Trends in steel cord reinforcement for today’s PCR and TBR tyres

A. Sezer

Steelcord Account Manager, NV Bekaert SA, Advanced Wire Products - Steelcord, Kortrijk, Belgium

Paper, German Rubber Conference 2006, 3-6 July 2006, Nuremberg, Germany, Deutsche Kautschuk-Gesellschaft e.V., Frankfurt, Germany

Published with kind permission of the Deutsche Kautschuk-Gesellschaft e.V., Frankfurt

Selected from International Polymer Science and Technology, 34, No. 9, 2007, reference GK 07/07/441; transl. serial no. 15764

Translation submitted by H. Yesson

INTRODUCTION

The tyre industry is becoming more competitive than ever with the increasing number of global players. Tyre manufacturers are always on the lookout for opportunities to improve the efficient use of resources, increase the useful life of tyres and keep the environment as clean as possible. Choosing the “right” steel cord structure for tyre reinforcement has an important part to play in achieving these objectives. For more than 50 years, Bekaert has been working closely with the tyre industry in order to track the latest developments, supply the most needed steel cord products and to maintain production at a high level under changing business conditions.

1. REINFORCEMENT FOR THE BELT PACKAGE

The belt of a tyre generates steering forces, improves traction (safety and performance), helps to form the desired tyre profile, influences the shape of the tyre footprint, has implications for tread wear and protects against impact and projecting objects.

The steel cord in the belt of a tyre has two main functions:

- It influences the rigidity of the belt package (the rigidity of the belt package affects the tyre footprint, wear, drive performance and drive comfort)
- It protects the tyre (especially the top layer) against dangerous impact from the roadway and prevents belt separation and moisture penetration.

2. MARKET TRENDS IN TYRE CORDS FOR PASSENGER CARS (PCR), SUVS AND LIGHT TRUCKS (LT)

Market development in this sector is relatively stable. The use of high-tensile (HT) steel cord products is virtually standard, and we are seeing a growing trend towards super-tensile (ST) grades.

For passenger car tyres the principal cord structures are 2x1, 2+2, 2+1 and 3x1, with monofilament diameters of 0.25 to 0.30 mm, while for SUV tyres and light truck tyres the dominant cord structures are 2+2 and 1+6 with monofilament diameters of 0.24 to 0.35 mm.

Recently we have also seen the use of cords with smaller monofilament diameters (0.23 mm or less) for low-profile ultra high performance (UHP) passenger car tyres.

3. PCR BELT CORDS AND RECOMMENDATIONS FROM BEKAERT

3.1 Commercially available cords

- 2+2/2+1 family: widely used throughout the world. Owing to their irregular cross-section, these cords offer good rubber penetration, but as a consequence the calendering process can cause them to protrude. Straightness, flaring, gaps and clumping are the main processing problems as the distribution of stresses between the monofilaments is uneven.
• 2x1 cords: the strength of this group is relatively low, which means that a higher EPI is needed in the belt package to achieve the required ply strength
• 3x1 open cords: rubber penetration is dependent on the tensile stress. In addition, their loose filaments mean that these cord grades have a disproportionately large cord diameter
• 3x1 cords with a wavy/helical monofilament arrangement; these have limited applications
• 5x1, 6x1 cords: most are produced with relatively small monofilament diameters (< 0.23 mm). They are primarily used for UHP tyres

Recommendations from Bekaert
• 3x0.30 HT Betru S
  Excellent rubber penetration regardless of the calendering process and of energy-elastic stresses.
  The rigidity of 3x0.30 HT Betru is considerably greater than that of 2+2x0.25 structures
  3x0.30 HT Betru offers an excellent strength to diameter ratio, and the ply thickness can be reduced (less rubber compound) by switching from 2+2/2+1 structures
• 2+1 and 2+2 cords are more sensitive to processing because of their irregular cord shape and their diameter (flare), whereas 3x0.30 HT Betru has a circular shape which is much easier to process
• The ply weight can be reduced by up to ±10% by switching from 2+2/2+1 cords to 3x0.30 HT Betru.
Table 1 shows the properties of various 2+2 and 2+1 cords in comparison to 3x0.30 HT Betru. The table also includes a basic comparison index for ply weight, based on equal ply strength.
• 5x0.22 ST Betru S
  Ideal for UHP tyres requiring flexible cords.
  Excellent rubber penetration regardless of stresses during calendering and the Steelastic process
  This is a circular cord which is very easy to process.

