as heat setting. During the heat-setting process crystallinity of synthetic yarns is modified bringing the desired changes in properties. The general physical properties of the cord or fabric can be adjusted by selecting the conditions of heat setting. Heat setting stabilises the yarn and reduces the changes in properties on exposure of the yarn to heat.

If the shrinkage of the yarn is restricted, a force is generated. This is known as the shrinkage force. In both nylon and polyester, this shrinkage force is approximately 1.8 – 2.0 cN/Tex. If during heat setting the tension applied is equal to shrinkage force, the yarn is held to length and the general stress/strain properties are not greatly altered, but residual shrinkage is greatly reduced. If the tension applied is greater than the shrinkage force, there is a net gain in length and an increase in modulus. Similarly if the tension is less than the shrinkage force there will be loss of length, ultimate strength is slightly lower and elongation at break is much higher than the unset yarn.

With a standard tyre-cord polyester, the general changes in properties are similar, but shrinkage is higher than specifically developed polyesters (for V-belts, etc.), to combine high modulus with low shrinkage, with polyester, varying from around 12 – 14 %. The higher tension setting gives a residual shrinkage of around 4 % and with the low-tension setting, it is possible to achieve shrinkages as low as 0.5 – 0.7 %.

The heat setting of nylon also reduces creep and growth under dynamic strain conditions. It is desirable to use a two stage process, with a high tension and temperature for the first stage, followed by a lower tension at a somewhat reduced temperature, for the second to obtain the optimum stability of the yarn or fabric.

Aramid benefits also from heat setting. The mechanism for this is not fully understood. The yarn has a moisture content of around 4%. After exposure to heat, the moisture will be removed, the modulus properties of the yarn are fixed and the regain of the yarn becomes 2 %. So there is a loss of some 2 % of moisture, which is irreversible, which results in the fixing of the modulus level. Subsequent temperature/tension treatment of the yarn does not significantly alter the modulus. For optimum modulus properties with aramid, the recommended tension/temperature for heat-setting is around 10 cN/Tex tension at a temperature no less than 225 °C.
Certain factors have also to be considered in case of fabrics. These are changes in the crimp levels and changes in the dimensions of the fabric. Those are controlled by various factors, including the type of fibres, temperature and tension applied, the loomstate fabric construction and the type of machine used for processing.

Woven the crimp in the warp yarns is usually higher than in the weft. This is logical, as the weft is laid in straight and the warp yarns crossed over it to hold it in the fabric structure. On unwinding the fabric from the roll and pulling it through the treating machine, tension is applied to the warp, which is therefore straightened out to a certain degree. This will result in loss of width. The lighter and more open the construction of the fabric the greater will be this effect. On a stenter machine this effect can be partially reversed when the fabric is held on the pins or clips, by stretching it and reversing the interchange of crimp, but on a tyre-cord machine there is no possibility of this.

As the fabric is heated to dry and bake the dip and to heat-set the yarns, the yarns will generate forces due to latent shrinkage. These forces depend on the temperature used and on the type of yarn. In a tyre-cord machine, the warp yarns are controlled so that the warp yarn shrinkage forces are counteracted, but there is no such restraint in the weft resulting in further loss of width and increase in warp end-count.

The extent to which this occurs is determined by the construction of the fabric, as these dimensional changes will continue until the various forces generated achieve equilibrium.

On a stenter machine the applied restraint is in the weft direction and the weft shrinkage force is largely counteracted. There is usually slight loss of width, but much less than with a tyre-cord machine.

4.3 Adhesive treatment

Adhesive treatment is usually combined with the heat-setting process. The fibre type dictates the actual adhesive system used. Some modifications to the basic systems are often necessary to obtain optimum adhesion to the special elastomers.

Cotton

Textile components made from cotton do not usually need any adhesive treatment. Adhesion is obtained by the mechanical anchoring of the staple fibre ends into the elastomer matrix. This mechanism has been studied and a relationship demonstrated between the number of protruding ends and the bond strength achieved. It has been shown that with rubbers, there is very little penetration of the elastomer between the filaments of the yarns.
Rayon requires an adhesive pre-treatment in order to achieve bond strength for reinforcement of elastomers.

The original systems were based on casein/natural latex mixtures, but the casein component is nowadays replaced with resorcinol/formaldehyde resins giving improved adhesion and more reproducible results. SBR latex was used with the shortage of natural latex during the Second World War.

When the production processes for rayon improved, it was found that the SBR latex/resin adhesives did not give adhesion good enough to realize the improved strengths of these yarns. To improve this, a terpolymer latex of styrene, butadiene and vinyl pyridine (VP) was developed.

Typical resorcinol/formaldehyde/latex (RFL) formulations are given in Table 6. For rayon the latex component is a mixture of SBR and VP latices, the ratio varying from 80/20 for the lower tenacity (standard) rayons to 20/80 for the higher tenacity and polynosic yarns.

There are two basic RFL formulations (see Table 6). One is based on an alkali catalyzed resole resin and the other on an acid catalyzed pre-condensed novolak resin. The novolak is a linear where the resole resin is more fully cross linked and additional formaldehyde is required to give the high degree of cross linking.

<table>
<thead>
<tr>
<th>Component</th>
<th>Resole System</th>
<th>Novolak System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Water</td>
<td>9.4</td>
<td>257.8</td>
</tr>
<tr>
<td>Resorcinol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novolak resin (75% solution)</td>
<td></td>
<td>13.4</td>
</tr>
<tr>
<td>Formaldehyde (37% solution)</td>
<td>5.1</td>
<td>13.8</td>
</tr>
<tr>
<td>Sodium hydroxide (10% solution)</td>
<td>0.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Ammonia (s.g. 0.88)</td>
<td></td>
<td>1.7</td>
</tr>
<tr>
<td>Latex (40% solids)</td>
<td>84.8</td>
<td>212.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>500.0</td>
</tr>
</tbody>
</table>

In the resole system there are two methods to prepare the dip. In the 'one-shot' method, the alkali catalyst is added after all the ingredients have been mixed together. In the two-stage method, the resin is allowed to condense before addition to the latex component. The major disadvantage of the two stage mixing process is that there is just a little control over the exothermic condensation reaction, which can become uncontrolled resulting in an over condensed resin.

The single stage method has a further advantage in that as the resin is formed in the presence of the latex comprising up to six resorcinol units giving a much-improved dispersion of the resin. This improved dispersion also occurs with the novolak system, as the cross linking of the linear pre-condensate occurs in the presence of the latex.
There is no big difference between the resole and novolak systems in performance, although the two-stage resole dips have a shorter useful storage life and also respond less favourably to short, high-temperature curing conditions.

Ammonia or sodium hydroxide as the alkali catalyst is used for the condensation reactions. It has been shown that with sodium hydroxide, the modulus of the resultant dip film is higher than when using ammonia. This may not have a great effect in many applications, where there is no requirement for high dynamic performance. This higher modulus can result in a loss of dynamic fatigue performance of the dipped textile in more severe dynamic applications.

The rayon is impregnated by passing it into a bath of the dip and the excessive dip is removed by squeezing. Dip solids pick-up is controlled by the solids content of the dip and by the efficiency of the excess removal system. The water is dried at temperatures of around 100 – 120 °C and the dried dip film cured by baking at a temperature of 140 – 160 °C. The time required for baking is between 60 – 90 seconds.

**Nylon**

The 6.6 and 6 nylonbs require a similar RFL system as rayon. 75 % of the rubber component should be the VP terpolymer for optimum results. It is considered to use 100 % of the VP latex in some applications.

The dipping of nylon is combined with the heat-setting process. The temperatures used are higher than with rayon in the order of 170 – 200 °C. This implies that the novolak or single-stage resole dip preparation is preferred. The single-stage resole systems gives optimum adhesion after baking for a short time (around 45 seconds) at temperatures of around 200 °C. To achieve optimum adhesion in the two-stage mix requires, it needs baking at least 105 seconds at 150 °C and the adhesion levels drop significantly at higher temperatures, even with reduction of the exposure time.

**Polyester**

With polyesters the basic RFL systems do not give satisfactory adhesion and alternative systems or pretreatments have been developed.

The original systems, based on solvent application of isocyanates, did not require further treatment. Those solvents are not favored in production environments. There are both health and fire risks.

The first attempts followed existing isocyanate chemistry. Instead of using solvent solutions of the straight isocyanate, used dispersions of blocked isocyanates. These are compounds in which the active isocyanate is reacted with another material, such as phenol, giving a product relatively stable at ambient temperatures and not so reactive. But at elevated temperatures dissociates and yields the active component again. These were used as a pre-dip, followed by an RFL dip giving reasonable
adhesion. Later the blocked isocyanate dispersion was added to the RFL in a single bath system giving results slightly inferior to the two bath systems.

Further development led to the DuPont D 417, in which a water miscible epoxy is added to the blocked isocyanate dispersion. This improves film formation and compatibility with polyester. The polyester is dipped through this giving a solids pick-up of 0.5%. After that the blocked isocyanate is activated at a temperature of 230 °C. Then the polyester is given a second dip with a standard RFL system. This system gives good levels of adhesion and is quite widely used.

Table 7. Formulation for polyester pre-dip; DuPont D 417

<table>
<thead>
<tr>
<th>Component</th>
<th>Parts by Weight</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Blocked isocyanate (40% dispersion)</td>
<td>72.0</td>
<td>180.0</td>
</tr>
<tr>
<td>Epoxy resin</td>
<td>27.2</td>
<td>27.2</td>
</tr>
<tr>
<td>Gum tragacanth solution (2%)</td>
<td>0.5</td>
<td>25.0</td>
</tr>
<tr>
<td>Dispersant (50% solution)</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Water</td>
<td>1,767.2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>2,000.0</td>
</tr>
</tbody>
</table>

Developments at single-stage treatments have been directed at modification of the resin component of the RFL. In one system the resin is modified by partial replacement of the formaldehyde with an aromatic or heterocyclic aldehyde. Although this is reasonably effective these systems do not appear to have found any wide acceptance.

All the treatments for standard polyester require high temperatures to achieve optimum adhesion, usually around of 230 – 240 °C. Application of these can be performed at the same time as the heat-setting.

Aramid

Aramid is chemically related to the nylons, but do not give as good adhesion when treated with the RFL dips. The two-stage systems can be used, but under certain conditions these may have deleterious effects on the dynamic performance of the treated cords.

Simple pretreatment for first dip of an epoxy is used, based on the reaction of epichlorohydrin with glycerol. The first dip is followed by a standard RFL second stage. The first stage requires a baking treatment of 60 seconds at 240 °C and the second stage a similar time at around 210 °C. The fibre companies nowadays provide pretreated yarns requiring only treatment with standard RFL systems.

The high-temperature treatment is required to obtain a good adhesion with the aramids. There may be some variations in adhesion, but that can be minimized by the incorporation of carbon black dispersion into the second-stage RFL dip.

The formulations are primarily for use with the unsaturated hydrocarbon rubbers (natural rubber (NR), styrene-butadiene rubber (SBR), butadiene rubber (BR) and
isoprene rubber (IR)). SBR compounds tend to give slightly higher levels than NR compounds, and those based on IR slightly lower.

However, when other matrix polymers, such as polychloroprene rubber (CR), nitrile rubber (NBR), PVC, butyl rubber (IIR) and ethylene-propylene-diene rubber (EPDM) are used, it is necessary to modify the RFL systems for optimum adhesion.

For PVC the adhesion is achieved by use of a primer coating using an isocyanate in the plastisol. With IIR and EPDM the problem is more complicated. In that latices of these polymers do not exist. The adhesion levels generally obtained with these polymers are inferior to those with the highly unsaturated polymers.

Sometimes RFL systems are modified to give other desirable properties, like in fire retardant materials, such as a dispersion of an antimony trioxide/halogen containing compound, can be added to CR based dips for fabrics to be used in fire retardant composites.

### 4.4 The in situ bonding system

An alternative system has been developed in which adhesion-promoting additives are incorporated into the rubber compound, which can then adhere to untreated textiles.

The major additives of this system are resorcinol and a formaldehyde donor. Hexamethylene tetramine (HMT) and hexamethoxy methyl melamine (HMMM) are normally used for this. These two will give moderate levels of adhesion. This can be significantly increased by the inclusion in the formulation of a fine particle size, hydrated silica.

This system gives good levels of adhesion to nylon and rayon. With polyester it is necessary to use a pretreated yarn to achieve satisfactory adhesion. With polyester the amine residues from the HMT component can cause significant degradation by chemical attack, due to aminolysis of the ester linkages in the polymer. So it is preferable to use HMMM as the methylene donor with polyester.
5. Textile cord testing

5.1 Determination of twist

Scope and principle

Method applies to a single yarn as well as to folded yarns and does not apply to monofilament yarns.

It covers the determination of the twist level, expressed as turns per metre length of the yarn before untwisting and under standard pretension, and the determination of the direction of twist, expressed in “S” or “Z” notation.

Twist is removed by rotating one end, while other end remains fixed, until filaments of yarn are parallel.

Test Procedure

Measurement must be done in standards atmosphere and samples must be conditioned. Standard pretension of (5,0 ± 0,5) mN/tex is used. Initial length between the clamps of the twist tester is 500 m, if the nominal twist level is lower 1250 tpm and 250 mm, if the nominal twist is higher than 1250 tpm.

Twist is removed by rotating one end, while other end remains fixed, until filaments of yarn are parallel.

Reporting

The direction of twist is expressed in “S” or “Z” notation and twist level is expressed as turns per metre.

