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31.08.07. METHOD OF MODULAR MANUFACTURE FOR LARGE-SIZE AUTOMOBILE TIRES

Victor Evseyevich Evzovich,
PhD in Technical Sciences,
Corresponding Member of Public Academy of Quality Problems RF,
Moscow
Artur Samvelovich Barsegyian
Director of OOO "SP-Service"
(a service company for large-size tires),
Moscow
Vladimir Efimovich Shekhter
Chief Technologist of Automobile Tire Production,
OOO "SP-Service".

Abstract. Giant OTR tires (GOTR) are not made in Russia. The annual import of only 33.00R51 tires, which are the most common in Russia, costs the country more than 10 billion rubles. The article considers a modular method of GOTR tire production in two stages. *The first stage* – a GOTR manufacturing plant produces "modules" i.e. incomplete tire blanks without tread, not fully vulcanized in a "smooth" ("slick") mold without its working surface engraving. *The second stage* – a Russian tire repair/retreading factory, located closely to GOTR tires consumers accomplishes assembly and vulcanization of modular tires in a serial segmented mold or by a modified moldless method used by tire repair/retreading plants. With minimum capital expenditures, the proposed method will raise tire uniformity, efficiency and repairability, will reduce the cost of tires at mining enterprises and their import dependence; improve environmental safety of production; it will contribute to the full utilization of existing

capacities, the creation of additional jobs, improvement of the technical and economic performance of tire manufacturers and consumers.

Key words: Modular tire. Modular two-stage production. Tire non-uniformity. Diffusion of gaseous substances from tire. Smooth (slick) mold. Tire delivery to consumers. Efficiency of modular tires for their producers and consumers.

1. Introduction

There are two categories of large-size automobile tires for open-pit haul trucks: large-size tires (OTR) 18.00-25, 21.00R35, 24.00R33 for haul trucks with a load capacity of 30 to 55 tons, and giant tires (GOTR) 27.00R49, 33.00R51, 40.00R57, 46/90R57, 59/80R63, 60/80R63 –– for haul trucks with a load capacity of 90 to 400 tons.

In recent years, the global tire market has developed a steady deficit of GOTR. As an example, the article considers the medium-sized 33.00R51 GOTR, which are the most popular in practice. This tire of the premium Bridgestone brand, the most common in Russia, has been adopted as a standard (reference tire)).

GOTR tires are not produced in Russia. The growing demand of domestic enterprises (primarily in the mining industry, open-pit mining) is satisfied with the supply of radial GOTR tires of leading tires companies - monopolists: Bridgestone, Michelin, Goodyear. The cost of these tires, including custom-house fees, is extremely high. The price of each tire exceeds the price of a medium-powered car, for example, the price of a 33.00R51 tire adopted as the standard is 1,320 thousand rubles. Expenses on GOTR, along with fuel, are the highest in the operation of special machinery (the second item in the budget of a mining facility). The annual import of 33.00R51 tires (about 8000 pcs/year) costs the country more than 10 billion rubles. Less expensive large-size tires from other manufacturers are losing their positions in Russia from year to year due to their relatively small mileages [**1**].

One of the reasons for the reduced service life of GOTR is their lack of uniformity. When making a tire in the conventional way during its vulcanization in the process of tread pattern molding, the tread rubber compound flows into the engraving recesses of the mold working surface, and drags the undertread rubber compound, impairing the stability of its thickness along the tire profile. Especially in tires with a deep articulated tread pattern. In radial tires with such a pattern there may be some displacement of belt cords and rising of belt edges (Fig. **1a**). As a result, tire uniformity becomes impaired, its performance, durability and repairabilty fall. Tire non-uniformity contributes to the emergence of local sites of increased heat generation and its failure. This is especially dangerous for highly loaded large-size tires that are prone to overheating to temperatures above critical ones. Heat withdrawal from their inner layers is extremely limited, due to the large thickness of the tire walls and its weight (from 1.3 to 5 tons), due to the large number of carcass plies and belts (which can withstand loads from 18 to 63 tons), and a heavy tread (30-40% of the total tire mass).

The large thickness of the cover rubber of large-size tires, especially in the shoulder area, prevents the exit (diffusion) of gaseous substances , i.e. air trapped during tire building, cement solvent vapors that have not had time to escape, water vapor and gases formed during vulcanization, which are the cause of internal defects (blisters, ply separations, porosity).

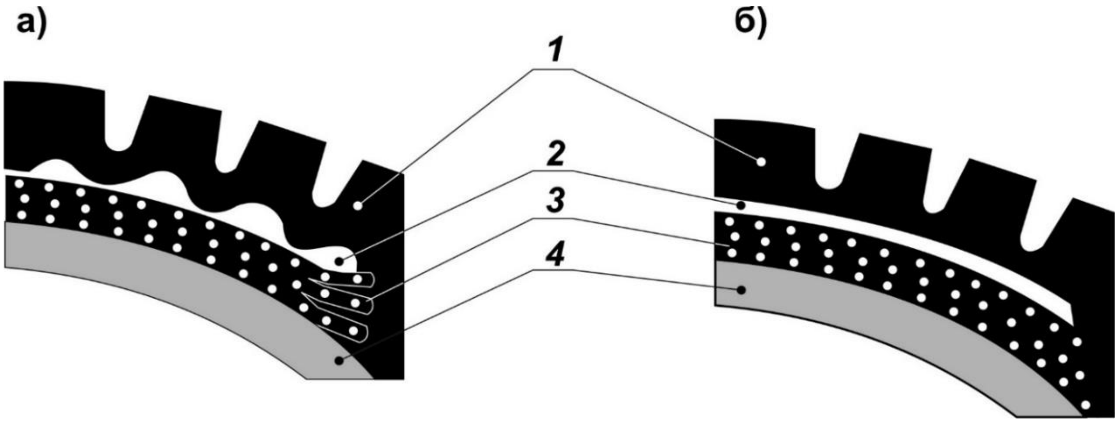

Figure 1. Sections of serial (a) and modular (b) tires: 1- tread; 2 – undertread (of white rubber); 3 –belt/breaker; 4 –carcass

In Russia, modern enterprises have been established for retreading of large-sized tires by molding and moldless (hot and cold) methods [**2**]:

– «Povolzhskaya Tire Company» (PTC) in the Samara Region uses the molding method of retreading with tire curing in a segmented mold, as in the production of new tires;

– “Ecopromservice” Company in the Kemerovo Region retreads large-sized tires using a moldless “hot” method with the application of tread by winding a narrow strip of rubber compound, curing in an autoclave and subsequent cutting of a tread pattern;

– OOO “Retreading Technology Service” (RTS) in the Leningrad Region retreads tires using a moldless “cold” process with the application of cured tread sections by the Rosler method. However, GOTR tires retreaded by this method have not found use in the foreign and Russian practice in severe conditions of the mining facilities [**1**].