3.2 Betru in comparison to open cord
Betru stands for Bekaert Total Rubber Penetration.

Rubber penetration is ensured by means of microscopic gaps which are formed by polygonal preforming of the monofilaments (Figure 1). Betru is a registered trademark of NV Bekaert SA.

What makes Betru superior to open cord (OC)?
• Betru cords remain open, regardless of the stresses acting on the cord during calendering or vulcanisation
  OC is much more vulnerable during processing due to creasing and broken welds
Figure 2 shows how rubber penetration can be influenced by the stresses acting on the open cord during calendering and the Steelastic process.

4. BELT CORDS FOR SUVS AND LIGHT TRUCKS AND RECOMMENDATIONS FROM BEKAERT
2+7xd S/S cords were traditionally used in this tyre segment until recently. In the developed markets a trend towards larger monofilament diameters and fewer monofilaments can be seen.

4.1 Commercially available cords
• 2+2x0.30/0.32/0.35 HT 8/S:
  Good rubber penetration; processing is a problem, however, due to roughness and straightness
• 1+6x0.24/0.28/0.30 HT S:
  It is not easy to combine good processing characteristics with rubber penetration. There is also a high risk of core movement as the core monofilament is not bonded

Table 1. PCR cords - comparison of the basic properties and ply weight of cords

<table>
<thead>
<tr>
<th>Structure</th>
<th>2+2x0.25 HT</th>
<th>2+2x0.25 HT</th>
<th>2+1x0.30 HT</th>
<th>3x0.30 HT Betru</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking force, N</td>
<td>530</td>
<td>605</td>
<td>665</td>
<td>660</td>
</tr>
<tr>
<td>Cord diameter, mm</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>Linear density, g/m</td>
<td>1.55</td>
<td>1.55</td>
<td>1.68</td>
<td>1.68</td>
</tr>
<tr>
<td>Cord rigidity, N/mm²</td>
<td>161</td>
<td>161</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Total ply weight, index, %</td>
<td>100</td>
<td>95</td>
<td>94</td>
<td>90</td>
</tr>
</tbody>
</table>

Figure 1. Betru preforming. Regular cord, circular shape, Open cord, pronounced circular shape, Betru, polygonal shape
Table 2. SUV and LT cords - comparison of the basic cord properties and ply weight

<table>
<thead>
<tr>
<th>Structure</th>
<th>2+2x0.35 HT</th>
<th>5x0.30 HT Betru</th>
<th>3x0.38 ST Betru</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking force, N</td>
<td>1060</td>
<td>1050</td>
<td>1025</td>
</tr>
<tr>
<td>Cord diameter, mm</td>
<td>1.05</td>
<td>0.81</td>
<td>0.83</td>
</tr>
<tr>
<td>Linear density, g/m</td>
<td>3.03</td>
<td>2.80</td>
<td>2.67</td>
</tr>
<tr>
<td>Total ply weight, index, %</td>
<td>100</td>
<td>89</td>
<td>88</td>
</tr>
</tbody>
</table>

5.1 Cords for medium-duty truck and bus tyres

- 3x0.20 + 6x0.35 NT and HT S/Z: widely used, inexpensive, but with limited strength. Owing to the gap between the 3x1 core strand, full rubber penetration does not occur in these cords.

