The analysis of directions of metal cord constructions developments depending on the place of application in tires of different function is carried out. The requirements to metal cord, which are necessary to be taken into account at development of its new type, are given. The peculiarities of perspective types of reinforcing agents for tires, and also advantages of new types of metal cord over the existing ones are shown.

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NEW TRENDS IN STEEL CORD DEVELOPMENT

Since the time when reinforcing material for tires and industrial rubber articles (steel cord) appeared, one can see its constant development in embodiment, as well as in strength characteristics.

Generally, this development is caused by requirements change in tyre industry. A lot of tyre enterprises aimed to reduce materials consumption, to reduce the loss in rolling, to increase the working life of tyres in order to develop their production. Due to this, the priority requirements for steel cord and rubber-steel cord composites for tyres will be: service life increase of steel cord rubber system; further decrease in breaker materials consumption due to the usage of high-strength and compact constructions of steel cord together with improved covering rubbers and technological processes to manufacture rubber-cord composites.

It is a common knowledge that steel cord of different constructions, having the same (effective) diameter, differs by different production costs and characteristics. In table 1 the role of steel cord construction is shown to reach them.

As you may see from the above analysis, there is a possibility to optimize a choice of one or another steel cord construction in terms of the price-required parameter set ratio. So, the priciest one is a rope steel cord constructions (3×3; 7×4; 3×7), less expensive – spiral constructions (3 + 6; 3 + 9; 3 + 9 + 15). The least labor-consuming constructions are the ones that are manufactured during one technological operation – simple, compact and special.

While improving the strength, it is of high importance not to allow its decrease at the process of steel cord laying. From this perspective, the most preferable is a steel cord of a compact construction. That is why among the constructions with equal quantity of wires, equal diameter and the same strength group, the compact steel cord strength level will be higher. While designing tyres, one of the most important indices is the load factor of reinforcing material that directly affects the specific amount of metal and respectively the weight of a tyre itself. This factor depends on intensity of steel cord strength change while running because of reduction in wire diameter as a result of fretting corrosion. The constructions that have a linear contact of wires between them, together with those that have a total penetration of rubber compound have the best resistance to fretting. Compact constructions, steel cord of one side rope laying (HE) and of special construction (with changeable geometry of wire positioning) belong to them. Flexural stiffness index in breaker – strip plies of tyres determines shape stability under load, the value of contact patch and, relatively, a level of resis-

T a b l e 1. **Influence of steel cord construction on its characteristics**

Characteristics	Rope type		Spiral type		Simple (compact)	Special
	cross.[1]	one-side.[1]	cross.[1]	one-side.[1]		
Cost of layer	***	***	**	**	*	*
Strength	**	**	**	**	***	**
adhesion to rubber	**	**	**	**	**	***
Toughness of breaker layer [2]	**	*	**	**	**	***
fatigue strength [2]	*	***	**	***	***	**
Resistance to fretting corrosion	*	***	**	**	***	***
Resistance to corrosion	*	*	*	*	*	***
Resistance to impact load	**	***	**	**	**	**(*)[3]
Resistance to core escape	***	***	**	**	*(*)[3]	***
Elongation at breaking	*	***	*	*	*	*(**)[3]

* – low property level; ** – middle level; *** – high level.[1] – cross or one-side lay; [2] – determined substantially by diameters of cord elements; [3] – depends on construction configuration.

tance to rolling. The usage of wires with increased diameter in steel cord makes it possible to assure the required stiffness of a breaker-strip ply and, as far as possible, to reduce the quantity of plies in a tyre. As a rule, increase of wire diameter is done for special constructions due to not large quantity of wires in a structure.

Adhesion index is determined by applied coating on a wire and by variety of steel cord surfaces. The steel cord of an open construction and with changeable geometry of wires positioning (2 + 1; 2 + 2) has the largest surface. Moreover, these constructions, due to complete penetration of a rubber compound into free areas between wires, increase their resistance to corrosion.

Fatigue endurance of a rubber-steel cord composite is determined by many parameters, but from a constructive perspective of steel cord: by wire diameters; relative position of wires; lay of wires; depth of rubber penetration. From this point of view the following steel cord constructions proved to be good: rope type with one-side lay (HE), spiral type with one-side lay (3 + 9; 3 + 9 + 15) and compact (1 + 18).

The resistance to impact loads is one of important tyre characteristics when operating in lack of roads conditions. Basically, it is determined by total elongation value when steel cord is undergone tensile test. A rope type with one-side lay (HE) construction and special with pre-deformation of wires (HI) construction have the highest resistance to impact loads from among all currently existing steel cord constructions.

