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PRODUCTION OF PROTOTYPES OF "YELLOW PAVING STONES" IN BULGARIA PART II: TRIBOLOGICAL AND MECHANICAL INDICATORS

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ABSTRACT

Under semi-industrial conditions prototypes of street paving stones of equivalent yellow colour and identical dimensions to the so-called "yellow paving stones" from the center of Sofia, were produced. The specimens produced by the working team have a higher coefficient of static friction against different counter bodies under both dry and wet conditions and a higher wear resistance than that of the reference articles. The newly produced specimens are characterized by a surface porosity of about 80 times smaller and water absorption of 19 times lower than those of to the original paving stones. The following characteristics are obtained: a compressive strength of 2900 kg/cm^2 - 3000 kg/cm^2, a wear resistance of 0,05 g/cm^2, micro-hardness of 760 kg/mm^2 - 800 kg/mm^2 and a thermal resistance of 30 heat cycles of air of a temperature varying from 500°C to 20°C. An application for a patent has been made and with it the team participated in the 7th ITI 2016 Exhibition, where it was awarded a Gold Medal of the World Intellectual Property Organization. Prototype samples have been donated to the Museum of History in Sofia, to Sofia Municipality and to representatives of potential investors. The prototypes were presented also to the Historical Museum of Popovo and the National Museum "Earth and Man" - Sofia.

Keywords: *petrugical material, tribological properties.*

INTRODUCTION

The production of yellow paving stoness as well as the synthesis of similar ceramic materials is carried out [1 - 7].

The team developed the composition of the yellow paving stones and participated in the elaboration of the first prototypes. The team consists of specialists from IMSET- BAS, headed by Prof. L. Lakov, Ph.D., and from „Rodna Industriya" Ltd., Popovo. The presented work is related to a technical solution [12], on the basis of which, at the request of the authors, a preliminary novelty study was carried out. The product developed corresponds to Art. 8 of the Patent law, which is a novelty. Innovative compositions and a technology for the production of prototype of new „yellow paving stones" have been developed, which are equivalent in colour and superior to the reference yellow paving stones in Sofia.

The results were presented in Conference held in Sozopol „NDT Days 2016", [13], IX International Scientific Conference „Design and Construction of Buildings and Facilities", Varna, 2016, [14].

EXPERIMENTAL

The samples were prepared according to [15].

The following physical and mechanical properties of the prototypes and the samples ("new" and "old") were examined: a relative density according to BDS EN 23369 - 2002; a volume of open and closed pores; water absorption (determined by standard methodology).

The volume of the pores was found by immersing the sample in toluene, holding it for a while, removing it, soaking the filter paper surface and weighing it on an analytical balance with an accuracy of $\pm 1.10^{-4}$ g;

The volume of closed pores was determined by the formula:

$$V_{(cl.p)} = V_o - V_{(th.)} - V_{(op.p.)}, \quad (1)$$

where $V_{(cl.p.)}$ was the volume of the closed pores, V_o was the total volume of the body with pores, $V_{(op.p.)}$ was the volume of the open pores, while $V_{(th.)}$ was the volume of the body determined by the formula:

$$V_{(th.)} = m/d_{(cr.)}, \quad (2)$$

where m was the weight of the body with pores, while $d_{(cr.)}$ was the density of the sample (body) calculated according to the phase composition of the material.

By tribological test carried out at different loads provided the characteristics of the static friction – the static coefficient of friction, the friction coefficient jump, the static and dynamic transition factor. The static friction coefficients were investigated against various counterparts (a rugged tire, a smooth tire, smooth sole-leather and rubbed sole-leather) at different loads under dry and wet conditions.

The abrasive wear was tested with the Patel-Disk tribotester under the following conditions: load P of 4.53 N (0.462 kg), a sample height of 10 mm, abrasive sandpaper (Silicon Carbide No 500), R = 0.037 m, a number of cycles N equal to 400, 800, 1200, 1600.

Water absorption was determined by standard ceramic methods.

A non-destructive control of the internal structure of the "old" and "new" samples was carried out with the help of a computer 3D tomograph Nikon XT H 225 (available in "SmartLab" of IICT-BAS). The computer tomograph provided the study of a wide range of sample materials and sizes, ranging from 20 KV to 225 KV. It provided a real-time 3D real-time imaging and featured a five-axis positioning system. The load capacity of the rotating table was 15 kg, while the maximum sample size was 25 cm x 15 cm x 15 cm. The maximum resolution of the detector was 1900 x1500 with an active area of 467 cm^2. The X-ray spot was less than 3 μm. The system had also computer software for analysis and 3D reconstruction of the internal structure of the site. The computer tomograph provided a detailed picture of the internal structure of the devices without destroying them. Computerized X-ray monitored both the presence of cracks and the homogeneity (or even caking) of the materials.

The air and fire compaction of the samples were determined and the preliminary technical and economic calculations were carried out to determine the cost of production in the future.

