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Steel cord with a complete penetration of compound into the structure

Latest tire life requirements gave rise to steel cord constructions with a complete rubber penetration into steel cord structure to be used in tire breaker layers. Since 2004 BMZ worked out methods and steel cord constructions having «Betru» advantages and eliminating drawbacks found in the above concept. Tire cord constructions manufactured with the new technology were designated «FRP» (Full Rubber Penetration). When processing open steel cord constructions in calenders, “openness” decreases or even disappears completely due to filament tension, i.e. rubber compound penetration inside steel cord is hampered. We can assert that introduction of «Betru» or «FRP» steel cord is a promising direction of further development of steel cord constructions for breaker layers of tires requiring reinforcing materials with high level of adhesion to rubber, complete compound penetration into the structure, and absence of inner layer wire migration with regard to outer layer wires. Besides, «FRP» steel cord has a number of significant advantages compared to other types of steel cord. That’s why it s reasonable to manufacture existing types of steel cord and develop new construction based on FRP technology.

Key words: *steel cord, tyres, full rubber penetration, reinforcing materials, breaker layers, adhesion.*

Tire industry development is always directed towards improvement of quality and life of both passenger and truck tires to increase safety of road traffic and repairability of tires [1]. Latest tire life requirements gave rise to steel cord constructions with a complete rubber penetration into steel cord structure to be used in tire breaker layers. Absence of channels without rubber in tire cord allows avoidance of the problem of steel cord corrosion due to moisture getting in between wires when a tire is punctured, as well as to reduce fretting because of wire friction during alternating bending with elongation in the result of wheel rolling. Such constructions include special tire cord (with variable geometric position of wires), e.g.: 2+1; 2+2; 3+2 etc., as well as open cord constructions: 1x3 OC; 1x4 OC, etc.

If compared with ordinary cord, disadvantage of constructions with variable geometric wire arrangement is an increased diameter of steel cord compared with steel cord having compact wire arrangement (Fig. 1). This will cause increased rubber consumption in tire production and higher cord filaments vibration during calendering which in its turn leads to their crossing in rubberized cord strip, i.e. to rejects.

When processing open steel cord constructions in calenders, “openness” decreases or even disappears completely due to filament tension, i.e. rubber compound penetration inside steel cord is hampered. Another disadvantage of an open construction is high elongation with low (up to 50 N) tensile loads which may impair tire reaction to steering [1].

A new concept of steel cord with high rubber penetration worked out by Bekaert - «Betru» (Bekaert total rubber penetration) is attractive because of the fact that tire cord diameter slightly exceeds diameter of a “closed” construction and during calendering “openness” of the construction is maintained for rubber penetration [2, 3].

In all «Betru» constructions wire forms a polygon (Fig. 2) in transverse projection.

In this connection, for multi-layer steel cord constructions insufficient wire abutting to each other is revealed and this may lead to inner wire layer migration problems when cutting rubberized strips and in finished tires through a tire bead. This may cause instability of tire cord during compression and early tire failure.

Since 2004 Byelorussian Steel Works worked out methods and steel cord constructions having «Betru» advantages and eliminating drawbacks found in the above concept. Tire cord constructions manufactured with the new technology were designated «FRP» (Full Rubber Penetration) [4-6].

When FRP steel cord is twisted, projection of bent wire on steel cord cross-section acquires star shape. Besides, large bend radius contacting the wires of the inner layer makes additional force interaction preventing wire migration in the steel cord structure due to friction forces (Fig. 3 and 4). Moreover, small bend radius at the peak provides increased unbending at tensile load compared to «Betru», thus guaranteeing clearance availability at a rather high level of tension (e.g. according to tension diagram 3×0.30 HT Betru wire unbending takes place with 60-80 N load, but 3×0.30 HT FRP steel cord wires unbend with 100-110 N load).