Resistance to core escape in a rubber free condition is provided by steel cord of a rope construction as well as an open steel cord and with a changeable disposition of wires. The first ones prevent a core from traveling by means of mechanical affect, but an open one by means of binding affect of a rubber mixture.

First-priority characteristics for carcass ply and breaker-strip ply of tyres, developed and field-proven long ago, are actual up to now (tabl. 2).

Table 2. **Priorities of steel cord performance characteristics**

Characteristics	BREAKER	CARCASS
Breaker-strip ply cost (carcass)	++	++
Strength	++	++
Adhesion to rubber	++	++
Weight of breaker-strip ply (carcass)	+	++
Stiffness of breaker-strip ply (carcass)	++	–
Fatigue strength	±	++
Resistance to fretting – corrosion	+	++
Resistance to corrosion	++	±
Resistance to impact loads	+	+
Resistance to core escape	++	±
High elongation at breaking	±	–

++ – crucially important; + – important; ± – of little importance or important in particular cases; – – it is undesirable.

On the basis of it, one can say that a breaker needs low cost steel cord, high strength, high adhesion, proper flexural stiffness, good corrosion resistance and no core traveling. Carcass tyre ply needs steel cord with low cost, high adhesion and tensile strength, good resistance to fretting corrosion and relatively with high fatigue strength.

As one can see in performance characteristics, a certain steel cord type is necessary for each tyre ply. A distribution chart of modern steel cord types according to rationality of application in tyre plies is shown below (Fig. 1).

Main development tendencies of reinforcing materials

Development perspectives of steel cord constructions

Carcass

Purposely to decrease tyre weight by thickness reduction of carcass and breaker plies remaining the same strength of bands, simplified steel cord constructions from super – and ultra-surer high strength wire find a bigger use. Several companies chose tyre development concept using the steel cord with component strength reaching 4100, and in some cases up to 4800 MPa.

Since high strength obtaining is eased by reduction in wire diameter, presently the following stages of steel cord elements strength are accepted (tabl. 3).

Table 3. **Differentiation of wire strength by groups depending on its diameter**

Strength level	High	Super high	Ultra high
Designation	HT (high – tensile)	ST (super tensile)	UT (ultra tensile)
Strength, MPa	3680–1400×*d**	4050–2000×*d**	4400–2000×*d**

* *d* – wire nominal diameter in mm.

BMZ is working on increase of steel cord tensile strength by more complete usage of material characteristics resources. The manufacture of ultra high strength steel cord is mastered with the strength of initial wire of 3500–3800 MPa. Active researches are being done to receive ultra high strength wire of 3800–4200 MPa. Presently, experimental samples of steel cord from such wire are being tested by consumers.

Replacing a common strength in a steel cord carcass, one of priority characteristics is increased – endurance. On the diagram below relative data for cycle quantity undergone by steel cord in a rubber free condition at tests for 3-roller bending with load of 20% from breaking strength is shown. The above constructions are counted upon to receive full-strength material.

As it goes from the diagram, with the increase of element strength and simplification of construction,