Recommendations from Bekaert

- 0.365+6x0.35 HT Betru: Preformed core for full rubber penetration and adhesion.
- 5x0.38 HT Betru: Full rubber penetration. More suitable for medium-duty truck tyres.

5.2 Cords for heavy duty trucks and buses

- 3+9+15x0.22+1 S/S/Z/S: Still widely used, but very expensive. The cord diameter is relatively large, and full rubber penetration does not occur. The cross-lay structure of the cord makes it difficult to increase its strength, so it is usually only available in NT versions.
- 3+8x0.35 HT S/S: Good value for money and rigid, but full rubber penetration does not occur.

Recommendations from Bekaert

- 3+8x0.33 ST Betru S/S and 4+6x0.38 ST Betru: Full rubber penetration, high strength, rigid and inexpensive. Replacing NT with ST can reduce the ply weight by ±15% due to the lower use of steel and rubber compound.
Figure 3 shows cross-sections of the following cord structures: 3+9+15x0.22+1 NT, 3+8x0.35 HT, 3+8x0.33 ST Betru and 4+6x0.38 ST Betru. The extent of rubber penetration can clearly be seen in the illustrated cross-sections.

Table 3 shows a comparison between the properties of 3+9+15x0.22+1 NT, 3+8x0.35 HT and 3+8x0.33 ST Betru cords. The table also includes a basic comparison index for ply weight, based on equal ply strength.

- HE cords (4x4x0.22 S/S, 3x7x0.22 S/S):
  These are generally very expensive cords with inadequate rubber penetration. We have found that they are gradually disappearing from use, being replaced by regular structures for working cord plies. Their elongation at break drops considerably when embedded in rubber.

Recommendations from Bekaert

- High-impact cords such as 5x0.38 HI:
  Good value for money, full rubber penetration, very good elongation at break and excellent impact absorption (both bare and when embedded in rubber). These cords are ideal for use at an angle in the outer plies, but because of their varying tensile deformation characteristics they are unsuitable in the low-load region for 0° applications.

Figure 4 shows the force/elongation curves for bare and embedded 3x7x0.22 HE and 5x0.38 HI cords. As the curves show, the overall elongation of the 3x7 cord drops markedly after the cord is embedded in rubber, whereas the 5x0.38 HI cord retains its good elongation even when embedded in rubber, due to the curved monofilaments.

![Figure 3](image.png)

**Figure 3. Cross-sections of TBR belt cords**

![Figure 4](image.png)

**Figure 4. Tensile stress/elongation curves for 3x7x0.22 HE and 5x0.38 HI cords**

<table>
<thead>
<tr>
<th>Structure</th>
<th>3+9+15x0.22 NT+1</th>
<th>3+8x0.35 HT</th>
<th>3+8x0.33 ST Betru</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking force, N</td>
<td>2750</td>
<td>3100</td>
<td>2950</td>
</tr>
<tr>
<td>Cord diameter, mm</td>
<td>1.62</td>
<td>1.42</td>
<td>1.34</td>
</tr>
<tr>
<td>Linear density, g/m</td>
<td>8.5</td>
<td>8.34</td>
<td>7.52</td>
</tr>
<tr>
<td>Total ply weight, index, %</td>
<td>100</td>
<td>89</td>
<td>84</td>
</tr>
</tbody>
</table>

Table 3. Heavy-duty TBR cords - comparison of the basic cord properties and ply weight
5.3 Market trends for truck and bus belt cords

The following trends are discernible:

- Simpler cord structures, i.e. fewer monofilaments (and hence easier rubber penetration) and larger (and therefore cheaper) monofilaments.
- Higher strength values, with the aim of reducing tyre weights and cutting overall costs.
- Preformed cords to allow rubber penetration and increase elongation.
- Substitution of HE cords in the top layers in order to reduce costs and facilitate rubber penetration.
- A combination of all these measures.