Due to the difficulties of collecting repairable large-sized tires, the created capacities for their retreading are used inefficiently, by less than 40% [**1**].

The "modular" tire production, which was investigated in detail at the Tire Research Institute, will help to overcome these difficulties and disadvantages, to reduce the cost of GOTR for their consumers, and eliminate their import dependence. Also, the method of “a two-stage tire building and curing” [**3,4**]: at first an incomplete tire blank is built and cured in a “smooth” mold (with no engraving on its working surface) – without tread, with decreased thickness of the undertread and sidewalls – to produce a “module”, and then the fully built tire is cured in a serial segmented mold. In the first stage, the above-mentioned flow of the rubber compound during vulcanization is eliminated, and the "exit" of gases through a thin layer of cover rubber is facilitated. All structural elements of the tire are fixed in the position assumed during assembly, which does not change during the second stage of modular tire production (Figure **1б**).

As a result, a tire with increased uniformity, good performance and high repairability is obtained [**3, 4**].

This article considers the features of the production process for modular GOTR tires, their effectiveness for manufacturers and consumers, the procedure and conditions for experimental verification of the modular production effectiveness.

Here below the least expensive way is presented to manufacture experimental modular tires in two stages [**3, 4**]:

– **the first stage** – manufacture of a “module” at a tire plant **(TP)**- manufacturer of comparatively cheap radial GOTR (in China, India, Belarus), for example, at the JSC “BelShina” plant whose 33.00R51 tires at a price almost 40% less than the reference price (Table **2**) have limited sales in Russia [**1**];

– **the second stage** – manufacture of a modular tire at a tire repair plant **(TRP)** in Russia, that retreads large-sized tires and is located closely to GOTR consumers.

Thus, there will be not ready-made tires imported to Russia, but their blanks – semi-finished (modules) at a zero customs duty. The manufacture of a modular tire from this semi-finished product im Russia, along with the raising quality of GOTR, will contribute to their imports phase-out (with a gradual transition to the full domestic GOTR production), to utilization of the existing capacities, creation of additional jobs, essential reduction of expenses for tire delivery to the consumer (Table **3**).

2. Specific features of the experimental modular production of GOTR in two steps.

2.1. Manufacture of experimental “modules” at a tire plant- manufacturer of GOTR. A tire plant (**TP**) produces modules as per the adopted technology of the serial production of large-size tires [**5**] with the use of the available standard set of equipment, supplemented with a “smooth” mold for module curing. The mold is not segmented, with an equatorial split and non-engraved working surface of the appropriate profile. The cost of such molds and their maintenance is at least half that of segmented molds used in the conventional technology [**1,6**].

The “module” made by TP contains all tire components, except for the tread, about half the thickness of the sidewalls and the undertread layer, which make up about 40% of the large-size tire mass (Table **1**). The share of the cost of the above said rubbers, without which modules are manufactured, is approximately 30% of the new serial tires cost [**6**].

The internal layers of the module are not fully vulcanized. It is known that to obtain a monolithic rubber product without pores, the degree of its vulcanization in the mold at the required pressure should be within 30-40% of the optimum [**2, p. 477; 5, p. 353**]. In addition, since the period of heating a blank to a required temperature

Table 1.

Mass of OTR tire cover rubber [6].

Tire size		24.00R35	27.00R49	33.00R51
Tire mass, kg.		785	1358	2214
Tire cover rubber mass, kg	Tread cap	207,6	382,3	618,8
	undertread	89,9	81,2	128,9
	sidewall	103,5	183,6	392,9
Mass of tread cap plus ½ mass of undertread and sidewalls, kg. (% tire mass)		304,3 (38,8)	514,7 (37,9)	879,7 (39,7)

Note: *calculation is done for the option of modular tire manufacture by the molding method. In the case of the moldess method, the module is manufactured with full-profile sidewalls marked according to the technical specifications for experimental modular tires.*

(the main part of the GOTR curing cycle) is proportional to the mass of the article, the module scorch time is 2-3 times shorter than the curing time of a serial tire (even with a one-and-a-half time margin for its vulcanization compared to the required rated conditions). Accordingly, the costs of energy carriers, curing bladders, and other expandable materials. are reduced by more than a half.

At the same time, the degree of cure of the external and internal surfaces of the module reaches the optimum. The outer surface of the module is suitable for mechanical processing in the manufacture of modular tires at the TRP, and the cured inner layer allows you to use cost-effective moldless and bladderless molding methods of modular tire curing. The module is transportable without its damage.

For the reasons mentioned above, the modules manufactured by the TP will feature higher uniformity and consistent quality compared to the tires produced by the TP in a conventional way; the risk of internal defects appearing during vulcanization (blisters, cavities, ply separations, porosity, etc.) caused by gaseous substances that easily diffuse through the thin layer of the module's cover rubber decreases; production rejects and expenditures for the manufacture of rejected products and their recycling are reduced; the volume of curing (and other) gases emitted into the atmosphere decreases in proportion to the reduced weight of the module compared to serial tires.

The TP will be able to produce large batches of the same type of modules instead of small batches of different models of serial tires, which will be manufactured at the second stage of modular tire manufacture – at the TRP. The cost of equipment changeover from model to model of manufactured tires is significantly reduced. A stable centralized supply of the TP products to the Russian market to large consumers (tire repair facilities) is provided, complete with the materials used in the manufacture of modules, necessary to finish the assembly of a modular tire. The problems of logistics, sales and storage of finished products are eased.

