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Researching the pneumatic tires based on polyurethane as an alternative for conventional radial tires

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In the last decades, researchers in rubber industry make efforts to introduce the production process of polyurethane as a substitution for tires based on natural and synthetic rubbers. Although there are not significant comercial uses of polyurethane tires, some known firms such as Goodyear &Rubber Co. are entering into a research project of the LIM (Liquid Injection Moulding) process. On the basis of recent exploring and experience, it is possible to expect that LIM tires will have some better performances compared to conventional tires such as: longer life, lower rolling resistance, lower wastes in production, etc. Further advantages are lower overall production costs and lower operating costs of LIM tires compared to conventional radial tires.

Key words: **polyurethane tires, rubbers, liquid injection moulding, fuel consumption, rolling resistance, radial tires.**

Introduction

IN the last decades, researchers in rubber industry make efforts to develop the processing for the production of pneumatic tires based on polyurethane materials (PUR), to lower production cost, increase life (longer mileage) and improve energy efficiency, in comparison with tires based on natural and synthetic rubbers.

The LIM (Liquid Injection Moulding) production process is based on relatively modest experience of few companies which in their work combine new achievements in the urethane chemistry field and in the development in construction and production of machines for moulding. This basic knowledge about materials (polyurethanes) and machines for liquid injection come mainly from the footwear industry where PUR materials are used for producing articles (shoe heels) for sports and other footwear.

Development and research projects are based on a multidisciplinary approach, showing the necessity to integrate practical production processes, inovations in tire construction and a suitable polymeric system of PUR materials necessary to satisfy very sharp performance requirements (characteristics) of tyres for different vehicles. There are efforts of potential producers of LIM PUR tyres to produce the products of such a quality which will have same or superior characteristics in comparison with the best radial tires, and in the same time with lower production costs.

The realization of these ideas was in the period from 1980 to 2000, but without adequate results which would give satisfactory performances and long service life. However, in the middle of 2001, the basic idea and development of PUR tires began actual aqain because a known firm Goodyear Tyre & Rubber Co. signed the contract with the research and development company Ameritype Corp. (USA) about developing automobile tyres based on polyurethane rubber [1,2]. Further investigations are expected to give results which correspond to existing standards, and better characteristics in a prolonged service life and lower rolling resistance, which will have a further effect in lower consumption of fuel in vehicles with LIM PUR tires.

Characteristics of pneumatics (tires)

Rubber is an esential tire element:it supports the vehicle load and shows low hysteresis and high treadwear resistance, gives good friction on the most roadsurfaces and high resistance to gases penetration, etc. Because of low resistance to breaking forces, rubber is reinforced with different textiles (cords).

Tire mechanics is the discipline which characterizes key performances of a tire: durability, treadwear, tire noise, energy consumption (rolling resistance), vibrations, and traction and handling.

Tire durability

Tire durability is determined by the initiation of a failure in one of the tire components, and propagation of this failure until a tear is formed rendering the tire unusable. The failure can be initiated by cord failure, rubber failure, or by adhesive failure between the cords and the rubber.

Treadwear

Treadwear is a key tire performance which impacts tire durability (useful life): The change in the profile of the tread surface also impacts noise, vibration performance, traction, and vehicle handling. Treadwear is driven by the fric-

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tional energy developed at the contact interface between the tire and the road.

Noise

Besides the acoustic pressure variations produced by air turbulence resulting from translational and rotational motions of the tire, two sources of noise can be identified as tire rolls: a) low-frequency structural noise associated with the tire cavity, and b) high-frequency noise associated with deformations of the tread elements. Footprint noise is influenced by the footprint shape and size, the footprint pressure distribution, and the characteristics of the tread.

Rolling resistance

As the tire rolls in use, every tire component is loaded to a certain level and then unloaded back to the original level. Due to the hysteretic nature of the materials, the total applied energy is not recovered; the lost energy is a function of the material and the strain cycle. Adding the lost energy of the various components yields the energy lost by the tire, l.e. its rolling ressistance.