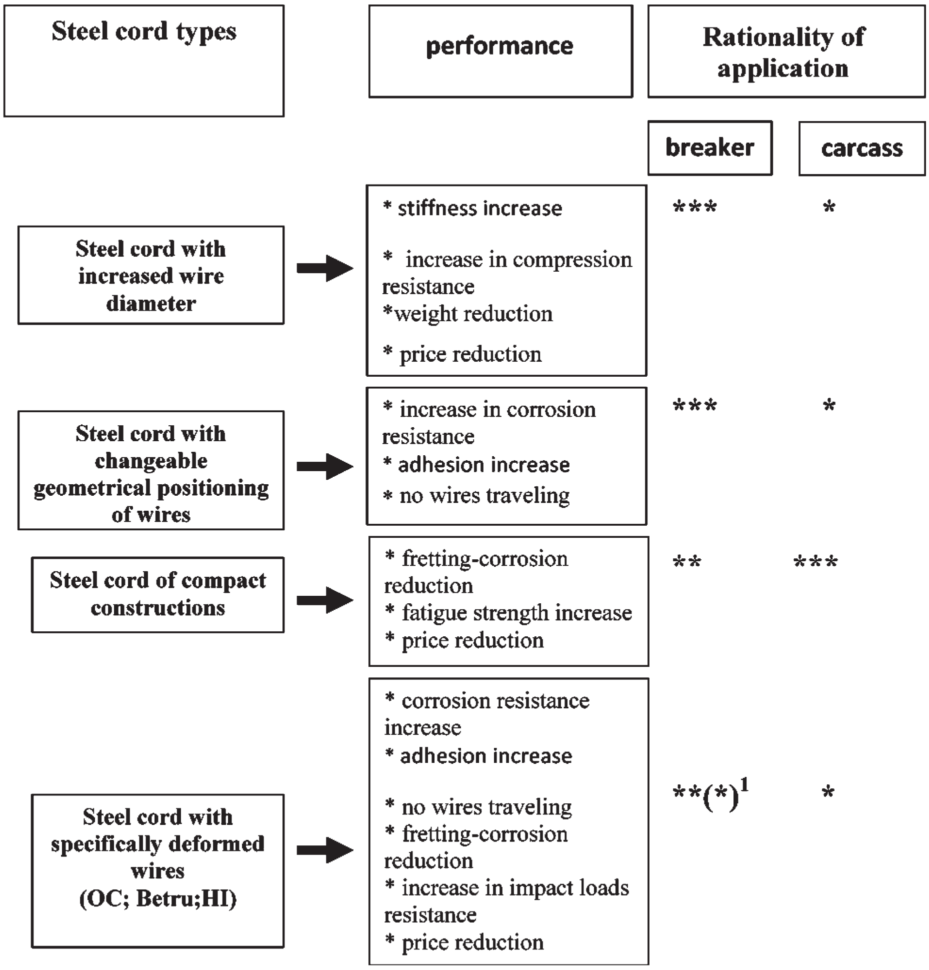

Fig. 1. Main development tendencies of reinforcing materials: * – as a rule, not desirably, ** – possibly, *** – most reasonably, I-MI- just as shielding layer

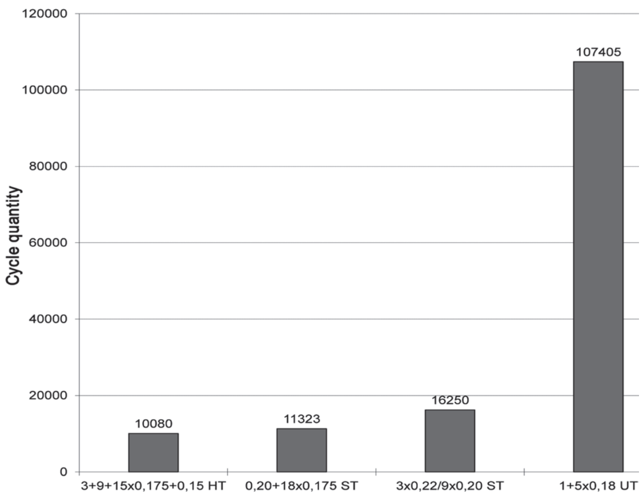

Fig. 2. Fatigue enduarance of steel cord constructions at 3-roll bending (20% load)

the quantity of cycles is appreciably increasing until the point of damage. According to the test results of experimental tyres, the usage of steel cord with ultra high strength in a carcass of automobile, light-truck and truck tyres instead of textile cord or high strength steel cord allows to reduce considerably rubber content and tyre weight; or with the same weight the construction strength is increased. It allows compensating costs that are caused by price increase for steel cord of a new generation. Application effect of this steel cord is shown in table 4.

T a b l e 4. **Efficiency of using ultra high strength steel cord in tyres**

Tyre type	Initial material	Threads quantity/cm	New material	Threads quantity/cm	Reached effect
195/75R14	2×0,30 HT	9,4	2×0,23 UT	13,4	Reduction of tyre weight by 15,6%
	2×0,30 HT	9,4	2×0,30 UT	8,1	Reduction of tyre weight by 6,2%
	2×0,30 HT	9,4	2×0,30 UT	9,4	Увеличение прочности на 16%
215/85R16	2+2×0,30 HT	5,1	2×0,30 UT	8,7	Reduction of tyre weight by 14,6%
	2+2×0,30 HT	5,1	2×0,35 UT	8,1	Reduction of tyre weight by 8,3%
225/75R15	polyester	2×11,8	2x0,18 UT	1×16,9	Reduction of tyre weight by 23,5%
	polyester	2×11,8	3x0,18 UT	1×11,8	Reduction of tyre weight by 23,5%

Thus, usage of new materials to produce steel cord allows reducing the weight and rubber content by 6 –25%.