The production of modules, along with the noted improvement in product quality and environmental safety, will increase the technical and economic efficiency of the TP. Taking into account only the factors related to the reduction in weight and curing conditions of modules, compared with serial tires, the cost of GOTR modules manufacturing is estimated at 60% of the serial tire cost [**6**]. We can expect that in production practice, the prime cost of modules will be less than 50%. According to JSC BelShina's calculations, the expected price of a 33.00R51 module will be 400 000 Rub., i.e. 48,5% of a new tire price (Table **2**), and that of the 27.00R49 module – 262 thousand rubles (47,6%)/ [**1**]

2.2. Manufacture of experimental modular tires at the Tire Repair Plant that has mastered retreading repair of GOTR tires.

Maufacture of experimental modular tires – application of rubber compounds received from the TP (for tread, cushion, belt, undertread, sidewalls) and tire curing – is carried out at the Tire Repair Plant (TRP), located close to GOTR tire consumers, with the use of the available equipment and under its technology for GOTR retreading by the molding, moldless hot and/or cold methods which differ in a number of advantages and disadvantages [**2**].

The molding method *is characterized by the following benefits:*

– when using the materials supplied by the TP and used in the serial production, and curing of a modular tire with the high pressure of pressing (2МПа) in the segmented mold as in the serial production of serial tires, with sidewalls engraving necessary for standard tire marking, a modular tire becomes practically indistinguishable from a serial tire, and its performance and service life are estimated as equal and higher than those of control tires of a serial model [**3, 4**];

– low customs duties for the used “raw” imported rubber compounds – 5% (same as for the “hot” moldless method of tire retreading);

– the prime cost and retreading cost of a tire is half as low as that of a new tire [**1**].

Disadvantages compared to the moldless method:

– higher capital investment;

– the range of retreaded tires is limited by the availability of segmented molds at the plant;

– the high cost of segmented molds, the high costs of their maintenance and replacement in the vulcanizers.

The moldless " hot " method *has the following benefits in comparison with the molding one*:

– less capital investment (and therefore less depreciation charges);

– practically unlimited range of tires to be retreaded;

– the ability to quickly change over from one tire type and size (model) to another;

– the ability to adjust the thickness of the applied tread and the depth of the pattern (when cutting it), depending on the margin of the tire carcass performance;

– reduced risk of rubber overcure at the base of the tread pattern recesses and its cracking during operation;

– higher throughput performance of the autoclave compared to an individual vulcanizer, at the same price, and consequently, less specific cost of tire curing.

Disadvantages of the method:

– due to the low working pressure of pressing in the autoclave (0.6 MPa), the solidity of the tread rubber is less, the adhesion and wear resistance of the tread are lower;

– increased consumption of tread rubber compound and additional costs of recycling rubber waste generated when cutting the tread pattern;

– the appearance of tires after the pattern cutting is worse than that of tires cured in the mold;

– sidewalls are practically not restored by this method.

Moldless “cold” method has the following benefits *(compared to the “hot” moldless method):*

– the tread sections to be used, vulcanized in the molds of special curimg presses under high pressing pressure (6.0-8.0 MPa), have a high-quality tread pattern, high rubber solidity and wear resistance.

The disadvantages of the method are:

– the high cost of cured tread sections of GOTR and their delivery . abroad;

– the range of retreaded tires is limited by the models of tread sections . delivered;

– sidewalls are not restored by this method;

– the high complexity of the tread sectors precision application on the carcass of the tire to be retreaded. The overall dimensions of the carcasses differ significantly from each other (even in tires of the same model **[2, p. 187, 188])**, making it difficult and sometimes excluding the exact matching of the patterns of the joined tread sectors. In case of failure to meet the requirements of the precision building technology there is a risk of the sectors joints opening in tire service. As mentioned above, GOTR tires have not found practifal application in the severe conditions of mining enterprises. In modular tire production, unlike retreading repair, this disadvantage can be eliminated by standardizing (matching) the dimensions and profiles of the "modules" suppled by the TRP, and cured tread sectors/their patterns,. However it will require additional investments in amounts unacceptable for the manufacture of prototype modular tires.

2.2.1. Features of the production technology of experimental modular tires

Figure **2** shows the flow chart of modular tire production at the TRP:

Unlike tire retreading repair technology, labor-intensive and energy-intensive operations are excluded or reduced, such as:

– the collection of retreadable tires, their washing, drying and pre-sorting are excluded;

– local damage repairs are excluded (for GOTR, the complexity of related repair of numerous damages is 85-90 % of the total labor input of their retreading), and the material consumption for this operation is excluded;

– skiving (cutting off) the remaining worn tread and buffing (usually to the middle of the undertread layer and sidewalls) are replaced with a less expensive, thin, velvety buffing (scarfing) of the module cover rubber surface to 1.5 mm in depth, thereby significantly reducing environmental pollution with buffing gases and dust compared to retreading repair.