5.2 Determination of thickness

Scope and principle

To determine the thickness of cord. A specimen of cord is held between two parallel circular faced anvils of a micrometer.
**Test procedure**

Sample is placed in middle of the anvils. The movable anvils are closed gradually in order to measure the thickness of the cord without crushing or flattening. Thickness is determined.

**Reporting**

Thickness is expressed in mm.

### 5.3 Determination of linear density

**Scope and principle**

To determine the linear density of a single yarn and folded or cabled yarn, expressed in units of tex system. The recommended submultiple is the decitex (dtex). Linear density is measured by weighing a known length of yarn.

Linear density is mass of the test specimen in grams divided by length of the test specimen in metres.

**Test Procedure**

A measured length of yarn is wound off under standard pretension and conditioned in the form of skein and weighed. The standard pretension for skein winding or sample cutting is (5,0 ± 0,5) mN/tex, calculated using the nominal linear density. The length of test specimen depends upon the nominal linear density. If the nominal linear density is up to 500 dtex, the length of test specimen is 100 metres. If the nominal linear density is 500 - 2000 dtex, the length of test specimen is 50 metres. If the nominal linear density is above 2000 dtex, the length of test specimen is 10 metres.

**Reporting**

Linear density is expressed in dtex.

### 5.4. Determination of amount of dip

**Scope and principle**

To determine the amount of dip on a laboratory sample of dipped cord. Water, finish and textile are eliminated, leaving behind the dip.
**Test Procedure**

The amount of dip content is calculated oven-dry mass of the pure (dip-free) textile material giving the dip content percentage. The drying time is 30 ± 5 minutes and temperature is 150 ± 3 °C. Samples are taken by reeling prepare 3 skeins, each 10 metres length. These are combined into a sample of at least 10 g. After determination of the oven-dry mass specimen is transferred into a 250 ml flask and 100 ml solution of 8 M potassium hydroxide is added. Water, finish and textile are eliminated, leaving behind the dip. (Potassium hydroxide is highly corrosive and skin, eye and respiratory irritant)

**Reporting**

The corresponding oven-dry mass of test specimen is collected and oven-dry mass of the dip rounded to the nearest milligram. Dip content as percentage of the oven-dry mass of the pure textile material is calculated.

**5.5 Determination of tensile properties**

**Scope and principle**

To determine tensile properties of filament yarns. A test specimen of yarn is mounted in the clamps of a tensile testing machine and stretched at a constant rate of extension until rupture. The clamps grip the test specimen without slippage or damage to test specimen, which can result in jaw breaks.

**Test Procedure**

Pretension on (5.0 ± 0.5) mN/tex, gauge length (500 ± 1,0) mm or (250 ± 1,0) mm and testing speed 50 - 1000 mm/min is used, depending the elongation at break of test specimen. The higher elongations at break the faster testing speeds and shorter gauge lengths are used. If the test specimen breaks inside the clamp or within 10 mm of the edge of the clamp, its classified as a jaw break and will be ignored and additional test specimen must be tested.

**Reporting**

Breaking force is expressed in Newton. Elongation at specified load and elongation at break and expressed in percentage.

*Figure 26.*
5.6 Determination of boiling water shrinkage

Scope and principle
To determine thermal shrinkage in boiling water. It is suitable only filament yarns with linear densities below 3000 dtex. The boiling point of water depends upon the atmospheric pressure at the time of measurement. Variations in atmospheric pressure can produce variations in results.

Test Procedure
A known length specimen is treated with boiling water for a specified time and shrinkage is determined.

Pretension on (5,0 ± 0,5) mN/tex is used during the length measuring. The boiling time is 30 ± 5 min and the drying temperature after boiling is 55 ± 5 °C.

Reporting
Boiling water shrinkage is expressed as percentage of the initial length.

5.7 Determination of hot air shrinkage

Scope and principle
To determine thermal shrinkage in hot air. A known length specimen is treated under specified tension in hot air at a specified temperature for a specified time. During the treatment the hot air shrinkage is determined.

Test Procedure
The standard pretension and measuring tension is (5,0 ± 0,5) mN/tex. For low shrinkage products measuring tension of (1 ± 0,1) mN/tex can be used. Common hot air temperature is 160 °C or 180 °C, depending on the material. The exposure time is 120 seconds for specimen of linear density up to 4000 dtex, above this linear density the exposure time is 240 seconds.

Reporting
Hot air shrinkage is expressed as percentage of the initial length.  

Figure 27.
5.8 Determination of drawing properties of POY

Scope and principle

To determine continuously the draw tension at a given draw ratio, drawing temperature and drawing speed. The draw tension test method is applicable to partially oriented yarns (POY). The yarn to be tested is fed from a package, pretensioned and hot drawn. A tension measuring head detects the force needed to draw the yarn under specified conditions.

Test Procedure

Pretension on \((5,0 \pm 1,0)\) mN/tex, draw ratio 1,50 – 1,90 and testing speed \((50 \pm 1)\) m/min is used, depending upon the preorientation of the yarn.

Dynamic draw tension test for POY can be used according to determination on tensile properties to characterize POY. The force needed to draw the yarn under specified conditions is measured.

If yarn breaks during test performance, test is repeated.

Reporting

Drawing force expressed in Newton

5.9 Determination of stiffness

Scope and principle

To determine the stiffness of textile cord by bending a sample. Force, which is needed for bending, is measured. Stiffness of textile cord has influences on cord processing and properties of end product

Test Procedure

Stiffness of textile cord is measured with tensile testing machine by using a sample rack in accordance with standard. The sample rack consists of two parts: a sample bender and a clamp. The length of the sample is 50 mm and it consists of 10 parallel cords. Coherence is made by using Scotch tape. Unnecessary bending of the sample must be avoided. Sample rests on 25 mm wide fontanel. By using the sample bender the textile sample is bended through the fontanel and force, which is needed for pulling the sample through the fontanel is measured. Speed of the moving clamp is 25 mm/min.

Figure 28.
Reporting

Stiffness is presented for one cord, so the result of the sample must be divided with 10. The result is presented in mN.

5.10 Determination of adhesion (H-test)

Scope and principle

To determine the force required to separate textile cords from rubber compound. Specimens of cord are vulcanised to rubber from both ends, so the test piece has the shape of H-letter. After vulcanization the force necessary to pull each cord linearly out of the rubber is measured. H-test is suited for textile cords which dtex is under 8000. If required the visual evaluation of rubber coverage is also determined.

Test Procedure

The length of test pieces is 25 mm. The rubber compound used to particular cord type is rolled to thickness of 1,6 mm and is cut to width of 6 mm. Bottom parts of the rubber and cords are set to the cold mold. The rest of the rubber is set to the top of the cords. To the under and top of the rubber is set supportive textilesheets. The vulcanization temperature is 150 °C and the vulcanization time is 30 minutes. After the vulcanization the test piece is removed immediately from the mold and it is allowed to cool to room temperature. The cords are pulled from the rubber with tensile testing machine with the speed of 100 mm/min.

The force necessary to pull each cord or wire linearly out of the rubber is measured. After the vulcanisation there has to be at least 16 hours waiting time (and at the most 4 weeks) before testing. With comparison tests the testing has to be done within the same day.

Reporting

The final result is the average force from 8 measurements.

5.11 Determination of strip adhesion of single textile cord

Scope and principle

The test covers the determination of the force required to pull simultaneously 20 single cords off from the rubber. After vulcanization the force necessary to pull each cord linearly out of the rubber is measured. If required the visual evaluation of rubber coverage is also determined.
**Test Procedure**

The rubber compound used to particular cord type is rolled to approx. thickness of 5 mm. 1 mm thick reinforcement material is set farthest down, then rubber. On the top there are 20 single cords in 25 mm wide area. A piece of paper of 40 mm length is set to the other end of the sample between rubber and cords. The vulcanisation temperature is 150°C and the vulcanisation time is 42 minutes. After the vulcanisation the test piece is removed immediately from the mould and it is allowed to cool to room temperature. All 20 cords are pulled simultaneously from the sample with tensile testing machine with the speed of 200 mm/min. The bundle of cords is attached to upper clamp and the other end of sample is attached to lower clamp. The test stops automatically when travel distance is 150 mm. The force is measured. After the vulcanisation there has to be at least 16 hours waiting time (and at the most 4 weeks) before testing. With comparison tests the testing has to be done within the same day.

**Reporting**

The average force required pulling 20 single cords off from the rubber is expressed in Newton.

**5.12 Determination of strip adhesion of rubberised textile cord**

**Scope and principle**

The test covers the determination of the force required to pull the 25 mm wide strip of the rubberised cord off from the sample. After vulcanization the force necessary to pull each cord linearly out of the rubber is measured.

If required the visual evaluation of rubber coverage is also determined.

**Test Procedure**

Sample layers are set one on top of another to the thickness of 7 – 8 mm. 40 mm length paper is set to the other end of the sample between two uppermost layers. Samples are set to cold mould. The vulcanisation temperature is 150°C and the vulcanisation time is 42 minutes. After the vulcanisation the test piece is removed immediately from the mould and it is allowed to cool to room temperature. In the middle of the sample 25 mm wide strip is cut to the uppermost layer. The strip is pulled from the sample with tensile testing machine with the speed of 200 mm/min. The strip is attached to upper clamp and the other end of sample is attached to lower clamp. Test stops automatically when travel distance is 100 mm. The force is measured.

After the vulcanisation there has to be at least 16 hours waiting time (and at the most 4 weeks) before testing. With comparison tests the testing has to be done within the same day.
**Reporting**

The force required pulling the 25 mm wide strip of the rubberised cord off from the sample is expressed in N/mm.
II STEEL REINFORCEMENT

1. Steel Cord

1.1 Definition

Steel is a metal alloy whose major component is iron, with carbon content between 0.02% and 1.7% by weight. Carbon is the most cost effective alloying material for iron, but many other alloying elements are also used. Carbon and other elements act as a hardening agent, preventing dislocations in the iron atom crystal lattice from sliding past one another. Varying the amount of alloying elements and their distribution in the steel controls qualities such as the hardness, elasticity, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but is also more brittle. The maximum solubility of carbon in iron is 1.7% by weight, occurring at 1130° Celsius; higher concentrations of carbon or lower temperatures will produce cementite which will reduce the material's strength. Alloys with higher carbon content than this are known as cast iron because of their lower melting point. Steel is also to be distinguished from wrought iron with little or no carbon, usually less than 0.035 %. It is common today to talk about 'the iron and steel industry' as if it were a single thing; it is today, but historically they were separate products.

Currently there are several classes of steels in which carbon is replaced with other alloying materials, and carbon, if present, is undesired. A more recent definition is that steels are iron-based alloys that can be plastically formed (pounded, rolled, etc.).

Steel cord is a major component used for reinforcing a radial tire. Steel cord is stronger than fibre materials, have excellent heat resistance, fatigue resistance, with no contraction. Steel cord is a tire reinforcement material with the highest growth rate.

1.2 Cord components

Steel cord has four basic components (see figure)

FILAMENT OR WIRE (1)
Metal fibre used as an individual element in a strand or cord. Standard filament diameters are 0.15/0.175/0.20/0.22/0.25/0.27/0.28/0.30/0.35 and 0.38 mm.
STRAND (2)
Group of steel filaments are twisted together to form a strand and several strands may be twisted together to form a cord or a cable.

CORD (3)
Formed structure composed of two or more filaments when used as an end product or a combination of strands or filaments and strands.

SPIRAL WRAP (4)
Spiral wrap filament wound around a steel cord to keep the large cord structure together.

1.3 Nomenclature system

A tyre cord construction is normally defined by
- Structure
- Length and direction of lay
- Product type

1.3.1 Structure

Rule

The description of the construction follows the sequence of manufacture of the cord i.e. starting with the innermost strand or wire and moving outwards.

Format

The full description is given by the formula:
\( (N \times F) \times D + (N \times F) \times D + (N \times F) \times D \)
\( N = \) number of strands
\( F = \) number of filaments
\( D = \) nominal diameter of filaments, expressed in mm

Example: \( (1 \times 3) \times 0.22 + (1 \times 9) \times 0.22 + (1 \times 15) \times 0.22 + (1 \times 1) \times 0.15 \)

If the nominal diameter is the same for two or more parts, it is only stated at the end of the sequence. The diameter of the spiral wrap is always stated separately.

Example: \( 3 + 9 + 15 \times 0.22 + 0.15 \)
1.3.2 Length and direction of lay

**Rule**

Sequence or order in the designation follows the sequence of manufacturing i.e. starting with the innermost strand and moving outwards.

Example: 3+9+15×0.22+0.15 (5/10/16/3.5 SSZS)
- 5 S: lay length and direction of the strand 3×0.22
- 10 S: lay length and direction of the layer +9×0.22
- 16 Z: lay length and direction of the layer +15×0.22
- 3.5 S: lay length and direction and direction of the wrap

1.3.3 Product types

**REGULAR CORD**
Cord in which the direction of lay in the strands is opposite to the direction of lay in closing the cord.

**LANG’S LAY CORD (LL)**
Cord in which the direction of lay in the strands is the same as the direction of lay in closing the cord.

**OPEN CORD (OC)**
A cord in which wires are loosely associated and movable relative to each other to enable rubber to penetrate into the cord.