Tire vibrations

Tire vibrations play a key role in vehicle ride quality. Tires absorb the external input from road irregularities; they generate the input due to tire nonuniformities. The lack of weight balance, the tread pattern input, and the tires modes of vibration interact with the dynamics of the vehicle to define the ride quality.

Traction and handling

The handling performance of a tire is determined by the forces generated at the interface of the tire with the road. Handling tests may be conducted on either dry or wet roads to evaluate vehicle's steering response, steering precision, and tracking.

Research and development of LIM tires

To produce LIM tires, great creativity must be applied in the field of polyurethane chemistry, tire design, great physical work: capital investiments which include machinery, tire moulds, etc. The Firm LIM International S.A. from Luxembourg with a factory in Austria was developed in the mid-1980s and appeared on the commercial market with PUR tires for different vehicles (trucks, buses, passenger cars, and tractors and off-the-road vehicles) [4].

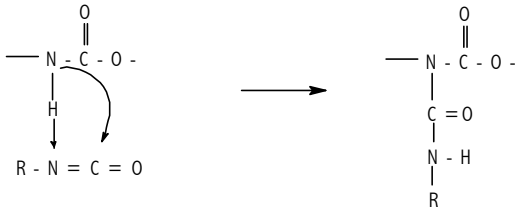
The activities, beging from the patent developing, basic PUR chemistry via the pilot production of a number of different tires to the applcation of continual tire testing programs, were organized in such a way that the testing results are considered at every step of product developing.

The polymer research program has identified optimal formulation materials with superior physical properties, meeting all requirements for their application in tire making. For the first time urethane materials based on LIM newly designed molecular structures were able to withstand the high dynamic stress appearing during tire operation without being destroyed by heat build up. Even under severe warming contitions LIM tires made of these polyurethane materials show lower heat build up than radial tires made of NR and other elastomers. Chemical development of polyrethane materials for LIM tire technology is based on the application of only such basic raw materials and intermediates for producing tires that make the production of LIM tires economically feasible. It is common for polyurethane materials that they are made in reaction between polyol and isocyanate [5,6].

Curing of these materials is possible:

- using multifonctional polyole
- using multifonctional isocyanate

Also, curing is possible using dihydroxile prepolymer with the excess of diisocyanate. The excess of isocyanate groups reacts with the reactive hydrogen atom forming alophanate links thus causing the curing of the polymer material.



alophanat link

Researchies showed that two groups of compounds are most frequently used for producing PUR material. The basic compound A is polyole, polyester with the end-hidroxile groups, while the component B is a curing agent, multifonctional diisocyanate (MDI-methyldiisocyanate; TDI – toluenediisocyanate, etc.). These compounds are delivered from producers of row materials in massive iron drums of 200 kg each. The desired color is already mixed into the polyol-component (A). PUR-raw material systems made by mixing the component A with the component B in a given ratio, are injected in a corresponding mould using the injection moulding machine, and then the product shape forming simultaneously occurs with the curing of materials at increased temperatures. The properties of a chosen compound for LIM process purposes are shown in Table 1.

Table 1. Physico-mechanical properties of PUR materials for LIM process

Properties	Testing standards	Value
Density, (g/cm^3)	DIN 53420	0.62
Tensile strength, MPa	DIN 53455	10
Elongation at break, %	DIN 53455	420
Tear strength, KN/m	DIN 53515	20
Abrasion, loss of weight (mg)	DIN 53516	30
Hardness, Shore A	DIN 53505	70±3
Bending fatigue on LIM flex, tester P-2 at -25ºC		>20,000 bendings

Table 2 gives PUR material properties for the production of filled tires.