RESULTS AND DISCUSSION

From the conducted studies it is found that the entire internal structure of the "old" sample contains "defects" (the material is not homogeneous). These defects are expressed as darker spots, whereas the presence of such defects was not observed in the „new" sample. Together with the prepared samples (conditionally referred to as „new", Fig. 1), the samples of original paving stones, imported from Austro Hungary (conventionally referred to as „old"), were also tested.

The specificity of production of this type of article is related to a narrow temperature range of high temperature liquid phase synthesis. It depends on various factors such as: material uniformity, a composition and a grain size of the raw materials, a molding method, a homogeneous temperature field, an atmosphere of the furnace space, a programmed heat treatment mode, etc. (Table 1).

From the conducted studies it was found that the entire internal structure of the „old" sample contains defects (the material is not homogeneous). These defects are expressed as darker spots, whereas in the „new" sample, the presence of such defects is not observed (Fig. 2).

Fig. 1. “Yellow bricks” produced in Bulgaria with an equivalent yellow colour, shape and dimensions compared to the original standards produced in Austro-Hungary at the beginning of the 20th century.

It is found in the course of the studies and tests carried out that the prototypes prepared are characterized by a higher static friction coefficient for all materials, environments and loads used (Tables 2 - 5, Figs. 3 - 10). This ensures better traction, less slippage and better safety (especially under wet conditions) when compared to the original pavement.

The mass wear refers to the ruptured mass of the surface layer within a specific friction path (rotation cycles) or a specific period of time. The graph shows the

Table 1. Physical and mechanical properties of prototypes (“new” model) and reference standards (“old” model).

Sample type	Density in a bloody state, g/cm^3	Surface porosity (open pores) %	Volume of closed pores cm^3/%	Water absorption %	Micro-hardness, kg/mm^2
„new” sample	2.321	0.0376	1.46 / 19.5	0.277	760-800
„old” sample	2.416	3.238	1.92 / 23.0	5.21	600-650

Table 2. Dry static friction of the pattern.

Load	19,4 [N] (2 kg)	38,8 [N] (4 kg)	58,2 [N] (6 kg)
STANDARD - rugged tire			
T_o [N]	9	15	24
COF μ_o	0,46	0,38	0,41
STANDARD - smooth tire			
T_o [N]	6,5	13	18
COF μ_o	0,33	0,33	0,30
STANDARD - smooth sole-leather			
T_o [N]	5	14	20
COF μ_o	0,25	0,36	0,34
STANDARD - rugged sole-leather			
T_o [N]	7,5	15	23
COF μ_o	0,38	0,38	0,39

Table 3. Dry static friction of the prototype.

Load	19,4 [N] (2 kg)	38,8 [N] (4 kg)	58,2 [N] (6 kg)
PROTOTYPE - rugged tire			
T_o [N]	11,5	21,5	31,5
COF μ_o	0,50	0,55	0,50
PROTOTYPE - smooth tire			
T_o [N]	8,3	18	27
COF μ_o	0,42	0,46	0,46
PROTOTYPE - smooth sole-leather			
T_o [N]	7,5	15	25
COF μ_o	0,33	0,38	0,42
PROTOTYPE - rugged sole-leather			
T_o [N]	9,2	18,5	28
COF μ_o	0,47	0,47	0,48

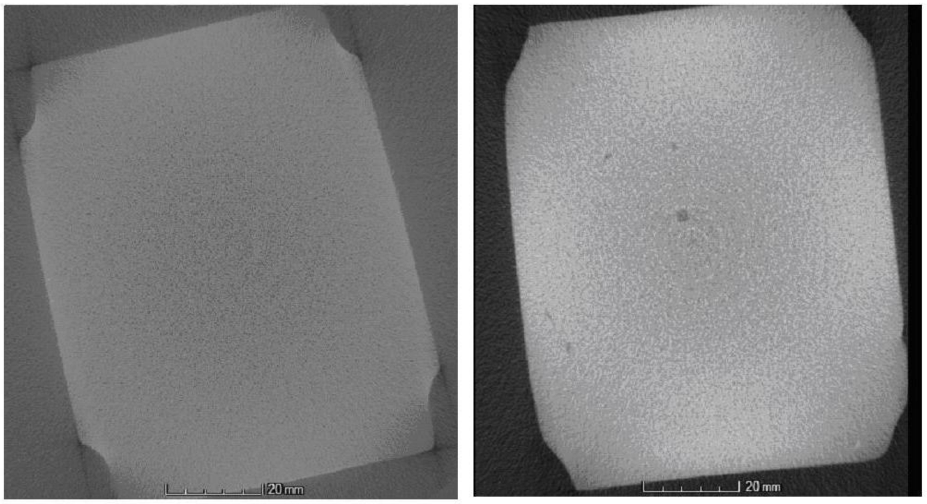

Fig. 2. Nondestructive benchmarking of the internal structure top view - a) prototype ("new" model); (b) benchmark ("old" model).