Breaker

Ultimately, we can make a general view of how steel cord constructions for a breaker will develop in the near future and it will help to reduce the weight of reinforcing materials in a tyre and the weight of a tyre itself, to increase corrosion resistance of steel cord in a rubber free condition, to reduce tyre's resistance to rolling, to reduce the surface unit cost of rubber-cord, to reduce the surface unit cost of a rubber-cord material. Below you can find examples of evolutional development of steel cord (tabl. 5, 6).

The major part of leading tyre companies set high requirements for steel cord corrosion resistance, used in a breaker because a big percentage of tyres prematurely out of service occur due to corrosion.

That is why actual constructions are 2 + 1 × *d*, 2 + 2 × *d*, 3 + 2 × *d*, they make an open passageway for a rubber mixture due to constructive disposition of wires. New steel cord constructions providing complete penetration of rubber mixture are cord «Betru» (Bekaert total rubber penetration) and «FRP» (Full rubber penetration), and also «HI» (High Impact) (Fig. 3).

All these constructions can be labeled as the steel cord type with preliminary deformed wires. They all remain open for rubber mixture flow through gaps at bending points while calendering. In the cross section a wire of steel cord 'Betru' makes a polygon. While laying steel cord «FRP», the view of curved wire is of star type in the cross section of steel cord. A big radius of bending touching wires of inner ply makes an additional power interaction. It prevents wires from traveling in the steel cord structure due to friction force. Cord testing for wire anchorage of inner lay is done in a rubber-free condition, as well as in a non-rubber-free condition in RUE 'BMZ'.

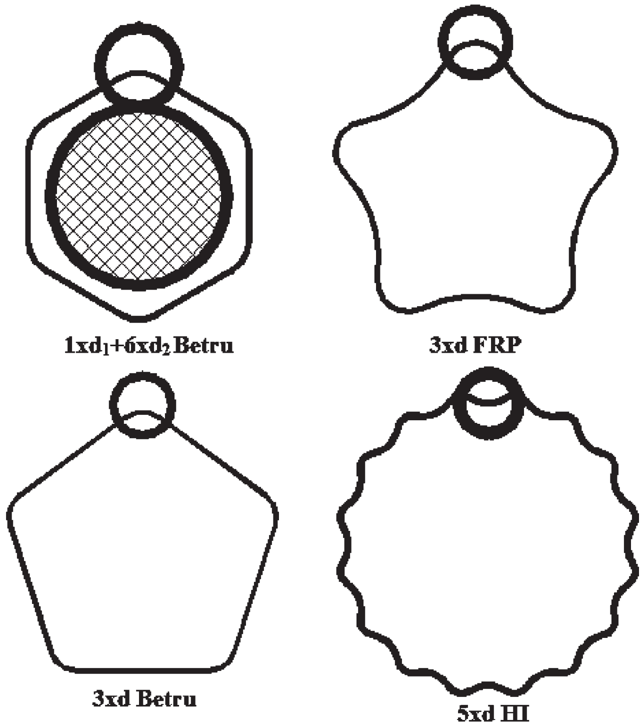

Fig. 3. Constructions of metal cord, enabling full rubber penetration

The advantages of metal cord of open constructions with different ways of wire deformations are shown in the table 7,8.

It is of high importance to avoid central wires traveling in a multiple ply steel cord which is used in a breaker of truck tyres. That is why a lot of tyre designers are afraid of using steel cord of compact constructions in a breaker or with one central wire without braiding wire. Although there are negative factors of applying braiding wire: steel cord weight and its diameter are increasing, flexibility is decreasing due to

Table 5. **Example of evolutional development of steel cord constructions for automobile tyres**

Construction	4x0,265	3x0,30 (HT) 3x0,30 OC (HT)	2x0,30 HT	2x0,32 HT
Wire	0,265	0,30	0,30	0,32
Strength group	NT	NT (HT)	HT	HT
Quantity of wires in a cord	4	3	2	2

Table 6. **Example of evolutional development of steel cord constructions for truck tyres**

Construction	3x5x0,18	3x0,15/6x0,27 CC	2 + 7x0,23	2 + 2x0,32 HT
Wire	0,18	0,15; 0,27	0,23	0,32
Strength group	NT	NT	NT	HT
Quantity of wires in a cord	15	9	9	4

Table 7. **Comparison of steel cord properties 0,40 + 6x0,38 of different configurations**