Table 2. Physico-mechanical properties of polyurethanes for producing filled tires

Properties	TDI ether	MDI ester	TDI ether	TDI ester	MDI estar	PPDi ester	Without label compound	Oil resistence compound	Black natural compound	Static conductivity compound	Universal compound
Hardness, (Shore A,D)	93A	85A	97A	61 D	91A	94A	75A	77A	65A	76A	67A
Compression modulus, MPa	36.4	24.5	45.5	55.3	39.2	37.8	10.5	9.0	8.7	10.6	6.3
Tensile strength, MPa	37.5	46.9	42.3	40.9	47.2	51.4	19.7	16.1	21	18.2	20.6
Elongation at break,%	540	650	490	480	680	860	540	460	590	360	690
300% Modulus, MPa	14.9	9.2	22	23.6	11.3	13.23	13.0	11.3	11.3	14	6.9
Rebound resilience (Baushore),%	39	44	45	33	42	64	50	26	54	32	38
Compression set,%	27	16	32	29	17	40	11	19	11	15	13

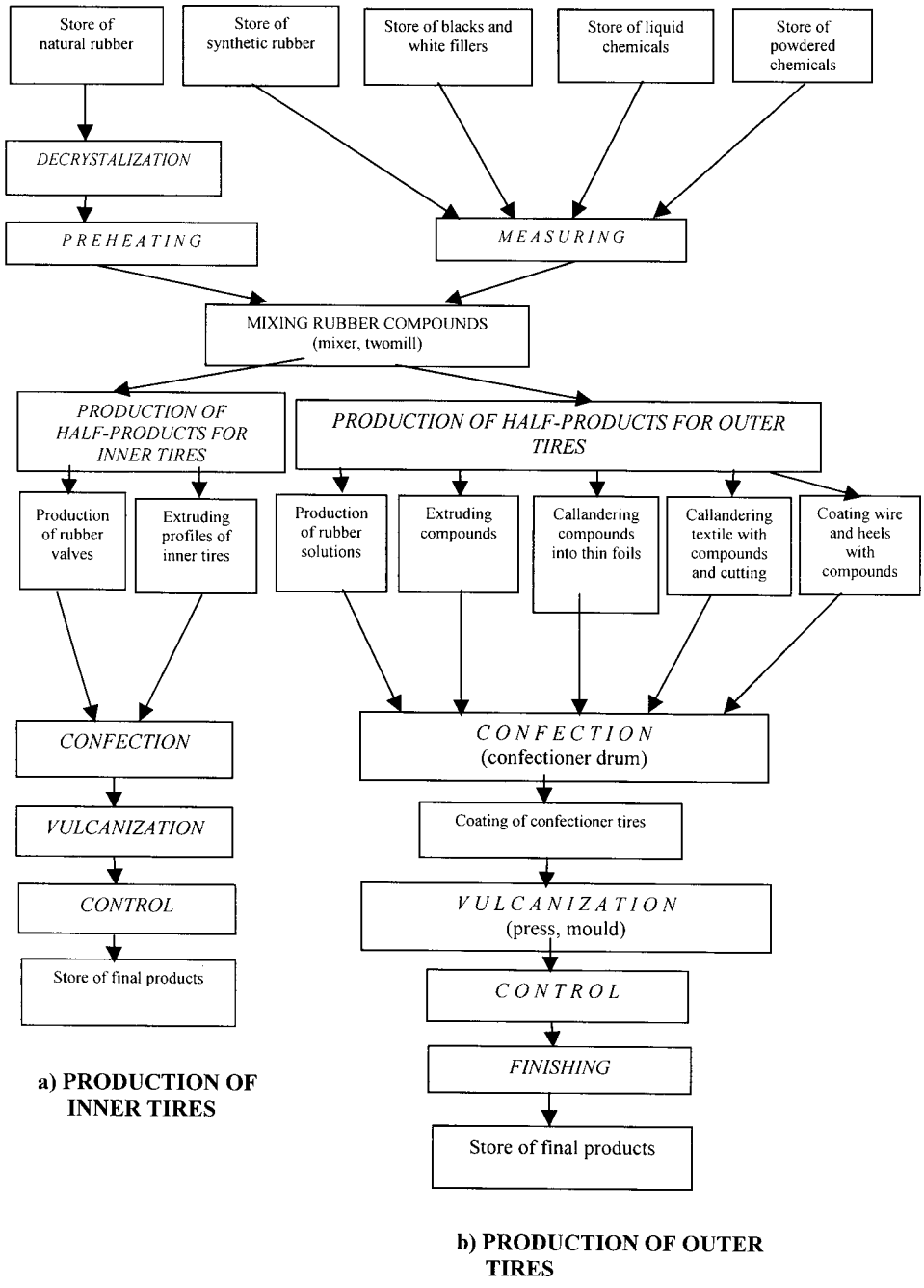


Figure 1. Technological scheme of the production of inner and outer tires

Research and development of a company for the production of LIM tires

In order to assure a smooth transition from development to production commercial operations, there are development and design firms (LIM, Ameritype corp.) which give and provide necessary support in connection with the development of materials, know-how technology, equipment, engineering services and administration [7].

The scope of their work includes:

- Feasibility studies of LIM tires production,
- Planning, technology, eingineering,
- Raw material systems,
- Delivery of machinery and equipment or turn-key plants for the manufacture of LIM tires,
- Installation and start-up of plant equipment,
- Transfer of know-how production and technical assistance,
- Product development and testing,
- Training of plant personnel.

Production technology of radial and diagonal tires

For the production of conventional radial and diagonal bias tires it is necessary to have the adequate equpment. In mixers and mills rubber compounds are produced, on the calander machine (4-mills) textiles with compounds, are coated on extruders half-products are produced: treads, rubberized wire wraps, etc. The confectioner tires are formed on confectioner drums and then shaped and vulcanized in moulds on presses. Besides the mentioned production equipment, it is necessary to use other equipment to finish and control products. The technological scheme for the production of conventional tires (inner and outer tires) is shown in Fig.1.

Market - potential and possibillities