Process flow diagram for modular tire manufacture at the Tire Repair Plant

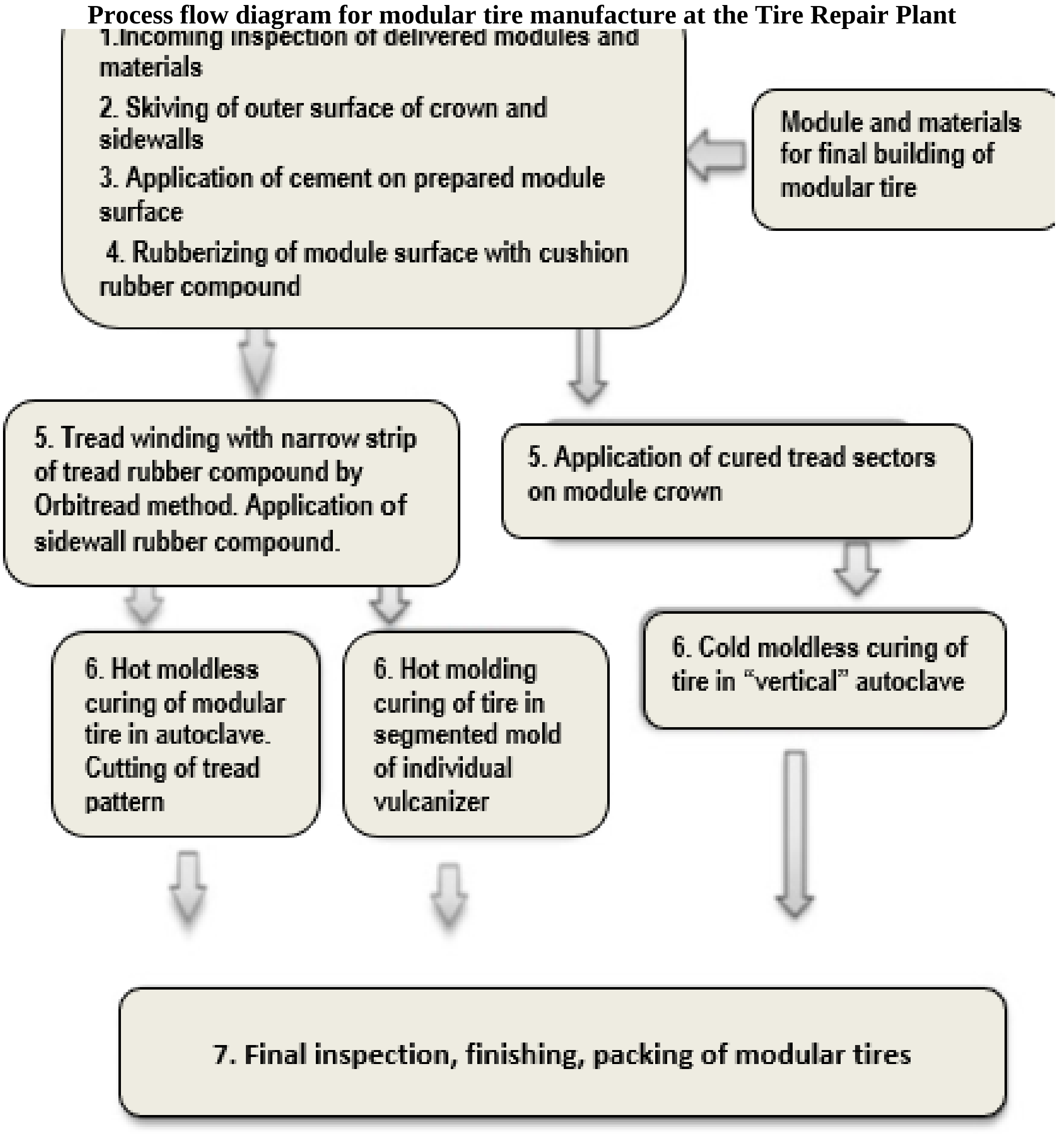

Figure 2. Flow chart of the second stage of modular tire manufacture at tire repair facilities by the methods of molding cure (Povolzhskaya Tire Company), hot moldless cure (Ecopromservice) and cold moldless cure (RTS).

The curing process becomes cheaper compared to tire retreading:

– the curing cycle is shorter by a fraction of the prevulcanization degree of the module inner layers, and, accordingly, the volume of emitted curing gases;

– the risk of ply separations and other defects emerging during vulcanization due to excessive carcass moisture, characteristic of worn tires to be retreaded, reduces and accordingly the cure process and industrial waste processing become simpler and cheaper.

As a result, in comparison with retreading repairs, the TRP's own technological costs for the production of modular tires (without material costs) are approximately halved, which make up 20-25% of the cost of materials in the cost of GOTR retreading [**2, p.588**]. The amount of the TRP's own technological costs (**Tc**) for the production of modular tires is determined by expression (**1**), which is 1/8 of the cost of materials:

$$Tc = P_m \times k : f = P_m : 8 \qquad (1)$$

where: P_m– price of materials, in this example P_m=139 000 rubles. (Table 2, item 3.1.2),

k – the ratio of the own technological costs of the TRP to the price of materials, k = 0.25,

f –- reducing by half the TRP's own technological costs for the production of modular GOTR's in comparison with their retreading repair, f = 2.

Environmental safety of production increases: waste and environmental pollution reduces in the main technological operations, including pollution by rejected tires with operational defects (usually up to 30% of the volume of production of retreaded tires at the TRP).

An essential feature of the technological process for the production of modular tires is the operation of rubberizing the surface of the module directly after its mechanical processing – "scarfing" with an abrasive tool ("velvet" buffing).

The above-said "scarfing" of the module (along with removing from its surface an oxidized film formed in the period after its manufacture, and creating a developed microrelief on the module surface, which increases contact with applied rubber compound) initiates the formation of chemically active sites – free radicals of polymer molecules, providing high bond sytrength with rubber compound [**2, p.45**].

With the conventional technology of retreading tires after their buffing, during a long period of related repair of local damage, active radicals are oxidized and almost lose their reactivity even before the protective rubberizing of the prepared surface (application of cement and a cushion rubber compound). The module does not require local repairs. Rubberizing the newly buffed module directly after its machining will allow maintaining its surface activity and, accordingly, achieving maximum bond strength (adhesion).

When retreading tires on their prepared buffed surface, cement is applied by airless spraying, and a calendered strip of cushion rubber compound is applied on a building machine. In this case, it is possible to have air trapped in the recesses of the buffed surface under the applied layer of the compound, and during vulcanization - the formation of air blisters at the junction of the module surface and applied compound and in its bulk, which can become the foci of tire failure during its operation. To prevent the appearance of those defects, special measures are used to remove air inclusions. For example, the use of special needle rollers during stitching of the cushion rubber on the stitcher, drainage with air-draining fabric threads applied when assembling the tire before applying the cushion rubber compound. However, these measures do not completely eliminate the appearance of those defects. A more effective measure is tire curing under a high pressing pressure, which provides an outlet (diffusion) of air from the rubber compound, which is still in a visco-fluid state.

The first and mandatory condition for obtaining a high bond strength between the "module" and rubber compound applied onto it, is their full tight contact that is reached by rubber flowing into the tiniest recesses of the developed microrelief of the buffed surface. Rubber compound flow increases with the rise of its temperature and contact pressure.