Steel cord construction	Diameter mm	Adhesion of steel cord with rubber, H	Pressure drop, MPa	Central wire anchorage in steel cord, H	Central wire anchorage in a rubber free steel cord, H
0,40 + 6x0,38 (common)	1,16	889	1,0	26	334
0,40 + 6x0,38 Betru	1,16	896	0,0	29	340
0,40 + 6x0,38 FRP	1,16	894	0,0	332	357

T a b l e 8. **Comparison of steel cord properties 3×0,30 of different configurations**

Steel cord construction	Diameter mm	Breaking strength, H	Adhesion of steel cord with rubber, H	Pressure drop, MPa
3×0,30 (common)	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

T a b l e 9. **Test results for steel cord constructions 3 × 0,15 + 6 × 0,265 and 2 + 1 × 0,15 / 6 × 0,265**

Construction	Lay, Mm and direction of lay	Steel cord diameter, mm	breaking strength, H	linear density, g/m	Taber hardness, g×cm	Cycle quantity before breaking*	Core pulling force, H/12,5 mm	
							original	In rubber free condition
3×0,15 + 6×0,265	10,0/10,0 S/Z	0,81	1005	3,03	41	18118	8,5	12,9
2 + 1×0,15/6×0,265	9,8/5,1/9,8S/S/S	0,82	1009	3,05	41	19941	11,7	32,8

high friction of wires, fretting corrosion is increasing and the price of steel cord is high. The modern development of steel cord with its target to provide a complete rubber penetration allows struggling against central wires traveling. That is why the cords «Betru», «FRP», the cords with periodical geometry change of wires distribution in a core find a use, providing a periodic linear touching while producing cord as per technology with compact disposition of wires (for instance: $(2 + 1) \times d_1 + 6 \times d_2$) (Fig. 5, *a*).

To prevent a central wire from traveling, the steel cord with preliminary deformed core is used (Fig. 5, *b*). A mechanical resistance to wire traveling occurs also due to interaction with rubber (tabl. 9), which penetrates into the gaps between wires of outside lays.

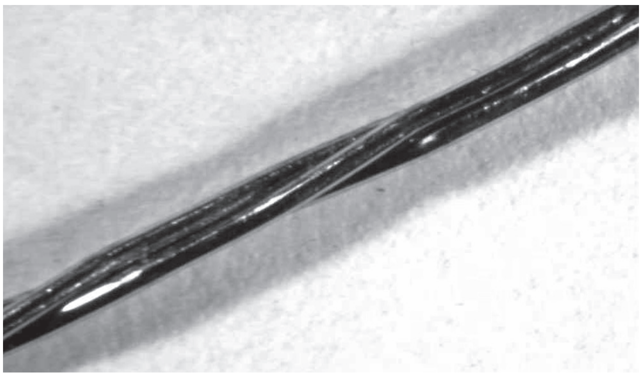

Fig. 4. Steel cord appearance 3x0,30 HT FRP

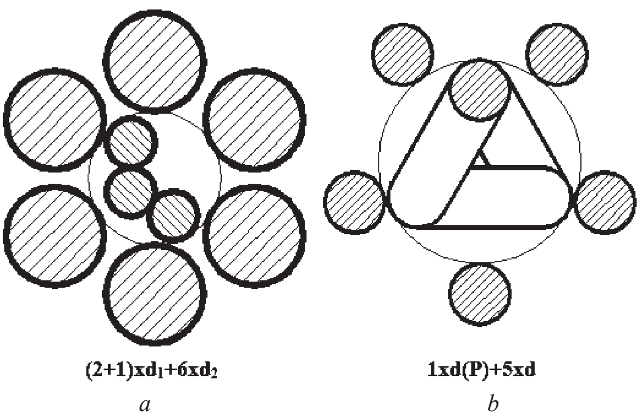

Fig. 5. Steel cord constructions with rubber complete penetration and an improved fixation of core's wires (P-preformed)

The usage of steel cord as reinforcing material for tyres and general mechanical rubber goods has not displaced completely the usage of textile cord. Up to now there is a big range of combined tyres, consisting of steel cord breaker and textile carcass. It is related to the advantages of textile cord in flexibility and endurance and the advantages of steel cord in stiffness, adhesive bond, strength, compression resistance.

Combination of all advantages will result in producing reinforcing material for tyres with unique possibilities. Many steel cord designers see the development in a combined steel cord. Basically, textile thread is placed into the center of a steel wires construction. Besides, a thread is a soft support, providing mobility of wires; it increases endurance of steel cord, fills in inner gaps between wires and is used as an element participating in aggregate breaking of steel cord.