A new procedure of the production of PUR pneumatic tires with LIM technology will have to convince potential investitors and customers of the economical advantages of these tires compared to classical (radial and bias) ones, which are being produced in a conventional way for almost 100 years. When compared to the conventional production process of radial tires, the LIM production process potentially offers certain techical and economical advantages. These advantages are resulting in lower production and operation cost of polyurethane LIM tires.

Figure 2. Plant with automatic control for preparing raw materials

Figure 3. Machine for the production of LIM tires a complete control over the process of producing tires for passenger vehicles by liquid injection moulding

Economy of LIM tires production

In comparison with the conventional production process of radial tires, the LIM tire process is characterized by higher costs of raw materials (polyurethanes are expensive compared to elastomer tire compounds), but main capital costs are substantially lower (facilities and equipment) and laboratory costs (facilities and apparatuses for the control of raw materials, half-products and final products-pneumatic tires).

All feasibility studies completed for various manufacturing locations in the world, show a rating in favour of the LIM tire production process compared to conventional production of radial tires, indicating as an advantage substantially lower total costs of the production of LIM PUR tires [4].

So a LIM tire factory compared to a rubber classical radial tire factory of the same output capacity requires about 30 % of the capital for the production (facilitions and equipment) and a control lab. Since the LIM process is fully automated, skilled labor is substantially reduced for testing materials, half-products and final products. Also, due to lower wastes (rejects) in the production process, labor costs in the production and control of LIM tires are reduced.

Since the LIM process is based on exothermic reaction molding, much lower energy is required in the liquid injection process compared to the vulcanization process of conventional tires in a press where higher curing temperatures (150-180 °C) are required.

Further advantages of the LIM process are offerred by the fact that a LIM tire production unit permits to operate a plant for tire production with an output capacity of only 2000 tires per day and still being profitable, while corres-

ponding conventional radial tire plants are profitable with the range between 25,000 to 30,000 tires per day.

The LIM process is used for the production of tires for passenger cars, damper and industrial vehicles, trucks, tractors and other agriculture mechanization vehicles (Fig.4). It is also used for the production of filled tires applited in industrial vehicles, agriculture and special purpose vehicles, etc (Fig.5).