**COMPACT CORD (CC)**
A cord in which the filaments have linear contact with each other.

**HIGH ELONGATION CORD (HE)**
Lang’s lay cord in which the strands are loosely associated and movable relative to each other, to allow the cord to be stretched substantially at a given load.
BETRU® CORD
Cord with gaps between the filaments. The gaps allow the rubber to penetrate the cord and thus to block any moisture conduit. The BETRU® filaments are formed so to have a polygonal curve instead of a circular curve as perpendicular projection.

HIGH IMPACT CORD
Protection layer cord of which the filaments are preformed thus that the cord has full rubber penetration. This avoids corrosion. The cord has a high impact absorption capability, as it has 5% elongation even when rubber embedded.

General Characteristics

Raw material: wire rod

Average steel composition:

Normal tensile
Carbon 0.725%
Manganese 0.525%
Silicon 0.230%
Sulphur 0.010%
Phosphorus 0.010%
Traces of copper, chromium and nickel.

High tensile
Carbon 0.825%
Manganese 0.525%
Silicon 0.210%
Sulphur 0.006%
Phosphorus 0.008%
Traces of copper, chromium and nickel.

Welds and splices

Continuous lengths are supplied which means that filament splices are permitted and cord welds are permitted and they should withstand a minimum load equal to 40 % of the breaking load. The increased diameter of the finished weld should not exceed the cord diameter by more than 15 %.

Coating definition

The conversion from mass of coating expressed in g/kg to thickness of coating expressed in micrometers is done according to the following formula

$$\text{Thickness} = \text{Mass} \times d \times 0.235,$$

where $d$ is the diameter of filament in mm.
1.4 Steel cord manufacturing process

The process:

- **Pickling**
  - Process of removing scale on the wire and surface cooling
  - Decoiling
  - Water-rinsing
  - Surface Coating
  - Drying

- **Dry Drawing**
  - Wire drawing process for designated wire diameter
  - Pay-off
  - 9-19 Blocks
  - Take-up

- **Brass Plating**
  - Brass Plating process of achieving dipping and adhesion over rubber
  - Uniform Moparasure
  - Rinising
  - Heating Furnace
  - Fluidised bed
  - Pirsoning
  - Cu Plating
  - Zn Plating
  - Diffusion Furnace
  - Wire
  - Cu-Zn

- **Wet Drawing**
  - Brass plated wire drawing process for designated wire diameter
  - Pay-off
  - 21-26 Dies
  - Take-up
**Cord spooling and packaging**

**Spooling**

Tyre cord is wound onto metal spools and usually there is an arrow on the flange that indicates the direction for unwinding the spool. Tire cord spools are designated as BS40, BS60 and BS80 and so forth, to indicate the weight of the cord on the spool. Spool dimensions are standardized so that tire manufacturers can use tire cord from any producer anywhere in the world.

<table>
<thead>
<tr>
<th>Type</th>
<th>BS40</th>
<th>BS60</th>
<th>BS60/17</th>
<th>BS80/33</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>225</td>
<td>250</td>
<td>250</td>
<td>295</td>
</tr>
<tr>
<td>L</td>
<td>117</td>
<td>117</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>M</td>
<td>107</td>
<td>107</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>N</td>
<td>150</td>
<td>153</td>
<td>215</td>
<td>215</td>
</tr>
<tr>
<td>O</td>
<td>17</td>
<td>27</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>P</td>
<td>3x13</td>
<td>3x13</td>
<td>3x13</td>
<td>3x13</td>
</tr>
<tr>
<td>Q</td>
<td>38</td>
<td>43</td>
<td>2/38+1/43</td>
<td>42</td>
</tr>
<tr>
<td>Approx. Mass (kg)</td>
<td>1.85</td>
<td>1.90</td>
<td>2.40</td>
<td>2.50</td>
</tr>
<tr>
<td>Approx. cord capacity (kg)</td>
<td>18</td>
<td>18</td>
<td>36</td>
<td>30</td>
</tr>
</tbody>
</table>
Packaging

Steel tire cord spools are wrapped, sealed and packaged in waterproof carton strapped to a pallet in units of approximately 1300 kg net mass. The pallet is made of wood or plastic. Boxes dimensions normally are: 1080 mm (length) × 810 mm (width) × 1200 mm (height)

Carefully packed laboratory samples of tyre cord can be attached to the corresponding unit.

Storage conditions

All units are provided with desiccant and a humidity indicator. Cartons can be stored for six months inside a warehouse where the combination of temperature and humidity does not lead to condensation. It is recommended to condition the units at ambient temperature before they are opened.

2. Bead Wire

2.1 Definitions

A bead wire is a major component used for reinforcing radial tires, while protecting the carcass plies from rubbing against the rim.

Beads are bands of high tensile strength steel wire encased in a rubber compound. Bead wire is coated with special alloys of bronze (copper and tin) or brass (copper and zinc). Coatings protect the steel from corrosion. Copper in the alloy and sulphur in the rubber cross-link to produce copper sulphide, which improves bonding of the bead to the rubber. Beads are inflexible and inelastic, and provide the strength to mechanically fit the tire to the wheel. bead rubber includes additives to maximize strength and toughness.
The bead component of the tire is a non-extensible composite loop that anchors the body plies and locks the tire onto the wheel assembly so that it will not slip or rock the rim.

The tire bead component includes the steel wire loop, apex or bead filler; the chafer, which protects the wire bead components; the chipper, which protects the lower sidewall; and the flipper, which helps hold the bead in place. The bead wire loop is made from a continuous steel wire covered by rubber and wound around with several continuous loops. The bead filler is made from a very hard rubber compound, which is extruded so as to form a wedge. The bead wire loop and bead filler are assembled on a sophisticated machine.

The precision of the bead circumference is critical. If too small, tire mounting can be a problem; but if too loose, the tire can come off the rim too easily under loading and cornering conditions. After the circumference is checked, the bead component is ready for the tire building operation.

**Diameter**

The arithmetic average of the maximum and minimum thickness of the wire measured in the same place and expressed in millimetres

**Breaking force**

The maximum force which a test specimen can support during a tensile test of loading to break, expressed in Newton.

**Tensile strength**

The breaking load or force of a wire per unit of cross-sectional area of the unstrained specimen, expressed in Newton per square millimetre or Megapascal.

**Elongation at break**

The increase in length of a test specimen which results from subjecting it to the breaking force in a tensile test expressed as a percentage of the initial length.
Arc Height

Arc Height is the amount (in mm) of bending a bead wire sample has when placed on 2 support points with an interdistance of 620 mm.

Torsions

The number of revolutions made by a specific length of wire when twisted until rupture on its own axis in one direction.

Coating

Mass of coating: The quantity of the covering layer applied to the surface of the wire expressed in grams per kg of wire surface.

Composition

The quantity of each of the components expressed as a percentage of the total mass of the coating.

2.2 General characteristics of bead wire

Raw material: wire rod
Bead wire is a hard-drawn high carbon wire made from quality steel rods. Wire rod feedstock is systematically rated for its quality level and performance.

Average steel composition:

Normal tensile
Carbon 0.725 %
Manganese 0.550 %
Silicon 0.250 %
Sulphur 0.015 %
Phosphorus 0.015 %
Traces of copper, chromium and nickel.

High tensile
Carbon 0.825 %
Manganese 0.520 %
Silicon 0.230 %
Sulphur 0.008 %
Phosphorus 0.010 %
Traces of copper, chromium and nickel.

Tolerances on diameter
± 0.02 mm if Ø < 2.00 mm
± 0.03 mm if Ø ≥ 2.00 mm

Elongation at break
Min. 5 %, total elongation for round bead wire.
Elongation < 2 % is available on request.
2.3 Manufacturing process

Pickling for pre-treatment -> First wire drawing -> Patenting -> Second wire drawing

After the second wire drawing, bead wire is plated with bronze before manufacturing.

Packaging
**Handsamples**

Upon request, a number of samples are provided. Per reel, 10 pieces of wire, each 450 mm long, are put in a plastic bag with desiccant, which goes with the shipment.

**Storage conditions**

All coils are provided with desiccant. The packing units can be stored for six months, inside a warehouse where the combination of temperature and humidity does not lead to condensation. It is recommended to condition the units at ambient temperature before they are opened.

### 2.4 General properties of beadwires

<table>
<thead>
<tr>
<th>Standard units</th>
<th>Reelless coil</th>
<th>Metal reel</th>
<th>Metal reel</th>
<th>Metal reel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1000</td>
<td>BS 450/6</td>
<td>BS 900</td>
<td>BS 1150</td>
</tr>
<tr>
<td>K Diameter of flange</td>
<td>mm</td>
<td>760</td>
<td>760</td>
<td>760</td>
</tr>
<tr>
<td>L Diameter of barrel</td>
<td>mm</td>
<td>437</td>
<td>355</td>
<td>355</td>
</tr>
<tr>
<td>M Overall width</td>
<td>mm</td>
<td>385</td>
<td>345</td>
<td>385</td>
</tr>
<tr>
<td>N Traverse</td>
<td>mm</td>
<td>280</td>
<td>320</td>
<td>280</td>
</tr>
<tr>
<td>O Bore</td>
<td>mm</td>
<td>70.5</td>
<td>70.5 or 33</td>
<td>70.5 or 33</td>
</tr>
<tr>
<td>P Number x diameter of drivehole</td>
<td>mm</td>
<td>2/35</td>
<td>2/35</td>
<td>2/20+2/35</td>
</tr>
<tr>
<td>Q distance drivehole/bore</td>
<td>mm</td>
<td>115</td>
<td>63.5+115</td>
<td>63.5+115</td>
</tr>
<tr>
<td>Overall diameter</td>
<td>mm</td>
<td>720</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Core diameter</td>
<td>mm</td>
<td>355</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Approx. Wire capacity</td>
<td>kg</td>
<td>445</td>
<td>445</td>
<td>450</td>
</tr>
</tbody>
</table>

%Sn: max. 3 %  
%Cu: 72% +/- 5%

### 3. Steel belt processing

To produce steel belts, the steel cords must go through a calendering process or a steel belt extruding process, for example steelastic process. Steel belts give the tire strength and dent resistance, while remaining flexible. Passenger tires are usually made with two belts. The individual cord plies of a cross-ply tyre are arranged in a criss-cross pattern at a certain angle – known as the cord angle. This angle determines the tyre’s characteristics. An obtuse cord angle, for example, gives
better ride comfort but reduces lateral stability. An acute cord angle increases directional stability at the expense of ride comfort.

3.1 Calendering process

Calendering process is an operation in which the rubber compound is pressed on and into cords. Because the bonding of steel to rubber is critical to performance, the calendering process is an important step.

The calender is a heavy-duty machine equipped with three or more chrome-plated steel rolls, which revolve in opposite directions. The roller temperature is controlled via steam and water. In this process, the rubber compound is applied to the cords. The steel cord spools are appropriate into use as such. Spools are set on a creel in a separate creel room. Temperature and humidity in this room are kept constant. From the creel the spools are collected as a fan and then directed through a reed blade that spreads the cords as a steel mat. Then those pre-set number of steel cords under proper tension are continuously pressed through two steel rollers, and rubber compound is added to the opening area between the rollers. Then the rubber compound is pressed into, on top of and on the bottom of steel cords. A continuous sheet of cord-rubber composite goes through several more rollers to ensure good penetration and bonding between the rubber and cords.

In this phase the speed of the calender and the temperature of the rubber have to be kept within specified limits. Otherwise the finished steel cord may turn grey and its adherence deteriorates.

Quality is measured by the thickness of the sheet, spacing between cords, the number of cords and the penetration of rubber into the composite sheet. Finished steel cord is reeled between plastics and the composite sheet is then cut into appropriate sizes, shapes, and angles depending on the desired contour of the tire.

3.2. Extruding process

The steel belt

extruding process features specialized "E" Die extrusion technique in the production of premium-quality steel belts for radial passenger and truck tires. In addition to automatic butt-splice control, precise cord end count control and a belt angle range from 18-90 degrees. This system improves gauge control, dimensional stability and productivity. Also, the system lowers maintenance, processing and labour cost.
while reducing scrap and waste material to assure you the ultimate in quality, versatility and efficiency.

The steel cord spools are set on multi pin creel (from 112 to 480 pin). There is normally two side shifting creels, so that swapping to new creel is faster. From the creel the spools are directed through the creel room roller guide and then through the wire guiding. After that cords are fed into E-type die head, which is attached to extruder. Rubber compound is extruded to the opening area between and on top of and on the bottom of steel cords in the die head. In the die head there is a temperature control unit and a die pressure control unit. After the die head quality is measured with infrared temperature control and sometimes with digital strip thickness indicator. Rubberised steel belt is cooled by shell type cooling drum unit. When steel belt is cooled, it is cut into appropriate sizes, shapes and angles with automatic bias cutter and splicer before wind up.
3.3 Cutting and splicing

The cutting system features cutter for producing steel cord breaker and steel cord body ply used in the production of premium quality radial passenger and truck tyres.

System is a very simple, there is let-off or so-called in feed and then cutter, conveying system and splicer before material wind up unit. System can be equipped with slitter unit, if slitting is needed.

4. Steel wire and cord testing

4.1 Determination of residual torsion

Scope and principle

To determine the residual torsion for a specified length of steel cord. Number of revolutions per specified length of the cord is counted, when it is allowed to turn freely.

Test procedure

The specimen is taken tangentially from the spool, which is placed on rotating mounting device.

3 m of the cord is first unwound and held firmly to prevent rotation, cut off and discarded.
Right angle bend is made (upward movement) of about 50 mm from the end of the cord. This bend is held tightly to prevent rotation while pulling out a specimen having a length of 6 m. Then the free bent end is released and allowed to rotate while the cord is free of external tension and friction.