As a rule, it results in the usage of expensive high-module threads of 'Kevlar' type, and it causes an increase in price for steel cord.

The test of steel cord $F + 12 \times d$ shows that due to big difference between complete elongation of a textile thread and a steel wire, the strength of an expensive thread is used by approximately 70% (Fig. 7), that is why the perspective of this direction is open to question.

There is another application of a textile thread – as a separation ply between wires in multiple ply constructions (Fig. 8).

A wire of an upper ply does not contact with wires of inner ply and between themselves in a ply thereby

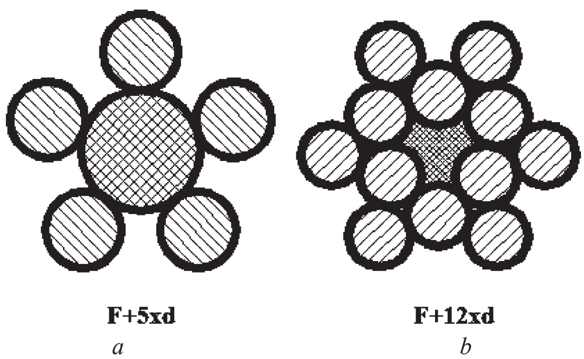

Fig. 6. Constructions of combined steel cord (F- fiber)

eliminating fretting corrosion. Forming gaps between wires of outside lays let rubber mixture penetrate in, preventing wires from migration and increasing corrosion resistance. Moreover, for this application of a textile thread it is not necessary to use expensive high module configuration.

Making up a conclusion, we can note that one direction in steel cord development lies in strength increase of the wire that is in use for all constructions. The next direction is to produce constructions with high penetration depth of rubber mixture due to the usage of constructions with changeable geometric disposition of wires with specially deformed wires like 'Betru' and 'FRP' types, and also multiple ply cord with changeable geometric disposition of core wires and a combined one with a textile thread.

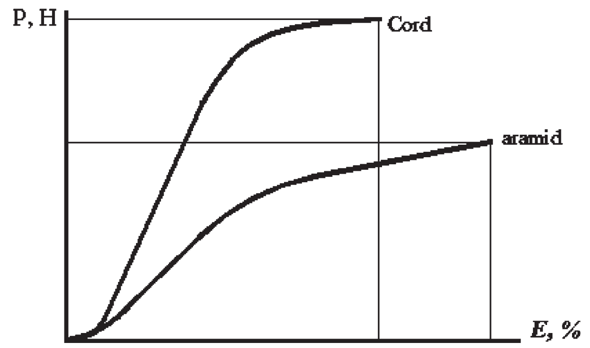

Fig. 7. Diagram of aramid core extension together with twisted steel cord

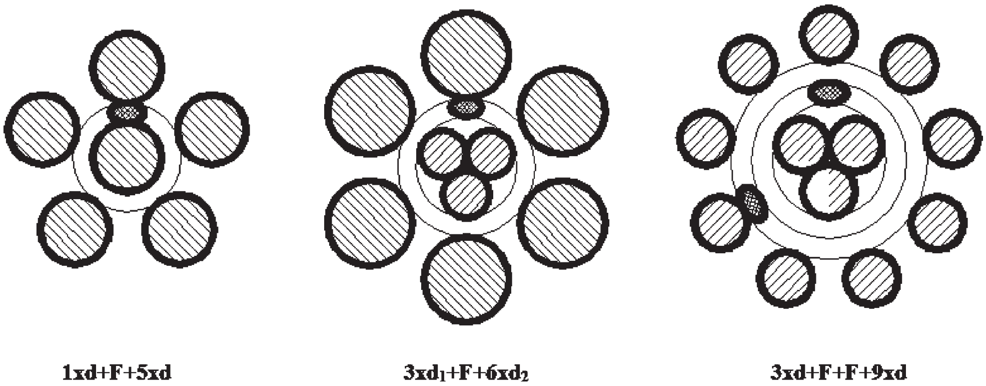

Fig. 8. Constructions of combined metal cord with textile fiber separating wire layers

For steel cord of a breaker ply the constructions with high stiffness should be developed by using wires of an increased diameter. The application of steel cord compact constructions and a combined one with a textile thread in a carcass ply is the most reasonable idea. They ensure high endurance level.

We hope that the submitted materials will help tyre designers to prepare the requirements for steel cord for new developments in tyre industry and to select analogous constructions purposely to increase performance characteristics of tyres.