6. STRENGTHENING THE CARCASS/BASE LAYER

The tyre is a flexible air chamber which carries the load. In the case of truck and bus tyres, high load conditions result in high inflation pressures. Steel cord is the most suitable material for withstanding the stresses that occur in inflated tyres under load. The inflation pressure is converted into a tensile stress in the carcass cords. At high speeds, alternating stresses generated in the carcass lead to dynamic bending stresses (which can result in possible fatigue problems) and to fretting, a long-term damage phenomenon caused by the constant rubbing of the monofilaments.

Fatigue and wear are becoming an increasing problem for truck tyres now that modern tyre manufacturers are aiming for a service life of 10,000,000 km with multiple retreads.

Resistance to fretting

In the interests of vehicle and passenger safety, the carcass cords must remain in good condition even after extended use of the tyre. The monofilaments that make up the cord lose part of their strength due to internal friction under dynamic stresses. The scale of this phenomenon is heavily dependent on the cord structure. Cord structures such as 3+9+15+1 (S/S/Z/S) have multiple contact points between the filaments, and this structure leads to substantial strength losses as compared with compact cords (e.g. 1+18 cc) or cords with the same lay direction (e.g. 1+6+12 Z/Z).

As Figure 6 shows, the damage caused by fretting in the images of cross-sections of 3+9+15+1 (S/S/Z/S) cords recorded after the simulation test (endless belt test) is clearly visible. It can be seen from Figure 7 that under the same test conditions the 1+18 cc cord shows only minimal damage due to fretting. The cables and monofilaments exhibit a substantial loss of strength and fatigue resistance proportional to the extent of the damage caused by fretting.

6.1 Commercially available TBR carcass cords and recommendations from Bekaert

- 3+9+15x0.175 S/S/Z/S. 3+9x0.22+1 S/S, 3+8 S/S:

Figure 6. Cross-section of 3+9+15+1 cord after 10⁶ cycles in the endless belt test

Figure 7. Cross-section of 1+18 cc cord after 10⁶ cycles in the endless belt test
These cords are still widely used, with considerable success in certain markets and in certain applications. Cords with a spiral wrap have lower fatigue resistance and reduced fretting resistance, and their larger diameter means that they require more rubber compound to coat them. It is difficult to increase the strength of the first cord because its cross-lay structure leads to loss of strength. The 3+8 cords have good fatigue and fretting characteristics. The absence of monofilaments in the outer layer means that the breaking force is lower, so the carcass has to be rather heavier in order to obtain the same overall strength.

Recommendations from Bekaert

- 3+9cc, e.g.
  3x0.22/9x0.20(+1) NT/HT    S
  3x0.24/9x0.225(+1) NT/HT    S

- 1+18 cc, e.g.
  0.20+18x0.175 NT/HT/ST  Z
  0.22+18x0.20 NT/HT/ST    Z
  0.25+18x0.22 NT/HT       Z

- 1+6+12 cords, e.g. (if processing of 1+18 cc is a problem or/and if compression resistance under severe load conditions is required)
  0.22+6+12x0.20 HT        Z/Z
  0.25+6+12x0.225 HT       Z/Z

As a general rule these cords are less expensive and incur less damage from fretting than the 3+9+15+1 cords. They are also available in higher strength versions (HT and ST).

As can be seen from Table 4, ply weight can be reduced by replacing 3+9+15+1 cords with 1+18 cc HT cords.

| Table 4. TBR carcass cords - comparison of the basic cord properties and ply weight |
|----------------------------------------|----------------------|----------------------|----------------------|
| Structure                             | 3+9+15x0.175 NT+1   | 0.20+18x0.175 HT     | 0.22+18x0.20 HT      |
| Breaking force, N                     | 1770                | 1540                 | 1945                 |
| Cord diameter, mm                     | 1.34                | 0.9                  | 1.02                 |
| Linear density, g/m                   | 5.42                | 3.71                 | 4.84                 |
| Total ply weight, index, %            | 100                 | 77                   | 82                   |