Number of rotations of the cord is counted and ended to the nearest one-half rotation. Clockwise rotating direction is denoted as (+) and anti-clockwise as (-).

**Reporting**

The direction of the rotation and the number of rotations is expressed in number of turns per 6 meters.

### 4.2 Determination of straightness: the arc height method

**Scope and principle**

To evaluate the straightness of steel cord by measuring the arc height over distance of 300 mm.

**Test procedure**

2 m of the cord is first unwound and discarded from the end of the spool. Specimen of 400 mm in length is taken avoiding any alteration of the straightness. The sample is put on the planar support and it is let to glide by hitting the apparatus lightly. The value of the arc height can be seen on the scale in mm, being the maximum distance between planar and the inner arc of the cord.

**Reporting**

The arc height is expressed in mm.

### 4.3 Determination of length and direction of lay

**Scope and principle**

To determine the length of lay and the direction of lay.

**Test Procedure**

Length of lay: The axial distance required to make a 360 degree revolution of any element in a strand or in a cord, expressed in millimetres.

Direction of lay: The strand or cord has an "S" or left hand lay if, when held vertically, the spiral around the central axis of the strand or cord conform in
direction of slope to the central portion of the letter "S"; and "Z" or right hand lay the spirals conform in direction of slope to the central portion of the letter "Z".

**Reporting**

The length of lay is expressed in mm to the nearest 0,1 mm and the direction of lay expressed in S or Z

### 4.4 Determination of linear density

**Scope and principle**

To determine the mass per unit by weighing cord specimen of known length, generally 1 m.

**Test procedure**

Specimen is taken directly from the spool and under tension on 10 N it is cut to a length of 1 m. Then sample is wrapped into a coil and weighed using analytical balance.

**Reporting**

Linear density is expressed in g/m.

### 4.5 Determination of breaking force and elongation

**Scope and principle**

To determine the breaking force and the elongation by clamping a cord in a tensile testing machine under a defined pre-tension and subjected to a constant rate of extension until rupture.

**Test procedure**

The distance between the clamps on a tensile testing machine is adjusted to length of 1000 mm. The displacement speed of the moving clamp is 100 mm/min. If the wrap presents, it is removed. Only clamps, which do not cause fractures in the vicinity of the clamped area, can be used.

The testing machine is started and operated until rupture. The highest force is noted and elongation is determined with extensometer.
Reporting

Breaking force and elongation at rupture is expressed.

4.6 Determination of cord thickness

Scope and principle

To determine the thickness of cord. A specimen of cord is held between two parallel circular faced anvils of a micrometer.

Test procedure

Sample is placed in middle of the anvils. The movable anvils are closed gradually in order to measure the thickness of the cord without crushing or flattening. Thickness is determined.

Reporting

Thickness is expressed in mm.

4.7 Determination of static adhesion to rubber compound

Scope and principle

The test covers the determination of the force required to separate steel cords from rubber compound. Specimens of cord are embedded in a block of rubber. After vulcanization the force necessary to pull each cord linearly out of the rubber is measured.

If required the visual evaluation of rubber coverage is also determined.

Test Procedure

The mould contains slots for 15 steel cords. Embedment length is 12,5 mm. The rubber compound used to particular cord type is rolled to thickness of 7 - 8 mm.

Bottom parts of the rubber and cords are set to the cold mold. The rest of the rubber is set to the top of the cords. The vulcanization temperature is 150 °C and the vulcanization time is 30 minutes. After the vulcanization the test piece is removed immediately from the mold and it is allowed to cool to room temperature. The cords are pulled from the rubber with tensile testing machine with the speed of 100 mm/min.
The force necessary to pull each cord or wire linearly out of the rubber is measured.

**Reporting**

The final result is the average from 10 measurements.

### 4.8 Determination of flare

**Scope and principle**

To determine the spreading of the filament ends of the strand is observed after cutting the cord or strand and the unravelled length is measured.

**Test Procedure**

Specimen is taken directly from the spool and a straight section of cord is cut at a right angle to the axis of specimen. Without disturbing the cut end, the most unravelled length is measured. When it is larger than the strand or cord lay length, there is flare.

**Reporting**

Flare or no flare

### 4.9 Determination of mass and composition of brass and coating

**Scope and principle**

To determine mass and composition of brass coating on steel cord using an Atomic Absorption Spectro photometer (AAS*). The brass coating is stripped from the steel using nitric acid, and the copper and zinc in solution are determined.

* AAS = a technique used for quantitative solutions determinations of elements in solution.

**Reporting**

Mass of brass expressed in g/kg and copper content in brass expressed in %
4.10 Rubberized steel cords

**Determination of rubberized ends, thickness and m²-weight**

**Scope and principle**

Number of rubberized ends per specified width of rubberized steel cord and m²-weight of specified length and width of rubberized steel cord is measured.

**Test procedure**

The numbers of rubberized ends are counted.
The dimension of rubberized steel cord samples are measured by ruler.
The surface area of the sample is counted by multiplying the length of the sample and the width of the sample.
The sample is weight and then m²-weight is counted (weight of the sample / surface area of the sample).

**Reporting**

The number of rubberized ends expressed in ends per 10 cm.
Thickness and m²-weight are reported.

4.11 Testing of bead wire

**SAMPLING**

Samples are taken of each shipment according to a frequency derived from the Military Standards 414 for variables and Military Standards 105D for attributes.

4.11.1 Determination of breaking force and elongation

**Scope and principle**

To determine the breaking force and the elongation by clamping a bead wire in a tensile testing machine under a defined pre-tension and subjected to a constant rate of extension until rupture.

**Test procedure**

The distance between the clamps on a tensile testing machine is adjusted to length of 1000 mm. The displacement speed of the moving clamp is 100 mm/min. If the wrap presents, it is
removed. Only clamps, which do not cause fractures in the vicinity of the clamped area, can be used.

The testing machine is started and operated until rupture. The highest force is noted and elongation is determined with extensometer.

**Reporting**

Breaking force and elongation at rupture is expressed.

### 4.11.2 Determination of bead wire thickness

**Scope and principle**

To determine the thickness of bead wire. A specimen of bead wire is held between two parallel circular faced anvils of a micrometer.

**Test procedure**

Sample is placed in middle of the anvils. The movable anvils are closed gradually in order to measure the thickness of the bead wire. Thickness is determined.

**Reporting**

Thickness is expressed in mm.

### 4.11.3 Determination of static adhesion to rubber compound

**Scope and principle**

The test covers the determination of the force required to separate bead wires from rubber compound. Specimens of cord are embedded in a block of rubber. After vulcanization the force necessary to pull each bead wire linearly out of the rubber is measured.

If required the visual evaluation of rubber coverage is also determined.

**Test procedure**

The mould contains slots for 15 bead wires. Embedment length is 25 mm. The rubber compound used to particular cord type is rolled to thickness of 7 - 8 mm. Bottom parts of the rubber and bead wires are set to the cold mold. The rest of the rubber is set to the top of the cords. The vulcanization temperature is 150 °C and the vulcanization time is 30 minutes. After the vulcanization the test piece is removed immediately from the mold and it is allowed to cool to room temperature. The bead
wires are pulled from the rubber with tensile testing machine with the speed of 100 mm/min.

The force necessary to pull bead wire linearly out of the rubber is measured.

*Reporting*

The final result is the average from 10 measurements.

### 4.11.4 Determination of bead wire coating

*Scope and principle*

To determine mass and composition of coating on bead wire

*Test procedure*

Bronze coating is directly analysed by means of x-ray fluorescence spectrometry on the wire. Components Cu and Sn are individually determined. The composition is expressed as % Sn relative to the total amount of Cu and Sn. Coating mass is expressed in g/kg wire. Brass coating is indirectly analysed by dissolution of the coating. Therefore, a known weight of bead wire is brought in a fixed volume of a stripping solution. The stripping solution consists of an ammonia and peroxidisulfate solution, which does not affect the iron. The dissolved coating is analysed by means of X-ray fluorescence spectrometry.

*Reporting*

The technique yields the weight of the coating per unit weight of wire and the composition of the brass expressed as the percentage of Cu in the total weight of the coating.
III PRODUCT REINFORCING

1. Reinforcing of tyres

1.1 Textile reinforcement

Textiles developed for use in tyres are small, but exacting part of the huge textile industry. Billions of different kinds of tyres are in use, for example tyres for bicycles to space shuttle landing gear. That means a wide range in technical needs. Carcass and belt textile provide the strength of the tyre. The mix of textiles is 59 % nylon, 34 % polyester and 5 % rayon (figure 29). Nowadays passenger and light truck tyres are over 95 % radial, with polyester replacing nylon and rayon as a carcass material. Development of “Run-Flat” and Ultra High Speed - tyres has increased the demand of Rayon, especially in Europe. Nylon still dominates in heavy-duty bias ply tyres, nylon 6 is concentrated in China, Russia and India and nylon 66 in Europe and USA. The main usage of nylon 66 is as a cap ply in radial passenger tyres.

The total usage of textiles in radial passenger and light tyres may be estimated that carcass cord comprise 5 % of the tyre weight. For example typical passenger tyre weighs 10 kilograms containing 0,5 kilograms of polyester cord.

<table>
<thead>
<tr>
<th>Global consumption of tyre textile cords</th>
<th>Total 1 132 000 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMLS Polyester</td>
<td>34%</td>
</tr>
<tr>
<td>Nylon 66</td>
<td>24%</td>
</tr>
<tr>
<td>Rayon</td>
<td>5%</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>35%</td>
</tr>
<tr>
<td>Speciality (aramid, hybrid, PEN, Lyocell)</td>
<td>2%</td>
</tr>
</tbody>
</table>

Figure 29. Consumption of tyre textile cords in the world
Because of constant demand for better tyre performance, the fabrics have changed a lot since the 1880s, when J.B. Dunlop developed early pneumatic tyres using expensive Irish flax. Very soon cotton replaced flax remaining the major tyre textile until after World War II. Continues filament viscose rayon was introduced in the late 1930s. After that nylon became available for tyres in the late 1940s. Rayon held sway in passenger tyres, because of poor characteristics with nylon due to its lower dimensional stability. In the early 1960s polyester was introduced to provide better dimensional stability than nylon and better strength than rayon. After that polyester has gone through several improvements and become the dominant textile for passenger and light truck radial carcasses.

Functions of tyre cords

Tyre cords are the strength elements of a tyre. Cords define the tyre shape, support the loads and contain the inflation gas. Cords provide the axial and lateral rigidity for acceleration, braking and cornering and dimensional stability for uniformity, handling and ride. Cords also provide fatigue, bruise and resistance to separation for durability. The weft is rarely spaced and it serves only to maintain a constant distance between the warp threads.
Cord requirements

- High axial orientation for axial stiffness and strength (high modulus in tension)
- Good lateral flexibility (low modulus in bending))
- Filament with high length to diameter ratio
- Filament with high tensile strength
- Filaments twisted into cords to function as a unit and exert axial strength
- Twist and tyre design to prevent cord from operating in compression

Ideal cord properties for a tyre carcass

- High tensile strength
- High tensile modulus
- Low bending modulus – low stiffness
- Dimensional stability – low shrink during cure, no flat spotting and no long term growth
- High toughness – impact and abuse resistance
- High durability – fatigue resistance, low heat generation while flexing, good adhesion to rubber, chemical, oxidation and heat resistance
- Low hysterisis loss at high speeds

Ideal cord properties for a radial tyre belt

- High bending modulus – high stiffness
- High tensile strength
- Ultra high tensile modulus
- High adhesion to rubber
- High compression modulus
- Good resistance to chemical attack

When choosing a textile cord, different things must be taken into account. These choices are predicted on the tyre specification for application and market. That means usually balancing cost against performance.

Different choices to choose right textile for carcass or radial belt

- Cost per unit length and weight
- Cord construction
- Tex – filament size and strength
- Chemical composition of textile
- Cord twist
- Number of plies in the tyre
- Number of cords per unit length in ply

Rayon is used both carcass and belt of passenger radial tyres, but it lacks strength to be used in heavy-duty tyres. Polyester cord is an excellent carcass material for use with steel belts becoming dominating textile cord all around the world. Nylon is a textile of choice in truck, earthmover and aircraft tyres.
Rayon

Rayon strength has been improved 300% since its introduction. Improving is made by improved coagulation and heat treatment. Rayon is an excellent choice for passenger tyres, because of its low heat shrinkage, high modulus and good adhesion properties. Rayon has lost market share to polyester due to higher cost with production. Rayon is used for racing tires and gained more markets due to manufacturing of Run-Flat and Ultra High Speed - tyres has increased. Usage of rayon is about 63,000 t/a, in tyres 58,000 t. Main usage is in Europe (46,000 t/a). Typical rayon constructions for passenger tyre carcass are 2/184 tex and 2/244 tex.

Polyester

Newest modifications of polyester results increased molecular weight and revised processing is called DSP-PET (Dimensionally Stable PET) or HMLS (High Modulus Low Shrinkage), with 50% increased modulus and 50% reduced shrinkage, bringing it close to rayon for dimensional stability. It’s relatively inexpensive making it a good choice for passenger and light truck tyres. Polyester is not recommended for use in high speed/ high load/ high temperature applications like aircraft or racing tyres, because of rapid loss in properties at tyre temperature over 120 °C. Annual usage of HMLS polyester in tyres is about 380,000 t. The most common constructions are 2/110 tex, 2/144 tex, 2/167 tex and 2/220 tex.