Figure **3a** shows examples of the rubber compound bond strength with the buffed vulanizate depending on the contact pressure at temperatures 19^0C, 85^0C and 143^0C. In all cases as the pressure grows, respectively, up to 10-12 MPa, 5-6 MPa и 1,0-1,2 MPa, an approximately the same maximum level of bond strength is achieved. Any further increase in contact pressure is not accompanied with the bond strength growth (horisontal branches of the graphs), i.e. it does not result in any increase of the achieved maximum contact surface. The value of the contact pressure required to obtain its maximum density (maximum bond strength) is inversely proportional to the temperature of the compound within the specified limits (Figure **3б**).

In the practice of worn tires retreading at the curing temperature of 143°C adopted for GOTR, the working pressure of pressing is set at the level of 1.8-2.0 MPa, which is significantly (1.5 - 2 times) higher than the minimum (optimal) value 1.0-1.2 MPa specified for this temperature. This margin is associated with the losses for the carcass stretching in the mold to form the tread pattern of the tires being retreaded, which have a large range of overall dimensions [**2, p. 187, 188**]. Considering the stability of the "module" sizes (unlike those of the retreaded tires), for the vulcanization of modular tires, the specified norms of the pressing pressure reserve can be reduced to 20-30%. This significantly simplifies and reduces the cost of equipment and the production process of modular large-size tires. Along with it, autoclaves used for moldless tire curing allow using the working pressure not more than 0.6 МПа, i.e. twice as low as the specified minimum required pressure for high-quality curing of retreaded tires at a temperature of 143^0C in the free state (even without any loss for the carcass stretching).

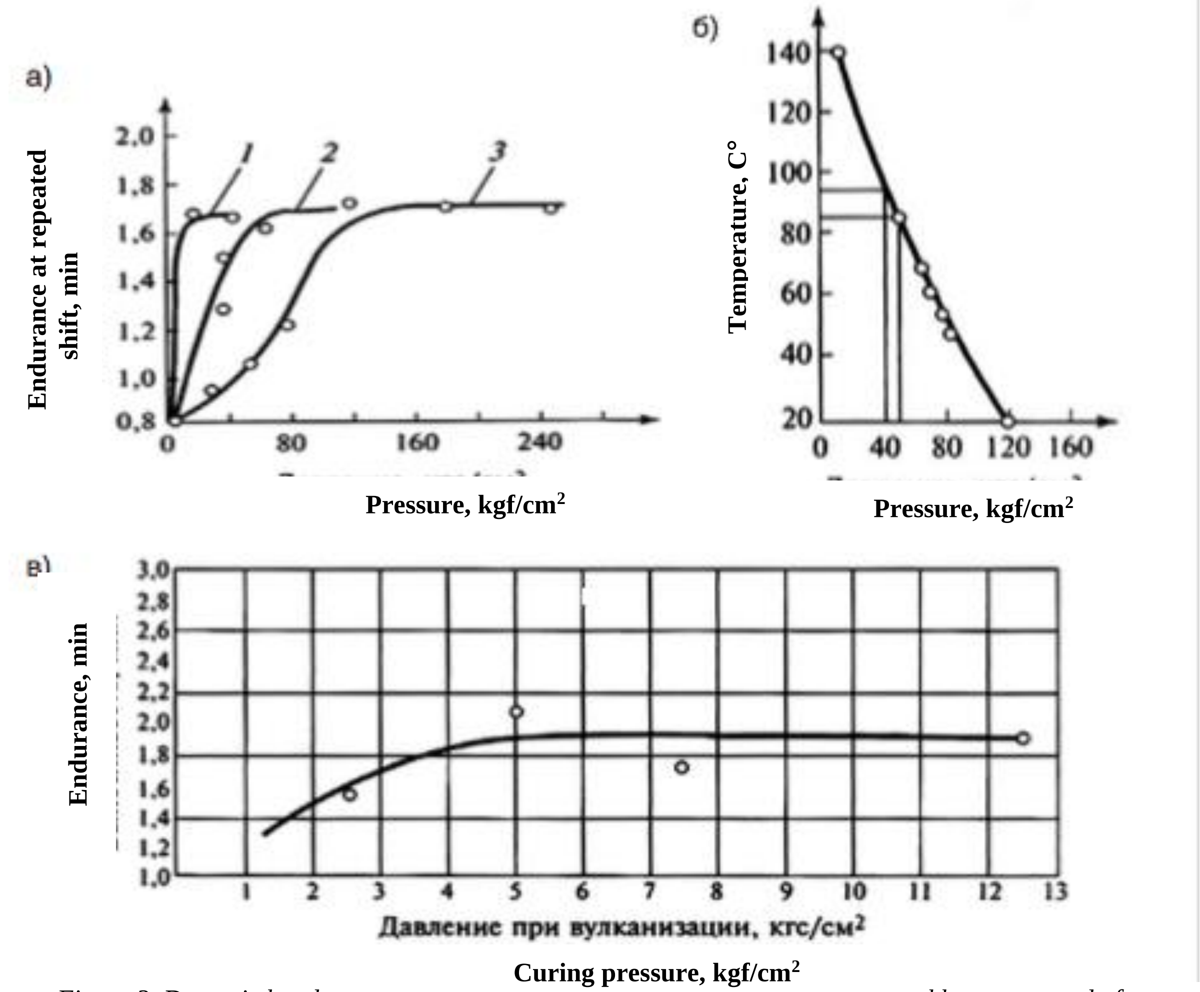

Figure 3. Dynamic bond strength (endurance at repeated shear) of rubber and rubber compound after co-vulcanization depending on temperature and pressure and their contact pressure before curimg:
а) bond strength dependence on contact pressue at the temperature of 1430C(1), 850C(2),190C(3);
б) changing of minimal contact pressure value, that provides maximum bond strength depending on contact temperature;
в) bond strength dependence on pressing pressure during co-vulcanization of rubber compound and rubber plied-up previously at 850C and contact pressure of 5 MPa.