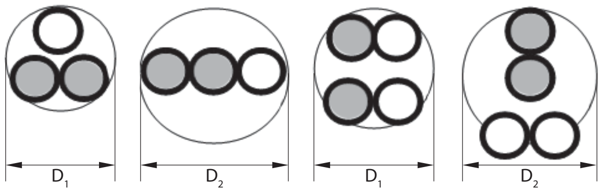

Fig. 1. Single-layer steel cord with variable geometry of wire arrangement on a lay length

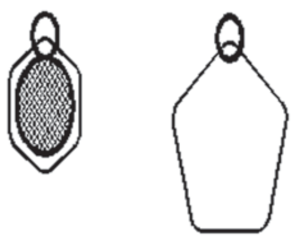

Fig. 2. View of deformed wire in cross-section of “Betru” steel cord

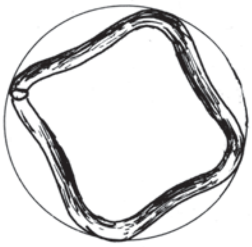

Fig. 3. Geometry of single wire projection on the transverse plane to steel cord axis after deformation and steel cord twisting

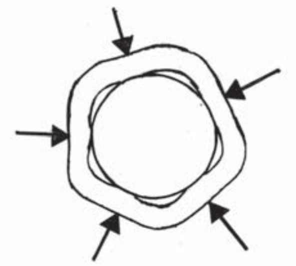

Fig. 4. Force influence of outer layer wires on to inner layer wires

For better penetration of a rubber compound projections of deformed adjacent wires on to longitudinal axis of steel cord are shifted as regards to each other as shown in Fig. 5.

Samples of FRP steel cord use may be constructions: 1z3; 1z4; 1z5, 1+3; 1+4; 1+5; 1+6; 1+7; 2+5; 2+6; 2+7; 3+6; 3+7; 4+7; 5+7, etc. Star shape wires may be available both in outer layer and in the core, separately and jointly. Fig. 6 shows steel cord 3z0.30 HT FRP appearance.

3×0.30 HT FRP cross section at different points along the steel cord length is shown in Fig. 7.

Another example of a specific use is steel cord 0.40+6×0.38 HT FRP is shown in Fig. 8 and 9.

Tables 1 and 2 give comparison of steel cord 0.40+6×0.38 and 3×0.30 HT characteristics of different constructions.

Table 1 shows that steel cord 0.40+6×0.38 FRP has the highest level of central wire stiffening both in rubberized and non-rubberized steel cord by virtue of a special wire shape. Besides, in rubberized steel cord blow-through test absence of air flow via the sample evidences complete penetration of rubber.

According to table 2, steel cord 3×0.30 FRP has not only complete rubber penetration, but advantageous adhesion to rubber. Obviously, this is obtained due to increase of steel cord and rubber contact area, as well as due to mechanical resistance the deformed wire to transverse movement in rubber.

Rubber penetration improvement changes steel cord behaviour in rubberized condition. Comparison of elongation diagrams of steel cord in rubberized and non-rubberized condition was carried out on samples removed from the strip (Fig. 10).

The diagram shows difference of elongation curve at the initial stage. This behavior can be explained by decrease of steel cord structural non-compactness due to filling of space between steel cord wires with rubber mixture during calendering. Breaking load of rubberized and non-rubberized steel cord is approximately of the same level.

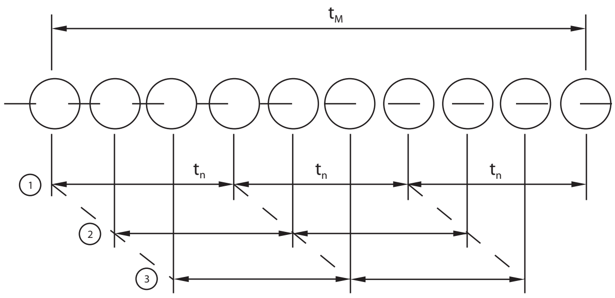

Fig. 5. Location of deformed wire zones on 3xd steel cord lay length: t_M **– steel cord lay length;** t_n **– projection of distance between small radius wire bend points on steel cord axis;** 1, 2, 3 **– number of dia. (d) wires according to arrangement on lay length.**