Nylon

Nylon is generic term for aliphatic polyamides. Two of those are used in tyres. Nylon 6 is a less expensive than nylon 66, but it is more sensitive to moisture and subject to loss in tensile strength if moisture is present during curing. Due to processing modifications nylon tyre cord strength is nowadays 50% higher than it was when it was introduced. Nylon is preferred in uses requiring carcass toughness, high strength, bruise and impact resistance and low heat generation for example in tyres for heavy-duty trucks, off-road vehicles and aircraft. In these applications nylon is generally used in the bias-ply tyre carcass or in radial tyre carcasses with steel belts. Typical construction for heavy tyre carcass is 2/188 tex or 2/210 tex. Also heavier 3/188 tex or 3/210 tex are used.

In radial passenger car tyres with steel belts, the cap ply is widely used. Due to the radial growth of the steel belts, a zero degree ply over the belt is placed. This cap ply restricts the growth of the steel belts at high speed, when tyre diameter and tyre temperature increases. Major requirements for cap-ply are modulus, shrinkage force and shrinkage. The higher the modulus, the greater will be the restraining force generated as the steel belts start to increase in diameter. Increasing shrinkage force increases the total restraining force. The shrinkage during curing ensures that the cap ply fits tightly over the steel belts.

Most common cap ply material for passenger tyres is nylon 66 due to its properties. Constructions like 2/94 tex 1/140 tex, 2/140 tex are used.
Also polyester cap ply is under development. It shows excellent flat spot property, good shrinkage behaviour and high modulus. The construction could be 2/110 tex.

**Aramid**

Aramid is wholly aromatic polyamide. The most common commercial material is Kevlar or Twaron. Those have very high strength, high modulus and low elongation. The major thing to slow adoption as a general radial belt material is relatively high cost. It suits well to replace steel as a belt material where weight is important like in the belts of radial aircraft tires. Construction like 2/168 tex can be used.

There is a lot of development work to combine aramid with nylon as a copolymer or so-called hybrid material to improve elongation and fatigue resistance. A combination of 1/168 tex aramid and 1/140 tex nylon 66 is used as a passenger tyre cap ply.

**Other textiles**

Other potentially useful fibers for tires are glass fiber and polyvinyl alcohol (PVA), though the usage has decreased during last years.

Glass fiber specific stiffness and strength are equal to steel. Some attempts have made to use glass fiber in the belt material, but those have ended premature failure. It works as a belt material if proper tread design and latex adhesive dips are used. But in cold weather use and with inappropriate tread it fails when it is put into compression.

Polyvinyl alcohol (PVA) fibers have properties similar to rayon and polyester. They have higher tenacity than rayon and lower shrinkage than polyester. This textile has been used successfully in the carcass and belts. A major drawback has been the lack of suppliers.

Polyethylene naphthalate (PEN) is similar to polyester. It has lower shrinkage, higher modulus, and higher Tg than HMLS polyester. It has potential as a carcass material as well as an overlay belt for light truck and as a cap ply for high-speed passenger tyre replacing nylon. A disadvantage is the cost, price is 2.5 times polyester.

Lyocell is made from cellulose like rayon but the manufacturing process is different, more simple and cheaper and more environmental friendly. Properties are somewhat different. Modulus is higher, the fatigue resistance and the elongation at break are lower. A lot of trials have been made but full-scale production has not yet started.
1.2 Steel reinforcement in tyres

The reinforcing materials of a tyre – tyre cord and bead wire – are the predominant load carrying members of the cord-rubber composite. They provide strength and stability to the sidewall and tread as well as contain the air pressure.

Steel tyre cord was developed 50 years ago and it was adopted in Europe with the advent of the radial tyre. The first radial passenger tyre was made in 1949, first radial truck tyre in 1952 and first radial OTR (off the road) tyre in 1959.

Steel cord met the requirements for a stiff, high modulus/high strength belt material at an acceptable cost, giving high strength and compression stiffness with acceptable bending stiffness, good resistance to fretting fatigue, and good adhesion to rubber. The stiffer steel belt provided the radial tyre with quicker handling response and longer tread life compared to the bias tyre.

Steel tyre cord is a niche product. About 2% of all steel wire rod and 0.2% of all steel used in the world is used for steel tyre cords totally 2000 kton. Steel tyre cord consumption 2005 in the world:

- Europe 21 %
- Russia 3 %
- North-America 19 %
- China 25 %
- Rest of Asia 23 %
- Rest of the world 9 %

In Europe the consumption is overall stable but clear shift from West to East Europe. Russia is still a small market but growing at 8% per year. In North America the consumption is decreasing 3% per year. Asia is already the biggest market and growing, especially in China the growth was 17%.

Steel cord usage in tyres:

In passenger car tyres the steel cord is used in the belt. In truck radial tyres steel cord is used both in the belt and in the carcass and in OTR tyres it is used as a breaker for puncture protection.

The functions of steel cord belt in the tyre:
- helps forming the desired tyre profile
- generates handling forces and improves tyre performance
- improves traction
- influences footprint shape
- influences wear performance
- protects and survives against impacts and protruding objects

Main role of steel cord in the belt is its influence on the stiffness of the belt package and its protection from impacts from the road.

For belt reinforcement desired properties are:

- high strength
- high bending stiffness
- ultrahigh dynamic modulus
- low growth and creep
- high compression modulus
- high fatigue strength
- For carcass reinforcement the desired properties are:
  - high strength
  - high durability
  - dimensional stability
  - high dynamic modulus
  - low heat generation

Traditionally steel tyre cord has tensile strength about 2800 MPa. This type of steel cord is called normal tensile (NT) or regular tensile. Higher strength steel cords have been developed to reduce the amount of steel needed in a tyre. This has been made by increasing carbon content in steel, by using better quality raw materials and by improving process. The tensile strength of different steel cord types is shown in Table 8.

Table 8. Tensile strengths of different steel cord filaments

<table>
<thead>
<tr>
<th>Filament</th>
<th>% Carbon</th>
<th>0.20 mm diameter</th>
<th>0.35 mm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal tensile (NT)</td>
<td>ca. 0.7</td>
<td>3000</td>
<td>2600</td>
</tr>
<tr>
<td>High tensile (HT)</td>
<td>ca. 0.8</td>
<td>3400</td>
<td>3000</td>
</tr>
<tr>
<td>Super high tensile (ST)</td>
<td>ca. 0.9</td>
<td>3650</td>
<td>3400</td>
</tr>
<tr>
<td>Ultra high tensile (UHT)</td>
<td>ca. 0.96</td>
<td>4000</td>
<td>3650</td>
</tr>
</tbody>
</table>

Lower tyre weigh increases tread life and decreases rolling resistance, which means better fuel economy.

Also high tensile and super high tensile bead wires are available today.
1.2.1 Steel cords for passenger car tyres

The belt of passenger car tyre helps forming the desired tyre profile, generates handling forces during cornering, influences footprint shape and wear performance, improves traction and protects against impacts.

Table 9. Typical steel cord constructions for PCR tyres

<table>
<thead>
<tr>
<th>Construction</th>
<th>Lay mm</th>
<th>Diameter mm</th>
<th>Breaking force min. N</th>
<th>Linear density (g/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x0.30 NT</td>
<td>14/S</td>
<td>0.60</td>
<td>365</td>
<td>1,12</td>
</tr>
<tr>
<td>2x0.30 HT</td>
<td>14/S</td>
<td>0.60</td>
<td>445</td>
<td>1,12</td>
</tr>
<tr>
<td>2+1x0.28 HT</td>
<td>oo/16/S</td>
<td>0.70</td>
<td>740</td>
<td>1,47</td>
</tr>
<tr>
<td>2+1x0.30 HT</td>
<td>oo/16/S</td>
<td>0.75</td>
<td>615</td>
<td>1,68</td>
</tr>
<tr>
<td>2+2x0.30 NT</td>
<td>oo/16/S</td>
<td>0.78</td>
<td>715</td>
<td>2,23</td>
</tr>
<tr>
<td>2+2x0.30 HT</td>
<td>oo/16/16/-S</td>
<td>0.78</td>
<td>825</td>
<td>2,23</td>
</tr>
<tr>
<td>3x0.30 OC NT</td>
<td>16/S</td>
<td>0.64</td>
<td>510</td>
<td>1,67</td>
</tr>
<tr>
<td>3x0.30 OC HT</td>
<td>16/S</td>
<td>0.64</td>
<td>620</td>
<td>1,67</td>
</tr>
<tr>
<td>3x0.30 HT Betru</td>
<td>16/S</td>
<td>0.65</td>
<td>610</td>
<td>1,68</td>
</tr>
<tr>
<td>5x0.22 ST Betru</td>
<td>9.5/S</td>
<td>0.60</td>
<td>580</td>
<td>1,51</td>
</tr>
</tbody>
</table>

The constructions 2+2 & 2+1x0.25 / 0.28 / 0.30 / 0.32 NT & HT are widely used worldwide. They have good rubber penetration but irregular cross section, which may cause some disadvantages like prone to jump outs during processing or straightness problems (tip rising, spacing). Also excessive cord diameter means more rubber to the belt.

The construction 2x0.30 HT is one of the most used construction today. The disadvantage is that you need high end count (epdm) to get the strength needed.

Open cord construction 3x0.30 OC NT & HT is used to improve rubber penetration. The disadvantage is that it has excessive cord diameter and the open construction is tension dependant and may close during the calendering.

To eliminate this disadvantage Bekaert has developed BETRU construction, where filaments are preformed and the cord cross section has polygonal shape. So 3x0.28 / 0.30 HT & ST BETRU constructions have growing market share. BETRU construction is independent of cord tension and stays open during calendering and vulcanization giving robust rubber penetration (BETRU = BEkaert Total RUbber penetration).

The constructions 5x 0.20 / 0.225 HT & ST are specific constructions for HP/UHP tyres, where flexible cord is needed.
The market evolution is rather stable. The constructions 2x1, 2+2, 2+1, 3x1 with filament diameter 0,25 ... 0,30 are dominant, in Europe 2x0,30 HT is the most popular. HT is standard but more and more ST steel is used. For UHP tyres / very low profile tyres low filament diameter ST steel cords will have stronger market position.

### 1.2.2 Steel cords for SUV and LT tyres

The Sport Utility Vehicle (SUV) tyres and the Light Truck (LT) tyres need stronger and heavier steel cord than PCR tyres. Traditionally the construction 2+7x0,22 was used but now a change to bigger filament diameters and less filaments has happened.

The constructions **2+2x0,30 / 0,32 / 0,35 HT** has good rubber penetration but processability is worse, roughness and straightness may cause problems.

**5x0,30 HT Betru** has good overall performance: cost, processability and rubber penetration.

**1+6x0,24 / 0,28 / 0,30 HT** has no total rubber penetration, risk for core migration. Bekaert’s Betru versions like **0,315+6x0,30 HT BETRU** or **0,365+6x0,35 HT BETRU** is said to eliminate this problem.

The construction **3x0,15+6x0,27** has no full rubber penetration and also production cost are high.

Constructions **2+4x0,265 HT** and **3x2x0,22** can also be used. They have full rubber penetration but processability is critical and they are expensive.
### Table 10. Typical steel cord constructions for SUV and LT tyres

<table>
<thead>
<tr>
<th>Construction</th>
<th>Lay mm</th>
<th>Diameter mm</th>
<th>Breaking force min. N</th>
<th>Linear density (g/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+7x0.22</td>
<td>6,3/12,5/SS</td>
<td>0,83</td>
<td>1000</td>
<td>2,74</td>
</tr>
<tr>
<td>2+2x0.30 HT</td>
<td>oo/16/16/-S</td>
<td>0,78</td>
<td>890</td>
<td>2,23</td>
</tr>
<tr>
<td>5x0.30 HT Betru</td>
<td>16/S</td>
<td>0,81</td>
<td>970</td>
<td>2,80</td>
</tr>
<tr>
<td>0.315+6x0.30 HT Betru</td>
<td>16/S</td>
<td>0,92</td>
<td>1480</td>
<td>3,99</td>
</tr>
<tr>
<td>0.365+6x0.35 HT Betru</td>
<td>18/S</td>
<td>1,08</td>
<td>1865</td>
<td>5,42</td>
</tr>
<tr>
<td>3x0.15+6x0.27 NT</td>
<td>9/10/SZ</td>
<td>0,85</td>
<td>1025</td>
<td>3,17</td>
</tr>
</tbody>
</table>

#### 1.2.3 Steel cords for truck radial tyres

The truck tyre carcass has to carry the load, survive millions of flexions and survive several retreads. For carcass typical constructions are 3+9+15x0.175/0.22+0.15 and 3+9x0.22+0.15 or more compact cord (CC) constructions like 0.22+18 x 0.20 NT&HT or 0.25+18 x 0.225 HT. The compact cords are produced in a single compact bundle in which the filaments have mainly linear contact with each other. The fretting fatigue is less than in the standard cord where severe fretting fatigue may occur at crossover points.

The truck tyre belt generates handling forces, improves traction and wear. It also protects against impacts. In the belt package there are normally four layers. The first layer can be lighter construction (3+9+15x0,175+0,15) than layers 2 and 3 (3+9+15x,22+0,15). The fourth layer is often from more flexible construction called high elongation (HE) or high impact (HI) cord. The HE cord is Lang’s lay cord in which the strands are loosely associated and moveable with respect to each other. This allows the cord to be stretched substantially and gives useful cut protection and impact resistance when used in the top belt of radial truck tyres. The elongation at break is 5-7 % than normally it is 1-2%. Typical constructions are 3x7x0,22 HE, 4x4x0,22 HE and 5x0,38 HI (High Impact).
The market evolution is going to compact construction without wrapping, thicker filaments, lower number of filaments and also stronger steel like HT and ST. Also preformed cords (like Betru) are used more. As an example 3+8x0.33 ST Betru or 4+6x0.38 HT Betru. The benefits are cheaper price, less fretting and higher strength.