Those examples of the bond strength dependence of rubber and rubber compound on the pressure and temperature of their contact show that in the systems under consideration, full contact of plied-up materials can be made before vulcanization during plying-up (during building of the article). In this case, during vulcanization, the pressing pressure can be significantly reduced compared to the optimal one. For example, if before curing, the contact pressure of a rubber compound, with a temperature of 85°C with the buffed surface of the "module", was 5 MPa, providing the maximum density of their contact, then during vulcanization of the modular tire at 143°C, the pressing pressure necessary to obtain the maximum bond strength is reduced by half – from 1.0 MPa to 0.5 MPa (Figure **3в**). This pressure in the autoclave is sufficient to exclude pore formation at the specified vulcanization temperature, to obtain a monolithic pore-free vulcanizate of the new cover rubber and its junction with the"module". However, in practice, when building a tire, it is difficult to obtain the specified high contact pressure. A well-known "combined curing method" is used for retreaded GOTR [**7, 8, 2, p. 477**] with the tire pre-cure by the molding method with high pressing pressure and then with its after-cure in an autoclave with low pressure. However, it requires expensive individual vulcanizers (although in smaller quantities), which does not allow the full use of the hot moldless vulcanization and is unacceptable for the manufacture of prototype modular tires.

The full contact of the rubber compound with the carcass during tire building is provided by an advanced method of the carcass rubberizing before tread application – the “CTC” method (“Cushion to casing”) of the AZ-VMI GROUP (Holland) [**2, p. 387**]. A thin layer of an adhesive rubber compound (cushion, belt) is applied by direct extruding on the prepared tire crown surface with a temperature of 80-95^{0}C. At the same time, due to the "rotating stock of the compound" in front of the profiling edge of the forming extruder head, the rubber compound is literally "smeared" into the relief of the rough surface, a full, tight contact of the compound with the retreaded tire is achieved, the compound flows into the smallest recesses of the buffed surface without any air trapping observed with the conventional technology of retreaded tire building. High bond strength is ensured.

This method has not found application in the restoration of GOTR tires due to the large number of their major external related injuries. There is no such obstacle in the modular production method. VMI has created a Base Constructor machine for "rubberizing" the carcasses of OTR and GOTR, which can be successfully used at the second stage of the module assembly (Figure **4**).

The CTC method will substantially raise the productivity and quality of building. The maximum density of the rubber compound contact with the module surface and, accordingly, the achieved maximum bond strength between them, will allow elimination of the unsafe operation of cement application.

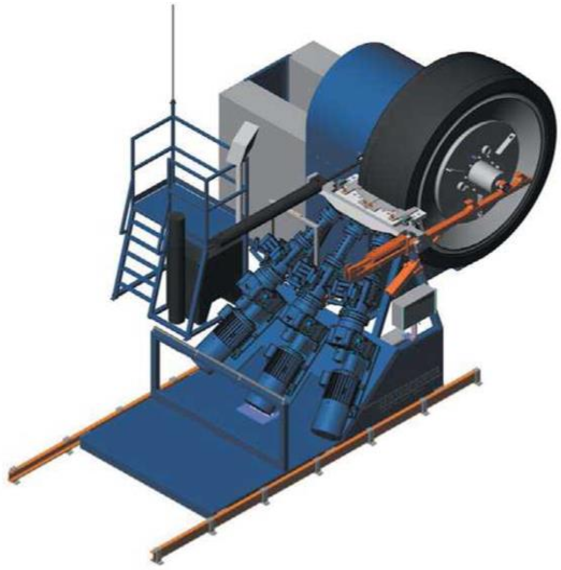

Figure 4. A prototype model of a building machine «Base Consructor" for rubberizing the carcasses of OTR and GOTR tires, developed by VMI Group (Holland).

Compared to retreading repair, in addition to the above listed quality-determining benefits of the modular tire production, there is a good margin of the carcass performance and high compatibility of the jointed materials:

– as a rule, the carcass of tires to be retreaded is weakened (fatigued) in the course of of the pre-repair tire operation, with multiple mechanical injuries, has a limited working capacity; a module has no such disadvantages;

– with the co-vulcanization of rubber compound and retreadable tire carcass of different manufacturers, with a different formulation of cover rubbers having undergone ageing in the process of pre-repair operation, it is impossible to provide compatibility of jointed materials and bond strength between them similar to those in the manufacture of a modular tire with the use of rubber compounds that have been used in the manufacture of the module.

The guarantee of experimental modular tire quality will be non-destructive control of each module and finished tire by a modern method – vacuum shearography, for example, on a unique machine in the Povolzskaya Ture Company (PTC) (Figure **5**), where a laser beam scans the inner surface of the tire at atmospheric pressure and in vacuum. By overlapping the obtained holograms the smallest (to 5 mm) hidden internal defects are detected (ply separations, blisters, porosity, foreign matter, corrosion spots on steel cord, its displacement and other non-uniformity), which cannot be identified by other known methods of non-destrutive control of tires [**2,** p.156,161]**.**

As a result, the product quality of the TRP is significantly improved. One can with confidence assume that the mileage of a modular tire is not less than the achieved level of retreaded tire mileage: 80% of the operating time of a new reference tire under the same conditions [**1**]. Along with it, we can expect the mileage of the modular tire equal to the pre-repair mileage of the standard [3, 4].

Experimental verification of this forecast is the main goal of this work.

Figure 5. OTR and GOTR vacuum shearography machine with a seat diameter of up to 63" manufactured by "Steinbichler" (Germany), model "Intact 4300-3, in the Povolzskaya Tire Company

The prime cost of a modular tire will be 556 thousand rubles. (Table 2, item 5), including the cost of the 33.00R51 module - 400 thousand rubles. [**1, 6**]. It is acceptable to adopt the selling price of a modular tire in the amount of 50% of the cost of the standard tire (660 thousand rubles), i.e. at the current price level of their retreading repair. At the same time, the profitability of the TRP will be 18.6%. (Table **2**).

Rhythmic receipt by the TRP of the main raw materials (modules and rubber compounds for the production of modular tires) will eliminate its current dependence on the inefficient collection of repairable, withdrawn from service, worn tires, will ensure its capacity utilization and the ability to fully meet the needs of an average-power mining and processing complex in modular 33.00R51 tires (750 pcs/y.) to replace the reference tires used by it (600 PCs/y).