Figure 4. Applications of different types of LIM tires

Figure 5. Applications of filled tires based on polyurethanes

Comparing characteristics of LIM tires and conventional radial tires

At the estimate of tire quality, from a customer's (motor vehicle driver's) point of view, the next tire characteristics are important: treadwear, prolonged service life – usefull time of exploitation and influence of tire types on lowering fuel consumption. There are also other important pneumatic tire characteristics such as: wet and dry traction, adherence, noise, etc. Some laboratory experimental data of comparative tests of LIM and radial tires showed that the LIM tires service life is 70% longer. The LIM firm tests also proved an average of 10% savings in fuel consumption for cars using LIM tires.

On an assumption that the life of such LIM tires is 100.000 km, and that one million cars with LIM tires have an average mileage of 25.000 km per year, with an average fuel consumption of 10 l per 100 km, about 300 million liters of fuel is thus saved annually.

This is very important from the ecological aspectas well, because there are proportionally less harmfull motor gasses, which contributes to increasing people's health and saving our planet.

Conclusions

Although this work mentions numbers of advantages of the future (futuristic) LIM process technology of the production of PUR tires compared to the conventional production process of radial tires such as: less capital investiments in equipment, moulds, production plants and labor, lower tire abrasion, prolonged service life of LIM tires and savings in fuel consumption of 10% in vehicles with LIM tires the reality and facts differ from that whichis shown by producers of LIM tires in their commercials and prospects.

The facts is that after 20 years of commercial attempts of few firms in the world with LIM tires, they are less present on the market. That fact gives great advantages to conventional radial tires which are still irreplacable and superior in quality (advantage elastomers compared to PUR materials), in construction of final products and in better exploitation characteristics.

However, recent engagement and interest of Goodyear Tire & Rubber Co. for investment and developing of LIM proces, means that hopes in the future of PUR tires are back, and that in the field of materials development, construction of products and necessary equipment, we should expect further development, which, will offer high quality of LIM tires making them an alternative and a worthy substitute for radial tires of traditionally high quality.

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Razvoj pneumatika na bazi poliuretana kao alternativa konvencionalnim radijalnim pneumaticima

Poslednjih decenija, istraživači u industriji guma ulažu napore da se uvede postupak proizvodnje poliuretanskih pneumatika kao zamena za pneumatike na bazi prirodnog i sintetičkih kaučuka. Iako još nema značajnije komercijalne upotrebe, neke velike firme kao Goodyear & Rubber Co. ulaze u projekat razvoja automobilskih pneumatika na bazi poliuretana postupkom tečnog injekcionog presovanja. Na bazi dosadašnjih istraživanja i ispitivanja očekuje se da poliuretanske gume budu boljih karakteristika u pogledu trajnosti, smanjenja otpora pri kotrljanju, procenta smanjenja škarta u proizvodnji i dr. Dalja prednost se ogleda u znatno manjim troškovima za proizvodna postrojenja livenih poliuretanskih guma u odnosu na opremu za proizvodnju guma na bazi kaučuka.

Ključne reči: **poliuretanske gume, kaučuci, tečno injekciono presovanje, potrošnja goriva, otpor pri kotrljanju, radijalne gume.**

Développment des pneus à base polyuréthanne comme l’alternative pour les pneus radiaux classiques

Les chercheurs dans l’industrie pneumatique font efforts de remplacer la production des pneus à base de caoutchouc naturel et sunthétique par la production des pneus à base de polyuréthanne. Bien qu'il n'y ait pas encore d’applications commerciales importantes, quelques grandes enterprises comme Goodyear & Rubber Co. ont entré dans le projet du développement des pneus d’automobiles à base de polyuréthanne par le moulage par injection liquide (LIM). Les dernières recherches et analyses démontrent qu'il est possible d’expecter meilleures caractéristiques des pneus à base de polyuréthanne en ce qui concerne la durée de vie, la résistance au roulement, la réduction des dêchets, etc. Les coûts totaux d’équipement et d’installation sont aussi un des avantages importants.

Mots-clés: **pneus à base de polyuréthanne, caoutchouc, moulage par injection liquide, consommation du carburant, résistance au roulement, pneus radiaux.**