Table 11. Typical steel cord constructions for truck tyres

<table>
<thead>
<tr>
<th>Construction</th>
<th>Lay mm</th>
<th>Diameter mm</th>
<th>Breaking force min. N</th>
<th>Linear density (g/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+9+15x0,175+0,15 NT</td>
<td>5/10/16/3.5/SSZS</td>
<td>1.34</td>
<td>1670</td>
<td>5.42</td>
</tr>
<tr>
<td>3+9+15x0,22+0,15 NT</td>
<td>6,3/12,5/18/3.5/SSZS</td>
<td>1.62</td>
<td>2600</td>
<td>8.50</td>
</tr>
<tr>
<td>3+9x0,22+0,15 NT</td>
<td>6,3/12,5/3.5/SSZ</td>
<td>1.170</td>
<td>1290</td>
<td>3.850</td>
</tr>
<tr>
<td>0,22+18x0,20 ec NT</td>
<td>12,5/Z</td>
<td>1.02</td>
<td>1565</td>
<td>4.84</td>
</tr>
<tr>
<td>0,22+18x0,20 HT</td>
<td>12,5/Z</td>
<td>1.02</td>
<td>1840</td>
<td>4.84</td>
</tr>
<tr>
<td>0,25+18x0,225 NT</td>
<td>16/S</td>
<td>1.18</td>
<td>2050</td>
<td>6,36</td>
</tr>
<tr>
<td>3x7x0,22 HE</td>
<td>4,5/8/SS</td>
<td>1.52</td>
<td>1720</td>
<td>6.95</td>
</tr>
<tr>
<td>4x4x0,22 HE</td>
<td>3,5/5/SS</td>
<td>1.32</td>
<td>1150</td>
<td>5.40</td>
</tr>
<tr>
<td>5x0,38 HI</td>
<td>14/S</td>
<td>1.34</td>
<td>1185</td>
<td>4.63</td>
</tr>
</tbody>
</table>

1.2.4 Steel cords for off the road tyres

Off the road (OTR) tyres had traditionally cross ply construction or they had bias construction having textile cord or steel cord as a breaker. Steel cord is used when good protection against punctures is needed for instance in the forestry tyres. The steel cord has to be flexible and to have good impact properties. This kind of properties you find in the high elongation cords mentioned earlier.

Radial off the road tyre constructions are very complex. They may have steel cord as a carcass and belt or only as belt. Also steel sidewall protection layers are useful against impacts and for improving vehicle driving stability.

For small size tyres typical steel cord construction is 3+9+15x0.22+0.15. In medium size tyres you can use constructions like 7x7x0,22+0,15 NT&HT or 7x7x0,25+0,15 NT&HT. In really big earthmover tyres they use 7x(3+9+15x0,245)+0,245 HT, which has breaking force so high as 24 500 N. Usually same cord constructions are used for carcass and belt. Upper belt layer/layers are often high elongation constructions like 4x6x0,25 HE.

Table 12. Typical steel cord constructions for OTR tyres

<table>
<thead>
<tr>
<th>Construction</th>
<th>Lay mm</th>
<th>Diameter mm</th>
<th>Breaking force min. N</th>
<th>Linear density (g/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+9+15x0,22+0,15 NT</td>
<td>6,3/12,5/18/3.5/SSZS</td>
<td>1,620</td>
<td>2750</td>
<td>8,500</td>
</tr>
<tr>
<td>7x7x0,22+0,15 NT</td>
<td>12,5/20/5/SZS</td>
<td>2,24</td>
<td>4650</td>
<td>15,20</td>
</tr>
<tr>
<td>7x7x0,25+0,15 HT</td>
<td>12,5/20/5/SZS</td>
<td>2,52</td>
<td>6350</td>
<td>19,80</td>
</tr>
<tr>
<td>7x(3+9+15x0,245)+0,245 HT</td>
<td>6,3/12,5/18/55/5/ZZSZ</td>
<td>4,84</td>
<td>24200</td>
<td>73,90</td>
</tr>
</tbody>
</table>
1.2.5 Bead wires for tyres

Tyre beads are made from single steel wires of larger diameter. They are manufactured by several different processes including tape-wound beads, single-wire wrapped beads or cable beads. Each type has certain performance or cost advantages. A similar wire is used all of these constructions. The wire diameter and number of wires (or turns) will depend on the size and load carrying requirements of a tyre. Beads are designed with load distortion resistance, rim slippage resistance and resistance to bead breakage during mounting. Wires for beads are normal or high tensile steel in various diameters, and bronze or brass coated for rubber adhesion.

Typical bead wires for passenger car tyres are 0,89 HT and 0,965 NT&HT. Also 0,86 ST is coming to market more and more.

In the truck radial tyres and off the road tyres heavier wires from normal tensile or high tensile steel are use. Typical products are 1,295 HT, 1,42 NT, 1,60 HT, 1,65 NT and 2,00 NT&HT.

<table>
<thead>
<tr>
<th>Table 13. Typical bead wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>0,89 HT</td>
</tr>
<tr>
<td>0,965 NT</td>
</tr>
<tr>
<td>0,965 HT</td>
</tr>
<tr>
<td>0,86 ST</td>
</tr>
<tr>
<td>1,295 HT</td>
</tr>
</tbody>
</table>

2. Reinforcing of non tyre applications

2.1 Industrial rubber products

The term “industrial rubber products” represents a very broad product array ranging from single-component all-rubber articles such as roofing or other membranes through to more sophisticated composites such as timing belts and multilayer high pressure hoses. Industrial products utilize the full spectrum of elastomeric material, textile, and metal reinforcement. Generalizations about product materials, performance, etc. are therefore impossible.
It is more appropriate to handle different product classes that must operate with similar pre-requisites, and discuss about different product classes that have to meet same type of performance expectations in their particular areas of operation.

In the next chapters of this course module, the reinforcing principles and the properties achieved are to be handled, in the cases of conveyor belts, V-belts and some special belts, as well as those of different hoses and pipes. Additionally, some applications of sheets and inflatable structures are to be inspected. The general principles of reinforcement are thought to cover most of the industrial and consumer products not handled in the following paragraphs.

### 2.2 Belting applications

Uses of flat conveyor belts, power transmission belts and V-belts for power transmission are to be found in almost all major machinery applications.

Conveyor belts are used throughout industry for transporting materials. Their applications are very varied, from carrying small items in light industry or supermarkets, to carrying bulk materials for many kilometers, as in pulp and paper or mining installations.

V-belts for different types cover applications ranging from fan belts for automobiles, belts for low-power drives for domestic, laboratory, and light industrial applications, to high-power belts for large industrial applications.

Textile cords or fabric and even steel cords constitute an important part of all rubber belting and hoses. The various types of cords used in the tyre industry are also in use in the belting industry.

#### 2.2.1 Conveyor belts

The most common forms of conveyor belts have a core reinforcement. For fabric belts, this can typically be either polyester or nylon, even though aramids have also established their standing in high duty applications. Steel cord reinforced belts can use brass-coated wire or cables, galvanized steel cables, or brass wire mesh.

The reinforcement cords are covered with a layer of rubber whose formulations are similar in composition to those found in wire coat and fabric coat compounds in tyres. The strength requirements to which the belt is designed, dictate the number of layers of reinforcement.

Typical structure of textile reinforced conveyor belts is show in figure 32 [metso.com]
The cover compounds found in conveyor belts are similar in nature to those found in large commercial truck tires. Lower performance belts, which may not require as high a level of tear strength as premium belts, might use SBR in place of natural rubber of truck tyres. Belts put into service in food processing facilities can have covers based on EPDM or food grade SBR. In environments, where the belt may be exposed to oils, a polychloroprene (CR), nitrile (NBR) or NBR/PVC based compounds can be used. Mining belts frequently require resistance to flames and burning and in some applications also antistatic properties.

Essential steps in making conveyor belts are:

- drying the fabric
- frictioning of the hot fabric with a rubber compound
- topping to give additional rubber between plies and the outer ply and cover, using a three- or four-roll calender
- belt building
- vulcanization.

The construction of conveyer belts may be straight-laid or graded-ply types (see Figure 33) with the joints in neighbouring plies being staggered to eliminate weakness and failure. As the last phase of manufacturing conveyor belts, the cover coat is applied by calendering.
Vulcanization of conveyor belts may be carried out in sections using press cure or continuously by means of Rotocure equipment. In press cure, vulcanization is done by heating in long presses, the belt being moved between successive cures by a length less than the length of the press platens. Since in this process the end or overlap zones receive an additional cure, it is desirable to minimize damage or weakness due to over-cure by using non reversing rubber mixes and allowing water cooling at each end section of the platen.

Typical textile reinforcement system of conveyor belts consist combinations of polyester (E) and polyamide (P) synthetic fabrics. The length-wise or warp threads fabric are most frequently polyester, and the cross-wise or weft threads are polyamide, so that designation according to the Table 3 (page 32) is EP. The role of the fabric is to ensure high tensile strength/weight ratio, required flexibility as well as low elongation and high mechanical impact resistance and chemical resistance.

Steel reinforced conveyor belts are used especially for transport over long distances and under demanding conditions. Small elongation under load and low transversal stiffness (good adaptability to conveyor bed) make them suitable for varying, demanding conditions.

The carcass used is a high-strength steel cord placed in one plane embedded in the rubber, safeguarding the perfect joint of upper and lower cover layer. Such a structure provides for high performance and resistance of the conveyor belt. The rubber covers protect carcass of the conveyor belt against outdoor climate conditions and mechanical damage. They must be resistant to aggressive action of transported materials and environment. In addition, they protect the conveyor belt carcass against abrasive effect of rollers and drums.

Some pictures illustrating different structures of conveyor belt, are shown in figures 34 and 35.
Figure 34. Examples of combination of rubber-textile and steel-cord reinforcement with one or more breaker plies to make shock resistant belts. The breaker material is penetration resistant polyamide, polyester, steelcord or aramid [Matador].

Figure 35. Example of the structure of a heat resistant conveyor belt [metso.com]

Examples of the possibilities for aramid fabrics reinforced conveyor belt is shown in the Figure 36 below [metso.com].
As presented earlier, aramid is as light as other synthetic fibres like polyester or polyamid, but as strong as steel. It has low elongation, practically no creep and excellent resistance against heat and chemicals.

As there can be a single fabric ply only, the carcass is light and flexible with optimum strength utilization. The power consumption of an aramid conveyor belt is reduced compared with other reinforcing systems [Trellex].

If increased impact resistance is required, additional Polyamid breaker plies can be utilized.

*Figure 36. Structure alternatives of aramid reinforced conveyor belts [Trellex/Metsa]*
2.2.2 Power Transmission Belts

There are many different types of power transmission belts. The most common is the V-belt, of which there are several variations, but there are also several other standard power transmission belt types in common use.

The V-belts usually consist of five sections:

- top section known as the tension section
- bottom section, called the compression section
- cord section located at the neutral zone
- cushion section on either side of the cord section, and
- one or two layers of rubberized fabric, called the jacket section covering the whole assembly.

In most types of V-belt, the reinforcing elements, which transmit the tension, are grouped in a plane close to the top of the belt in tension section, called also cord line. Principle of V-belt structure is shown in Figure 37.

![Figure 37. Cross-section showing V-belt construction. [Plastics Technology Handbook, Manas Chanda and Salil K. Roy in Plastics Engineering Serie, CRC handbooks]](image)

The requirements for the fabrics used in V-belts (and also for other belt products) are

- Resistance to fatigue
- Excellent dimensional stability
- Adhesion to the rubber components
- High modulus
- Minimal heat shrinkage
- Sufficient tack (adherence to other components) for the build process
- Unaffected by moisture

Characteristic of the V-belt system is that the belt is wedged in the groove of the pulley, but does not bottom in the pulley groove. As the tension is carried by the cords in the top of the belt, there is a tendency for the center of the belt to be distorted downwards. Two standards of section ratios have been developed: the classical V-belt and the newer wedge belt (see Figure 38).
The classical V-belt has a shallower profile than the wedge belt, and therefore can run on smaller diameter pulleys than the deeper wedge profile. However, with the deeper base section, the wedge belt can run at higher tensions than the classical V-belt and can therefore transmit more power at the same pulley diameter and width.

Industrial V-belts can be jacketed with a woven fabric, or they can be raw-edge type, without fabric on the sides of the belt which contact the pulley walls. The base rubber contains short fibres aligned across the belt.

The variety of basic V-belt construction is shown in Figure 39.

Variable-speed belts used on continuously variable transmissions (CVTs) that require precise continuous control of pulley speed ratios. They are much wider than ordinary V-belts.
To achieve the required lateral stiffness with longitudinal flexibility, short fibre reinforcement, oriented across the width of the belt is often combined with a moulded or notched base.

There are two main methods for building V-belts:

1) Relatively short length V-belts are built layer by layer as a wide sleeve on rotatable collapsible drum formers. The sleeve is cut into the required widths and necessary cross-section. The carcase can also be built on a two drum system, which enables easy adjustment of belt length and belt removal, by simple adjustment of the two drum centers. With either of these systems, grooved drums can be used to eliminate the skiving cutting step. Whichever method of building is used, the principle is the same in that the reinforcing cords are wound under tension, onto the base rubber. The top rubber is applied to complete the carcase, which is then removed for cutting and skiving, when necessary.