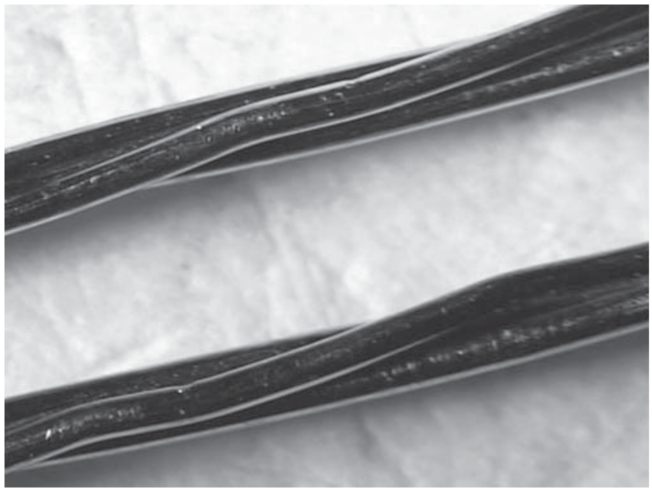

Fig. 6. Steel cord 3×0.30 HT FRP appearance

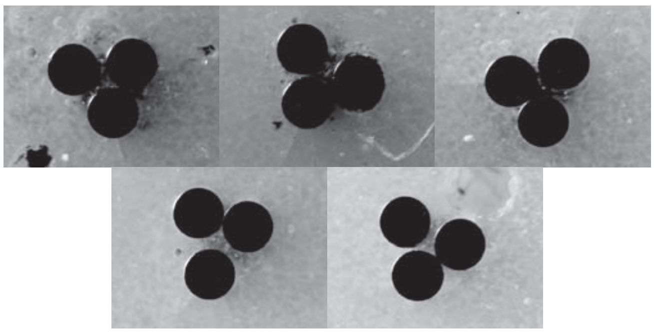

Fig. 7. Geometrical location of wires in steel cord 3×0.30 HT FRP

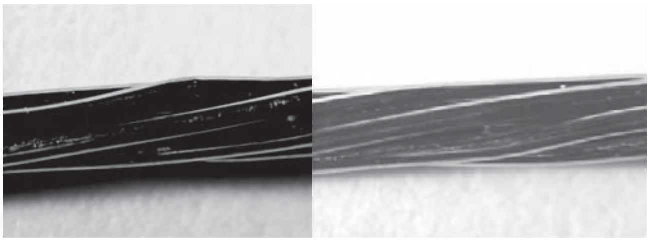

Fig. 8. Steel cord 0.40+6×0.38 HT FRP appearance (at 16$^{\times}$)

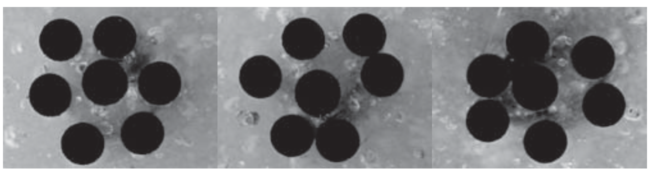

Fig. 9. Transverse arrangement of wires in steel cord 0.40+6×0.38 HT FRP

Table 1. Comparison of steel cord 0.40+6×0.38 characteristics of different constructions					
Steel cord construction	Diameter, mm	Steel cord to rubber adhesion, N	Decrease of pressure, MPa	Central wire stiffening in steel cord, N	Central wire stiffening in rubberized steel cord, N
0.40+6×0.38 (ordinary)	1,16	889	1,0	26	334
0.40+6×0.38 Betru	1,25	896	0,0	29	340
0.40+6×0.38 FRP	1,19	894	0,0	332	357

Table 2. Comparison of steel cord 3×0.30 characteristics of different constructions				
Steel cord construction	Diameter, mm	Breaking force, N	Steel cord to rubber adhesion, N	Decrease of pressure, MPa
3×0,30 (ordinary)	0,64	662	584	1,0
3×0,30 Betru	0,67	628	598	0,0
3×0,30 FRP	0,68	612	605	0,0

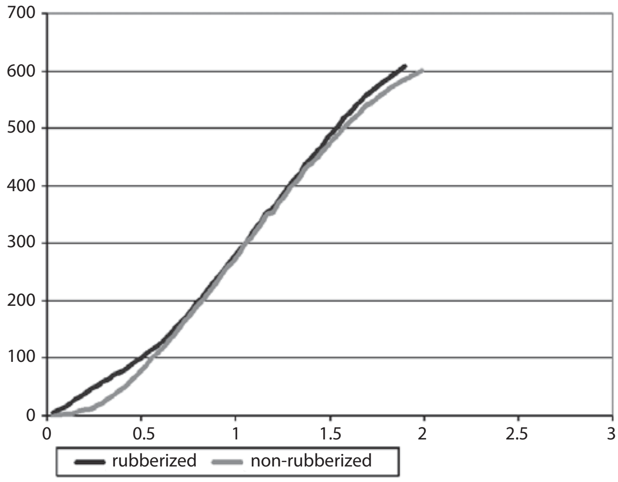

Fig. 10. Elongation diagram of 3×0.30 HT FRP rubberized and non-rubberized

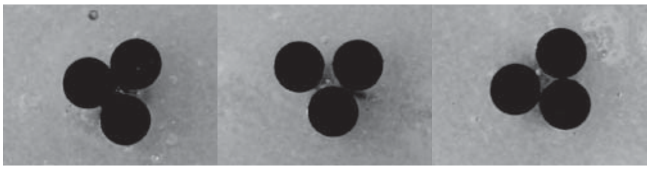

Fig. 11. Geometrical arrangement of wires of steel cord 3×0.30 HT FRP with one deformed filament

Similar result of steel cord openness for complete compound penetration into steel cord structure is obtained in twisting of steel cord 1×3 with one deformed filament according to FRP technology.