The profit of the TRP will achieve 78 mil.rub./year, (Table **2**). The possibility of a significant increase in the capacity of the TRP - "Ecopromservice", located in Kuzbass, is being stipulated to supply all mining enterprises of the Kuznetsk Basin with the necessary modular tires in the amount of more than 4.8 thousand pcs./y. In this case the profit of the TRP will achieve **0,5 bln. rub./y.** and the number of jobs will increase significantly.

3. Technical and economic efficiency of modular tires for their consumers.

With the switch-over to using modular large-size tires, a mining company will be free from import dependence in providing its GOTR needs, and will reduce its expenses on tires. Instead of expensive imported tires, it will receive similar modular tires of a domestic TRP, which are not inferior to imported tires, at a significantly lower price. It will reduce losses associated with long-distance transportation of tires from abroad and customs expenses (Tables **2, 3**).

The manufacture of high-quality tires by the TRP downstream the consumers of GOTR, for instance, “Ecopromservice” located practically in the territory of the Mining and Processing Complex (MPC) in the Kemerovskiy Region, will allow meeting the consumer’s needs in terms of prompt tire supply of required models, as there is a possibility of small-series tire production at comparatively low labor input for equipment changeover. The feedback with GOTR manufacturers will improve in the issues of improving their quality, consideration of consumer claims and information about the mileage of tires of different models in specific operating conditions.

Table **2** shows the results of calculating the projected efficiency of modular tires on the example of an average power MPC in the Krasnoyarsk area with an annual consumption of reference tires 33.00R51 – 600 pcs/y. As noted above, the calculation cautiously assumes that the price of a modular tire is 50% of the reference price, and its mileage is 80% of the reference mileage, i.e. at the level of mileages and prices of currently retreaded GOTR tires. The cost of 1 km of the 33.00 R51 modular tire mileage compared to the standard will decrease by 3,992 rubles/km, and for its entire mileage – by 396 thousand rubles/pc. The savings on the annual MPC consumption of 750 pcs./y. of modular tires 33. 00R51 will amount to 297 million rubles/y. (37.5% of today's MPC’s expenses for tires, Table 2). With the consumption of those tires throughout the country, being 7700 pcs/y. [**1**] the savings will be **~ 3.8 bln.rubles/y**.

Moreover, in assessing the efficiency of modular tire production it is necessary to take into account the increase in repairability compared to serial tires due to their uniformity and, consequently, an additional reduction in the cost of 1 km of tire mileage.

Table 2.

Calculation of the efficiency of the modular production method of GOTR 33. 00R51 tire exemplified by the average power MPC in the Krasnoyarskiy Krai with an annual consumption of reference tires 33. 00R51 - 600 pcs/y.

Item number	Indices	Tire 33.00R51
1.	Price of a new tire, thousand rubles.:	
1.1.	reference (premium brand)	1320[1]
1.2.	OAO “Belshina”	825[1]
2.	Price of a BelShina module, thousand rubles (% of item 1.2).	400[2.2, 3.1] (48,5%)
3	TRP expenses on production of a modular tire:	
3.1	BelShina rubber compounds for manufacture of a modular tire at TRP:	
3.1.1	mass, kg/pc. (Table 1)	879,7[3.2]
3.1.2	cost, thou.rub./pc. (% of item 4).	139[3.2] (88,9%)
3.2	Other (“own”) technological expenditures of TRP for production of a modular tire, thou. rub./pc. (% of item 4).	139:8=17,4[4] (11.1%)
4.	Prime cost of manufacturing a modular tire at TRP , /item 3.1.2 + item 3.2/, thou.rub.	156,4
5.	Prime cost of a modular tire /item 2+ item 4/, тыс. руб. (% от item 1.2).	556,4 (67,4%)
6.	Mileage of a reference tire, thou.km.	124[2.1]
7.1.	Mileage of a modular tire, thou.km. (% of item 6, see above in the text of the article).	99,2 (80%)
7.2.	Same as above, fraction of item 6.	0,8[5]
8	Price of a modular tire, thou.rub. (% of item 1.1, see above in the text of the article).	660 (50%)
9.	Profitability of TRP on each modular tire /item 8 – item 5/, thou.rub./pc. (% of item 5)	660-556,4 = 103,6 (18,6%)
10.	Benefit of MPC on every reference tire replaced by modular tires /item 1.1 – (item 8: item 7.2) /, thous.rub./pc. (% of item 1.1)	1320 – 660:0,8= 495(37,5%)
11.	Cost of 1km of a modular tire mileage, rub./km /item 1,1: item 6/	1320:124=10,645
12.	Cost of 1km of a modular tire mileage, rub./km /item 8: item 7.1/	660:99,2=6,653
13.	Cost reduction for 1km of each modular tire mileage compared to the tire reference /item 11- item 12/, руб./км. (% of item 11)	10,645 - 6,653 = 3,992 (37,5%)
14.1	Annual consumption of reference tires 33.00.R.51 by MPC , pcs./year	600[2.1]
14.2	Cost of MPC’s annual consumption of reference tires 33.00R51, /item1.1 x item 14.1/, mil.rub.	1320x600=792
15.1	MPC’s annual consumption of modular tires replacing annual consumtion of reference tires /item 14.1: item 7.2/, pcs./year	600:0.8=750
15.2	Cost of MPC’s annual consumption of modular tires, /item 15.1x item 8 /, mil.rub.	750x660=495
16.1	Annual saving of MPC’s expenditures on tires, mil.rub. (% of item 14.2). Calculation versions:	
	1. /item 13 x item 7.1.x item 15.1/	3,992x99,2x750=297 (37,5%)
	2. /item 10 x item 14.1/	495x600 = 297 (37,5%)
	3. /item 14.2 - item 15.2/.	792-495 = 297 (37,5%)
17.	Profit of TRP on the production of modular tires that replace the annual consumption of reference tires by MPC /item 9 x item 15.1/, mil.rub./year (% of item 5 x item 15.1)	103.6x750=77.775 (18,6%)

Note (references):

1. *S.V. Khalepo: Commercial offer No. RO-NVF/251 dated 18.06.2019. Novokuznetsk.*

2. *A.S. Barsegyan:*

2.1. *The use of reference GOTR Bridgestone premium brand in Russia by major users of subsurface resources 20.02.18, 26.06.19, 17.07.19.*

2.2*. “Information memorandum on the results of the meeting with JSC BelShina specialists” 11.05.2018г.*

3. *I.V. Kotliarov:*

3.1. *Expert assessment of the cost of manufacturing "modules" for the two-stage production of OTR and GOTR in JSC BelShina. Bobruisk, 15 March 2017".*

3.2. "*The share of tread, ½ of undertread and ½ of sidewalls in the cost of All-Steel tires 33. 00R51",* April 2016 г.