2) Particularly larger and wider cross-section belts, can be built individually on V-grooved pulleys, using base rubber extruded to the required cross-section.

After the individual belts have been prepared, the fabric jacket is applied. For the jacketing, a strip of bias cut fabric, usually frictioned to give a tacky finish, is applied.

**Timing belts**

Timing belts are a modification of corded flat belts. Transverse teeth moulded on the belt engage transverse notches in the pulleys and provide a positive drive as distinct from a frictional drive, as illustrated in Figure 41. Because of the tooth engagement, it is essential that the cord structure of the belt be as inextensible as possible.

*Figure 41. Structure and function of the timing belt*

[http://www.popularmechanics.com/automotive/how-to/4212995.html](http://www.popularmechanics.com/automotive/how-to/4212995.html)
For exact timing, it is essential that the cord structure of the belt be as inextensible as possible. Steel, glass and aramid are mostly preferred here, but satisfactory belts can be made from polyester cord in some applications.

Timing belts are built and cured on the same mould. The mould is a cylinder with the notches for the teeth cut in the surface. The face fabric is wrapped around this mould, followed by the rubber and the reinforcing cords are wound on. A sleeve on the outside of this assembly applies pressure during the cure in an autoclave. After cure, the assembly is slit to give the required belt widths.

**Flat Belting**

There are plied and solid-woven flat belt types. These are basically similar to conveyor belting and are essentially produced in the same manner. The core of flat transmission belting is of ply construction, built from layers of rubberized fabric, similarly as conveyor belting. It has usually rubber covers of equal thickness but thinner than usual for conveyor belts, and is vulcanized in a flat press or on a cylindrical drum rotary vulcaniser.

Where a light and very flexible belt is required for special duties, the textile core can be woven as an endless band and impregnated with rubber using either latex technology or solution dipping.

A non-reinforced plastic belt can also be used as flat belting. The tensile structure is then an oriented polymer sheet, usually nylon, which is faced with a material of suitable friction and wear behavior, such as polyurethane or leather.

**Cut-Length Belting**

There are applications where a V-belt of endless construction cannot be fitted to a drive, e.g. when a shaft has bearings at each side of the pulley. Instead, an appropriate length of belting is cut from a roll of stock and a joint is formed between positioned ends. This kind of belt is termed cut-length V-belt.

The jointed belts have to be rated at lower levels of power transmission than belts of the same cross-section made as endless loops.

Some extruded plastics belting without textile reinforcement can be used as cut-length belting. Polyurethane is suitable as it can be butt-welded with a hot blade to make up the loop. The resilience of an un-reinforced belt may be advantageous in drives with a pulsating load.
Types and effects of the textile reinforcement

When power is transmitted from one pulley to another through friction against a belt, it is evident that the tension on one strand of the belt will be higher than on the other, namely there will be a tight side and a slack side.

As the belt passes round the driven pulley, from the slack to the tight side, the tension in the belt must increase and therefore, the belt will, albeit only slightly, extend in length. The elastic extensibility is, of course, largely dictated by the characteristics of the reinforcing cords.

On account of the slip between belt and pulleys, there will be heat generated and wear will take place.

At higher values of torque, the slip will increase, which in turn increases the heat build up and the surface wear. Additionally, with many types of cord reinforcement, the increase in temperature will also cause some loosening of the belt, increasing still further the degree of slip. To avoid this, cord reinforcement with very low elongation characteristics would be desirable, but this introduces other problems, particularly with systems where there may be any vibrations and pulsing. Too high tensions and transient power peaks can cause a V-belt to turn over, resulting in rapid breakdown of the belt in addition to reducing belt and bearing life.

The most common fibre used for V-belt reinforcement is polyester. The majority of these are relatively heavy cabled cords. Typical constructions include singles and cabled cords which are manufactured from specially developed yarns, with high modulus and low shrinkage, after the standard dipping and heat setting process.

In order to achieve a clean cut and to prevent subsequent fraying of the cut cord in service, a solvent-based adhesion system is used, which can fully penetrate the cord and firmly bind the individual filaments together as well as imparting a high level of adhesion to the cord.

As to the textile jacket or cover components in V-belts, these are generally relatively dense plain weave construction fabrics. They are made of cotton or synthetic fabrics, realizing the high abrasion resistance requirement. For instance, air textured nylon construction performs well for this application. In order to keep up the flexibility of the belt, the jacket fabric is usually cut on the bias after calendaring and wrapped round the belt carcase, after cutting and skiving. For heavier and larger belts, two or even three layers of the cover can be applied, with disadvantageous increase in rigidity of the final belt.

For flat belting carcasses, EP fabrics (e.g. polyester warp/nylon weft $EP125$ or $EP160$) are mostly used. Also combined yarns of cotton with either nylon or polyester are in use, although there is still a small demand for all-cotton belts, too.

In the 1980s, special high modulus, low shrinkage (HMLS) polyester filament yarn was developed for the V-belt (and tyre) market. Belt cords made from this yarn
have high dimensional stability, low elongation, low creep, and high dynamic integrity.

2.3 Hoses

A hose is actually a reinforced tube. A rubber hose has three concentric main layers. The innermost part consists of a rubber lining required to resist the action of the material that would be carried through. The outer top layer is meant to play the role of a protective layer to resist weathering, oils, chemicals, abrasion, etc. Between the inner lining and the outer cover is a layer of reinforcement of textile yarn or steel wire applied by spiralling, knitting, braiding, or circular loom weaving. A cut woven fabric wrapped straight or on the bias may also be used to reinforce the inner lining or tube. For good performance, all these components must be well consolidated together during manufacture.

The process of hose building consists of extruding the lining or tube, braiding or spiralling the textile around the tube, and applying an outer cover of rubber to the reinforced hose using a cross-head extruder. Several methods, either continuous or batched processes, are employed for vulcanization

There is a wide range of hose types available, depending on the type of medium to be carried, the pressure and the volume to be transported. The reinforcement can be applied either as single end cords or as woven fabrics. The reinforcement is required to contain the operating pressure, to prevent undue movement or snaking of the hose, and to impart the burst strength under the most severe operating conditions.

With single-end reinforcement, the cords or wire are applied helically; the angle of this helix is critical in controlling the behaviour of the hose under pressure. If the helix angle chosen is approximately in so called neutral angle, 54.75°, there will be minimal change in the hose dimensions when pressure is applied. If the angle is lower than this, the hose will tend to expand and shorten under pressure, while if the angle is greater, it will lengthen. With fabric reinforcement, it is common to cut the fabric on the bias, so that on wrapping around the core tube, the angle of the yarns in the fabric approximates to this neutral angle.

2.3.1 Different reinforcement types used in hoses

There are several methods for the manufacture of hose reinforcement structure, such as braiding or spiraling with single-end yarns, and helical wrapping, both with single end yarns or with fabric. All methods necessitate their own manufacturing techniques.
Braiding

Braiding method is mainly used for smaller bore hose, up to around 50 mm internal diameter, particularly for medium to high pressure applications, such as automotive brake hose. In this process, the inner tube is extruded onto a suitable mandrel and then passed through the braiding head. Here, a number of single-end packages are arranged and rotate around the tube, to give the braiding pattern of winding and interlacing as required, as illustrated in Figure 42.

Depending on the bore size and the application, an outer layer of rubber may be extruded onto this braid. For the higher rated burst strength hoses, a second layer of braiding and further cover of rubber can be subsequently applied.

![Individual yarns, over 2, under 2](image)

Figure 42. Braided reinforcement of the hose

For the smaller tubes, up to around 10 mm internal diameter and 15 meter length, short steel rod mandrels may be used. In longer tubes, up to about 500 m length, fairly hard long flexible material can be used as the mandrel.

For the short rigid mandrels, an unset finely woven nylon fabric composite, which will shrink and consolidate the hose during cure in an autoclave, is wrapped on the mandrel in a curing line. The long lengths are mainly vulcanized continuously, using a pressurized curing line. In order to ensure easy release of the hose after cure, the braiding yarn is of low shrinkage, such as rayon or high modulus, low shrinkage polyester.

For the majority of applications, a high modulus yarn, such as polyester or rayon, is applied, to give a resultant hose that will not expand or change dimension significantly on application of pressure. For the highest pressures, steel wire or aramid fibre can be used.

In the hoses specifically designed for power steering assemblies, polyamide is the preferred yarn, as this allows some expansion of the hose on the initial application of pressure, thus damping any sudden power surges, which could result in reduced control of the steering movement of the unit.

In fuel system braided hoses, with inner tubes of highly oil resistant rubber, the outer layer must combine oil resistance with good ageing and ozone resistance. The rubber with good electrical conductivity and steel wires are incorporated.
Spiralling

Spiralling is principally similar to braiding and is used mainly for the larger bore high-pressure hoses, from 50 up to 200 mm bore diameter. These kinds of hoses are typically used in hydraulic assemblies. In spiraling, the yarns or wires are wound on helically, with individual yarns or wires being laid together in the neutral angle of wrap, giving complete cover of the yarns. In order to prevent twisting or curving, an even number of layers, with alternate direction of lay, is applied, with a layer of rubber between each layer of reinforcement.

Wrapped Hose

Wrapping techniques is mostly used for large bore hoses, (≥ 50 mm), and are used for pumping on building sites and in places where removal of surface liquids is required.

Wrapped hoses are built on a large lathe or building table, usually with a mandrel. The inner rubber lining is firstly wrapped onto the mandrel, and then the fabric reinforcement layers wound on. The fabric may be cut into relatively narrow widths, so that it can be spiralled on, or can be bias cut into wider sections, so that it can be wrapped directly onto the inner tube. Both of these methods allow the warp to lie at approximately the neutral angle. To avoid collapse under vacuum, helically wrapped heavier wires can be applied.

Generally, these hoses are wrapped with a pressurizing nylon curing liner and cured in an autoclave. Wrapping fabric removed after cure, leaves the characteristic imprint on the surface of the hose.

Square woven fabrics are usually used for reinforcement. Cotton, and today increasingly synthetic materials, either rayon or polyester, are used in wrapping reinforcement. Polyester is more favoured for the larger bore and higher strength fabrics, particularly because of its better resistance to moisture. Adhesion can be achieved in case of polyester by use of dipping or using isocyanate containing solvent doughs.

Knitted reinforcement

Hoses with knitted reinforcement are frequently used for the coolant or radiator hose in motor vehicles, often requiring changes in bore size, with many bends and curves. The inner tube is extruded and the reinforcement fabric is then knitted directly onto it, in a similar manner to the braiding system.

Cotton has been the traditional reinforcement for this type of hose, but use of polyester and even aramid is increasing, particularly with the increasing temperatures under the bonnet of modern cars.
2.3.2 Special hose types

Fuel hose designs

Depending on the application, these hoses are reinforced with knitted, braided, or spiralled yarn, most commonly based on rayon, polyamide, or aramid fibres. The outside of the hose is covered by a heat- and ozone-resistant material possibly with other specific requirements from the outer environment. Injection-molded non-reinforced fuel hoses are used in some applications.

Examples of fuel hose structure alternatives are given in figures 43 - 45 below.

Figure 43. Example of steel wire reinforcement [Hyosung]

Figure 44. Veneer hose design. [Compound Development and Applications George Burrowes, The Goodyear Tire & Rubber Company, Lincoln, Nebraska, U.S.A. Brendan Rodgers, The Goodyear Tire & Rubber Company, Akron, Ohio, U.S.A.]

Figure 45. Barrier hose design.
**Coolant hoses**

**Materials**

Rayon, suitable for service up to 120°C, has long been used as a cost-effective reinforcing yarn for coolant hoses. With increasing under-the-hood temperatures, the more heat-resistant aramids, capable of operating up to 230°C, are used in preference to rayon for the more demanding coolant hose applications. Good abrasion resistance is essential when yarns contact each other in hoses subjected to vibrations.

**Oil suction and discharge hoses**

These large bore hose, up to 600 mm diameter, lengths up to 30 m, are used for loading and discharging oil from tankers at the oil terminals. The basic construction of this type of hose contains inner tube reinforced with helically laid single end reinforcement, usually a heavy polyester cabled cord, and outside this is wound a helical heavy steel wire, to prevent collapse of the hose under vacuum. Outside this, a closed cell foam may be applied as a flotation layer, covered with a thin rubber cover reinforced with breaker fabric.

### 2.5 Miscellaneous applications of reinforced rubber

The preceding chapters have covered the major areas of reinforcement of rubbers, i.e. tyres, different belts and hoses, but there are still numerous applications which do not fall within these groups. For instance, there are applications of coated fabrics for various purposes, different diaphragms, and snowmobile tracks, just to mention a few.

The examples handled in the next paragraphs hopefully shed light to the great variety of application possibilities, including also many commodity goods.

#### 2.5.1 Applications of coated fabrics

The major applications of coated fabrics are in inflatable constructions and coated rubber sheeting, used in the flat state. There are many uses for such constructions, not only for inflatables but also for many shielding applications, oil booms, dams and flexible storage systems etc.
2.5.1.1 Inflatable structures

Inflatable reinforced structures are typically manufactured from fabric which has been treated with a relatively thin coating of the matrix polymer. For some applications, a thicker coating is required and is usually applied by calendering. After preparing of the required thickness of rubber, the unvulcanized sheets are usually rolled onto a steel tube with a light untreated separating nylon fabric, to prevent the layers sticking together, and then cured in an autoclave.