In this variant of steel cord 3×0.30 HT FRP manufacturing, two filaments have minimum residual bending deformations and are defining for relative elongation value of the whole construction. Thus, this construction combines a higher module of elasticity at elongation which actually coincides with closed constructions of steel cord (Fig. 12) and its openness for compound penetration (Fig. 11) corresponding to open steel cord constructions.

The most important test for compound flowing is hot calendaring on LOMK 800 calender.

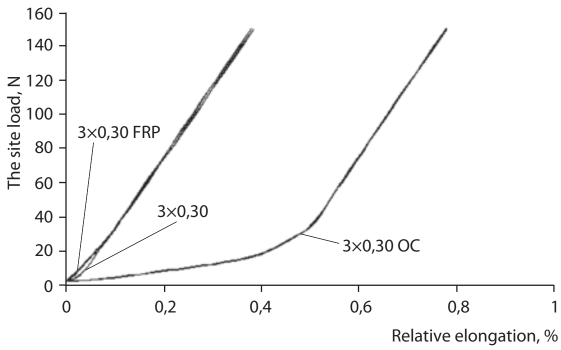

Fig. 12. Comparison of elongation diagrams of steel cord 3×0.30 with various deformation of separate filaments (the site load, N on the axis of ordinates and relative elongation, %, on the axis of abscissa)

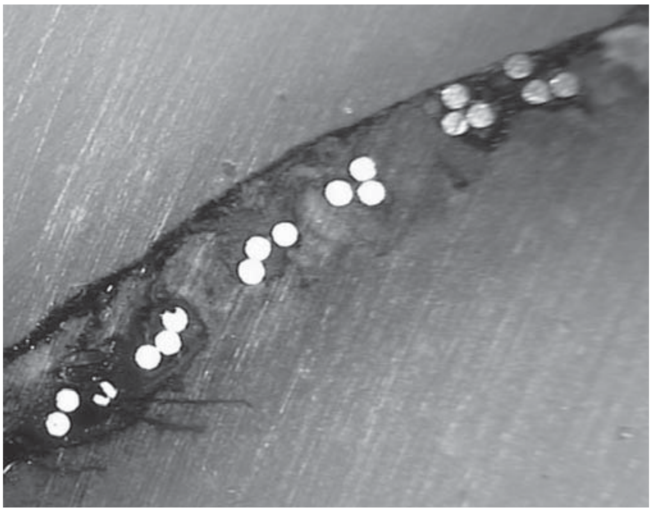

Fig. 13. Cross-section of a rubber-steel cord strip

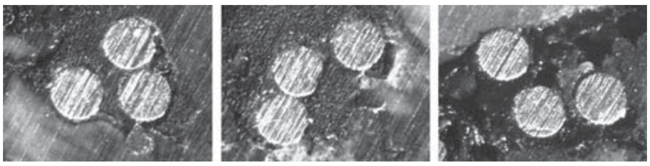

Fig. 14. Segments of a rubber-steel cord strip: geometrical arrangement of wires after calendering

So as to determine steel cord behaviour during rubber coating in the metallographic lab visually, transverse sections of rubber-coated strips were prepared (Fig. 13 and 14).

In the pictures received (Fig. 13 and 14) loose abutment of wires ensuring complete compound filling of steel cord structure during calendering can be seen. This evidences that steel cord retains it openness for compound at tensile loads during calendering.

Thus, we can assert that introduction of “Betru” or “FRP” steel cord is a promising direction of further development of steel cord constructions for breaker layers of tires requiring reinforcing materials with high level of adhesion to rubber, complete compound penetration into the structure, and absence of inner layer wire migration with regard to outer layer wires. Besides, “FRP” steel cord has a number of significant advantages compared to other types of steel cord. That’s why it s reasonable to manufacture existing types of steel cord and develop new construction based on FRP technology.

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