4*. Formula* ***(1)*** *in the text of the article.*

5. *0.8 – the ratio of the estimated mileage of modular tires to the mileage of the reference (see above in the text of the article).*

The use of modular tires supplied by domestic tire repair facilities, instead of imported GOTR, will reduce the costs associated with long-distance transportation of tires from abroad and customs costs. As a result, the cost of delivering tires to Russian consumers is significantly reduced.

Table **3** presents the described-above low-cost option for the production of experimental modular tires: the manufacture of experimental modules 33. 00R51 in JSC BelShina (Bobruisk, Belarus) and the manufacture of modular tires from them at the Tire Repair Plant "Ecopromservice" (Belovo, Kemerovo Region), maximally close to the GOTR consumers – Kuzbass mining plants. (Kuzbass consumes the lion's share of GOTR volumes delivered to Russia, about 50% of all deliveries [**1**]).

The calculation is made using an example of a conventional, average power Mining and Processing Complex (MPC) in Novokuznetsk with the consumption of reference 33. 00R51 tires - 600 pcs. per year. As can be seen from the table, in the given example, when this MPC switches to operating modular tires produced by the Tire Repair Plant "Ecopromservice" (Belovo, Kemerovo Region) instead of the standard ones, the cost of tire delivery including the module delivery from Bobruisk to Belovo, will be reduced by half, i.e. by 17550 thousand rubles/year (57%).

Table 3.

Cost of delivery[1] of standard and modular tires 33.00R51 to the Russian consumer in Kuzbas as exemplified by the average power MPC in Novokuznetsk

Tires in use	Reference Bridgestone tires			Modular tires replacing reference tires, manufactured by "Ecopromservice" from the modules of JSC "BelShina"		
Indices	Delivery cost of one tire, rub./pc.	Annual consumption by MPC, pcs../y.	Total cost of tire delivry per year, thou.rub../y.	Cost of delivery per unit of production, rub./pc.	Annual consumption by MPC, pcs../y.	Total cost of delivery of modular tires and modules per year thou.rub../y.
Cost of reference tires delivery to the mining plant from Japan and replacement modular tires from Belovo (Kemerovo)	68000[3]	600	40800	6000[3]	750[4]	4500
Cost of "modules" delivery to Belovo from Babruysk (Belarus)				25000[3]	750[4]	18750
Total, thou.rub../y. %%	40800 . 100			23250 57		

Note:

1. *The cost of delivery includes transport expenses, handling and duties*

2. *A medium-power MPC with annual consumption of 600 reference GOTR 33.00R51 tires*

3. *A.S. Barsegyan: expenses on delivery of modules and tires*

4. *The number of modular tires replacing reference tires, consumed annually by MPC (Table* ***2****, item 15.1).*

4. Summary

4.1. The two-stage method of producing modular tires will improve the uniformity and performance of tires, reduce the import dependence of mining enterprises in providing GOTR, and improve environmental safety.

Creating your own GOTR plant in Russia requires a lot of financial costs, time, and is not realistic today . The proposed production method requires minimal capital investment – the existing capacities, personnel and standard equipment of a TRP and a TP are used (with the exception of "smooth" (slick) molds).

The production of modular tires by domestic tire repair facilities from relatively cheap semi-finished products - "modules", along with the acceleration of import substitution, will contribute to the creation of additional jobs, utilization and expansion of existing capacities of TRPs, and a gradual transition to a full cycle of GOTR production in Russia.

High efficiency is predicted for modular tire producers and consumers.

4.2. The calculations and forecasts of the expected effect given in the article are subject to experimental verification based on the results of comparative tests of modular, serial, and reference tires.

Experimental modular tires will be manufactured in the least expensive way described: 33.00R51 modules will be manufactured in JSC "BelShina", whose relatively inexpensive GOTRs have limited demand in Russia. Experimental modular tires will be manufactured in Russia by the molding and/or moldless hot method at a tire repair plant that has mastered retreading of a worn-out GOTR tread and is maximally close to their consumer.

Comparative laboratory and bench tests of the prototypes of modules and modular tires will be conducted under the procedures evaluating the quality of serial tires (their uniformity, performance, compliance with the requirements of current standards for GOTR). It is planned to perform holographic control of uniformity and internal defects of all experimental modules and modular, serial and reference tires on the GOTR shearograph available in the Povolzhskaya Tire Company.

In-service tests will be conducted under the operating conditions of mining enterprises serviced by the above mentioned TRPs, and using similar tires of convenitional production of leading world companies, as well as batches of serial tires produced by the tire plant-manufacturer of experimental modules.

Based on the results of the practice of manufacturing and testing experimental modular tires, the actual level of their technical and economic efficiency for producers and consumers, environmental safety (reduction of environmental pollution) will be assessed , the most efficient method of modular tire manufacture will be chosen.

4.3. The expenditures on manufacturing and testing of modular tires 33. 00R51 will amount to 10 million rubles, including the production and laboratory indoor tests of their prototypes – 3 million rubles. It is possible to conduct preliminary tests of modular tires 24. 00R35, for which the specified expenditures will be 4 and 1.5 million rubles, respectively.

In all cases, the cost of manufacturing "smooth" ("slick") molds for modules curing is included: for 33. 00R51 it is 1800 thousand rubles, for 24. 00R35 – 760 thousand rubles.[**1**]

5. References (Sources).

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The authors invite interested persons, enterprises and organizations, including mining companies, to participate in this project.