**Inflatable boats**

The most commonly thought inflatable structure is the inflatable boat, dinghies. Its basic construction consists of a buoyancy tube all round the craft, a fabric floor and one or two inflatable thwart. The thwart gives some lateral stability and also increase the buoyancy, especially if the buoyancy compartment is punctured. Dinghies can accommodate about six people.

There are also much larger (up to 6 meters) applications than dinghies, i.e. riverboats. They can be paddled in rapids or fitted with a low power outboard motor. The largest boats can accommodate even 16 people.

Many sports boats, intended to travel at higher speeds, differ in construction from the dinghy in that a rigid traverse is incorporated at the rear and also wooden floorboards are provided.

The inflation pressure used in inflatable boats is about 15 – 25 kPa.

Nylon fabrics are widely used for all types of inflatable structures, although the use of a suitable polyester fabric is also allowed. For dinghies, sport boats and larger boats a range of nylon, plain weave fabrics is extensively used. The stress in the fabric due to the inflation pressure is quite low and in consequence the tensile strength is of less importance than the tear resistance. As there is no significant fatigue problem with the fabric, yarns with little or no twist are used.

Polyester based fabrics have two advantages over similar nylon materials. Both advantages are due to the higher modulus of polyester. One problem in the manufacture of boats is a distortion of the structure in the coating processes, causing the boat shape distortion. This is minimized if polyester is used, since the fabric extends less under the same inflation pressure. The higher modulus of polyester is also an advantage in floor fabrics for boats that are motor driven.

Polyester has, however, processing disadvantages when compared with nylon. PET is rather difficult to achieve good adhesion required and also it may degrade when heated in the presence of some rubber compounding ingredients, particularly when the rubberized fabric is cured in steam.

Pictures of inflatable boats are seen in figures 47.
By using aramid, weight can be reduced, since this fibre is more than twice as strong as nylon or polyester. For example, aramid fabrics of 85 g/m² give approximately the same tensile strength and tear resistance as a 170 g/m² nylon fabric. An extra weight reduction can be achieved by eliminating wooden floorboards since the high modulus of aramid gives sufficient rigidity to the floor.

As the coating compounds of inflatable structures, natural rubber, CSM and its compounds (chlorosulphonated polyethylene), TPE-U (thermoplastic polyurethane elastomer, heat weldable) and PVC have been used.
Oil booms

There are principally two types of oil booms, foam filled boom and inflatable booms. Inflatable booms are typically used onboard safety vessels where a filled boom would be too bulky. The reduced volume of an inflatable boom is an asset when boom has to be transported, possibly by air, to the spill site. They are typically used in open waters where the higher buoyancy to weight ratio assists the performance of the boom in waves.

Inflatable booms are either self-inflating or pressure inflated. Self-inflating booms rely on springs or coils that are compressed in storage, when deployed the springs open drawing in air via one way air valves.

With the growth in the offshore oil industry and with the transportation of vast quantities of oil and oil derived products by sea, there is an inherent risk of spillage and consequent pollution. One method to minimize the effects of such spillages is to contain the oil by means of a flexible boom and pump the oil from the surface into a container from which it may be recovered.

One requirement of the boom is that it can be stored in a small space and be deployed quickly. A type which fulfils this requirement consists of a coated fabric tube which may be stored wound on a large reel in the deflated form (see Figure 48 above). The provision of two compartments enables the boom to stay afloat if one compartment is punctured.
The material used in making the boom is not required to withstand severe conditions. The stress in the base fabric is quite low as a low inflation pressure is used. The coating material must be oil resistant, and cracking when stored in the flat condition for prolonged periods must be minimal. The types of material employed in the buoyancy tubes of inflatable boats are suitable. A nylon fabric is normally used. The coating may be based on CSM or PU, as for inflatable boats, but usually it is polychloroprene, PVC or a PVC/nitrile rubber blend.

**Inflatable Dams**

In some areas, it is desirable to be able to control water levels, by means of temporary structures. Principle of inflatable dam is shown in figure 49. Conventional dams are not feasible or are not required to be permanent, so a system for using inflatable structures has been developed, as illustrated in Figures 50 and 51.

![Figure 49. Principle of inflatable dam](http://www.greenworks.tv/radio/todaystory/20020725.htm)

**Figure 50. Inflatable dams use rubber bladders that are inflated by air to impound water in the spring and deflated when the boating season ends.**

[http://www.greenworks.tv/radio/todaystory/20020725.htm]
The structure is usually made of nylon fabric, coated with a polychloroprene. It can be made up in sections, up to 3 metres high and over 100 metres in length. The edges are anchored with concrete slabs. The structure can be inflated either with air or with water, the latter giving somewhat improved stability.

Under normal conditions, the dam can be deflated, giving minimal restriction to the water flow, but when required, it can be rapidly inflated, giving control of the flow rates and levels.

**Inflatable Buildings**

These structures are usually rounded in cross-section and have rounded ends. The edges are anchored with blocks of concrete or sand, or similar weighted materials and ropes. A complete seal is not needed, as some circulation of the air inside the structure is necessary for adequate ventilation. Rain does not represent any problem, as the curved structure allows it to run off freely and even snow will only lodge on the top-most area of the roof, because of the shape, and any internal heat will reduce this by melting.
The required pressure is of the order of $10^{-20}$ kPa. The access to the building has to have an air lock system (double door system). Use of several pumps at installation will reduce the time to complete inflation of the building. The most strength requirements are so caused by weather conditions and by some mechanical shocks.

### 2.5.1.2 Non-inflated structures

Besides the applications based on inflated structures, there are many applications where similar materials are used flat or filled with some material, for storage or transport. There are also many applications for flat coated sheeting to be used as a shielding layer against different hazards.

Many applications of non-inflated sheeting are processed by spreading techniques, described in section 3.2.

**Liner applications**

In different liner applications, the coated fabric is used to contain a liquid in the reservoir, or to form an impermeable layer on the bottom or walls or it may be used on the surface as an evaporation hindrance, etc. For the bottom liner, a relatively smooth base of the reservoir must be prepared. The liner is rolled out on this ground, and the edges of overlapping sections are then adhered together, using cold curing cement. The edges of the whole sheet are anchored around the reservoir.

![Figure 53. Principle of reservoir liners](image)

Nylon is the preferred fibre for such installations, as it has lower modulus and higher elongation than polyester. This means that it will be more resistant to puncture and damage than a corresponding polyester product. Butyl rubber is the preferred coating material, as this gives the best resistance to weathering and ageing.
**Flexible Storage Tanks**

Flexible Storage Tanks can be used as fuel tanks, e.g. embedded in the wings of aircraft, or as large pillow tanks, for storage or transport of fuels, water, etc.

The aircraft fuel tanks must be highly resistant to puncture damage and ideally. To achieve the optimum resistance to puncture, aramid fibres offer the best reinforcement. The coating has to be resistant to the different types of fuel to be carried.

For the large pillow tanks, the reinforcement is usually polyester, as this gives good resistance to puncture and imparts an inherent stiffness to the installation when full. These tanks can have sizes up to several thousands of litres.

**Hovercraft Skirts**

The hovercraft is a vehicle held above land or water by an air cushion. There are lift fans to provide air to inflate the flexible skirt, which maintains sufficient pressure to lift the vehicle above the underneath. The pressure in the skirt is about 3 kPa. Another class of hovercraft has solid sidewalls and a flexible skirt at the front and rear. This latter type is not amphibious.

Small crafts can operate satisfactorily with simple skirts composed of light fabrics. Because of the relatively small amount required, no specially develop materials are needed.

If the surface over which the air cushion vehicle travels is smooth, then a fairly rigid wall around the periphery may be used to contain the air. In the case of vehicles which are required to traverse rough ground or an uneven water surface, a flexible skirt, which accommodates the contour over which the vehicle is traveling, is essential. The most commonly used systems consist of a trunk, to the bottom of which a number of sealing fingers are attached. Air is pumped into the trunk and from there it passes into the seals and into the cushion area. Both the trunk and the seals are fabricated from rubber coated fabrics.

The trunk-fibre type hovercraft skirts are typically made from nylon, as this gives the best properties of high adhesion (even as wet), and good flex fatigue resistance. As the ends of the fingers are subject to very rapid flexing, the fabrics are usually woven from cords with high twist levels, to give the optimum resistance to flex fatigue. This also gives very compact yarns so the fabrics are usually of quite open construction with relatively large interstices, which enables good penetration of the rubber through the fabric contributing to the high levels of adhesion required. The matt construction also gives a higher tear resistance and consequently an improved lifetime for the fingers.

In some types of skirt, there is advantage in the use of polyester, as the higher modulus reduces the expansion of the cells under pressure, which improves the performance of this type of construction.
For most applications, polychloroprene (especially for trunks), natural rubber (fingers) or a blend of NR with polybutadiene have generally been used. Any contamination by oil, or aging processes will probably not cause significant deterioration of the units within their normal expected life (hundreds of hours).

**Snowmobile tracks**

Snowmobiles (skidoo) are in many ways similar to scooters, but with the wheels replaced with a belt and with small skis at the front, for steering (see figure 54). The standard machines powered by small petrol engines travel at speeds of up to around 80 km/h but the sport machines, with larger engines are capable of speeds of up to 190 km/h.

![Figure 54. Structure of snowmobile [Camoplast.com]](image)

The drive is brought about with a special endless belt, with molded on lugs, to give traction in the snow, as illustrated in Figure 55. For the standard drives, a two-ply nylon carcase is generally used, giving good performance and with good resistance to damage if it strikes hard objects hidden in the snow. These fabrics of leisure skidoos are generally P160 class, like in conveyor belting. For the racing sport machines, however, polyester warp fabrics, similar to EP 160 or 200 are used, as these, with the higher modulus, give better traction and response, but with the potential of greater damage on impact.

![Figure 55. Snowmobile tracks [Camoplast.com]](image)
Protection suits and hoods

Quite an important field of applications for non-inflated fibre reinforced materials are different kind of safety suits and hoods, which are to protect e.g. against chemical, biological or nuclear hazards. Naturally this kind of reinforced can be used as water protecting suits, as raincoats and diving suits etc. The customer organisations for this kind of products may be for instance emergency services, military and general protection, nuclear or chemical industry, pharmaceutical industry, food processing industry, medical services, hazardous material handlers, or industrial safety authorities.

The hazard type dictates the special requirements for the safety suit or attachment. The suits can be single use or reusable, or they can be positive pressure inflated to prevent the hazardous gas to intrude inside the suit. Various solutions for protective suits are based also on laminated multi-layer barrier films (e.g. Tychem® BR and Tyvek® QC, patented by DuPont).

There are numerous standards, legislation and classifications on occupational health and safety issues, concerning the requirements for the safety suits and accessories. For instance, the American OSHA Standard calls for 4 levels of protection, A through D, and specifies in detail the equipment and clothing required to adequately protect the wearer at corresponding danger levels.

**Level A** represents the greatest danger of respiratory, eye or skin damage from hazardous vapors, gases, particulates, sudden splash, immersion or contact with hazardous materials. It calls for total encapsulation in a vapor tight chemical suit with self-contained breathing apparatus (SCBA) or supplied air and appropriate accessories.

**Level B** situations call for the highest degree of respiratory protection but a lesser need for skin protection. It calls for a positive pressure supplied air respirator plus hooded chemical resistant clothing (overalls and long sleeved jacket; coveralls; one or two piece chemical-splash suit; or disposable chemical-resistant coveralls.

**Level C.** Level C protection should be used when liquid splashes or other direct contact will not adversely affect or be absorbed through any exposed skin.

In EU, the protective clothing requirements are described in standard European standard EN 943.

The whole protecting clothing includes typically, in addition to safety suit, a phase mask, protective gloves and boots, as shown in figure 56.
Figure 56. The components of protective clothing.

**Materials**

The selection of the reinforcing garment depends on the special requirements by the application. For instance, tensile, tear and puncture properties are important, as well as the abrasion resistance, flexibility and wearing comfort in many cases. In addition to good barrier properties, also thermal insulation and inflammability properties are often required. As the textile material for the reinforcement, e.g. cotton, polyamide, polyester and polyaramide have been used.

As the polymeric material on the suit material surface(s), PVC, CSM, chloroprene, nitrile or fluorine rubber and butyle rubber(s) or rubber based composites have been used. Recently, also different multilayer plastics structures have been developed for special applications.

Example of the garment material of chemical safety suit:

“The material is based on a woven polyamide fabric coated with elastomers. This construction maximizes strength and durability of a material while maintaining
softness and flexibility. The combination of butyl rubber with Viton® fluorine rubber on top offers an outstanding resistance to chemical attack from a wide range of different chemicals (Trellchem® Super VP1, http://www.trellchem.com)

**Processing of the suit materials**

As described in chapter 3.2, different coating or spreading techniques can be used, when combining the textile and the rubber, especially in case of thin rubber coatings.

Principally, in the fabrication of the reinforced garment, different knife coating and roller coating systems, or combinations of them are used. In some cases, dipping or calendering can be used, too.

In context with the techniques using doughs with different viscosities, attention has to be paid on the solvent drying without any bubble formation, which would deteriorate the barrier properties of the protective suit.

**Product examples:**

1) Some illustration of different suit alternatives for OSHA classes A –D, can be found e.g. from the references.

http://www.approvedgasmasks.com/protective-clothes.htm

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