Table 4. Wet static friction of the pattern.

Load	19,4 [N] (2 kg)	38,8 [N] (4 kg)	58,2 [N] (6 kg)
STANDARD - rugged tire			
T_o [N]	10	20	32
COF μ_o	0,52	0,52	0,55
STANDARD - smooth tire			
T_o [N]	8	21	30
COF μ_o	0,41	0,54	0,52
STANDARD - smooth sole-leather			
T_o [N]	8	25	40
COF μ_o	0,41	0,64	0,69
STANDARD - rugged sole-leather			
T_o [N]	10	25	41
COF μ_o	0,52	0,64	0,70

Table 5. Wet static friction of the prototype P.

Load	19,4 [N] (2 kg)	38,8 [N] (4 kg)	58,2 [N] (6 kg)
PROTOTYPE - rugged tire			
T_o [N]	18	25	43
COF μ_o	0,93	0,64	0,74
PROTOTYPE - smooth tire			
T_o [N]	14	28	41
COF μ_o	0,72	0,72	0,70
PROTOTYPE - smooth sole-leather			
T_o [N]	17	38	50
COF μ_o	0,88	0,98	0,86
PROTOTYPE - rugged sole-leather			
T_o [N]	15	31	47
COF μ_o	0,77	0,80	0,81

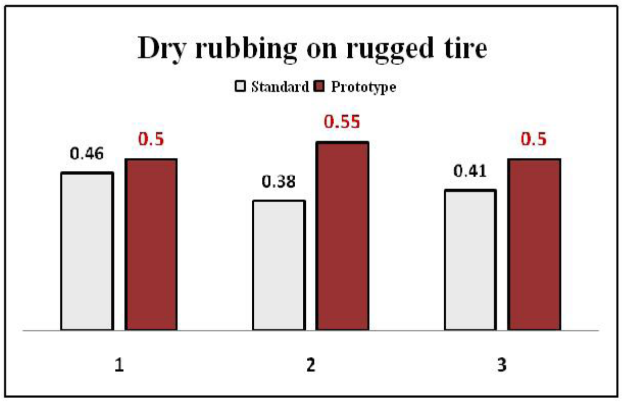

Fig. 3. Static friction coefficient on a rugged tire under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N.

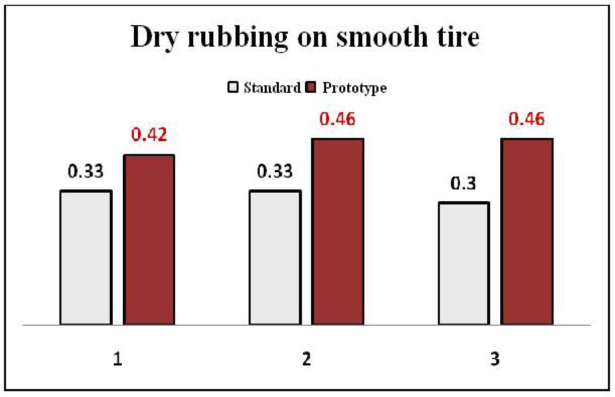

Fig. 4. Static friction coefficient on a smooth tire under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N.

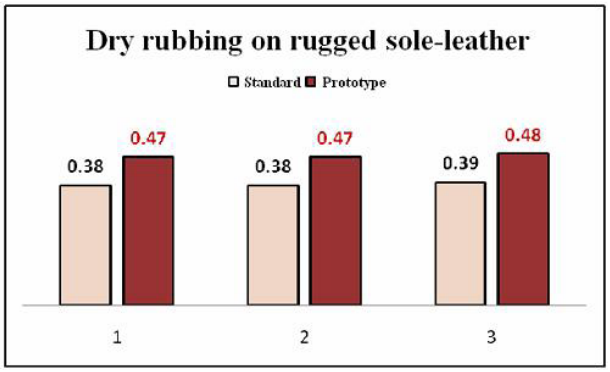

Fig. 5. Static friction coefficient on rugged sole-leather under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N.

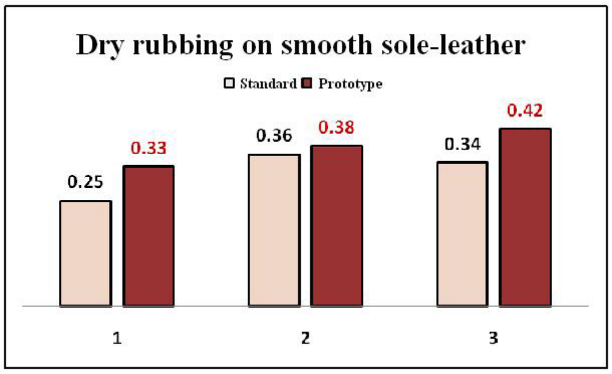

Fig. 6. Static friction coefficient on smooth sole-leather under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N

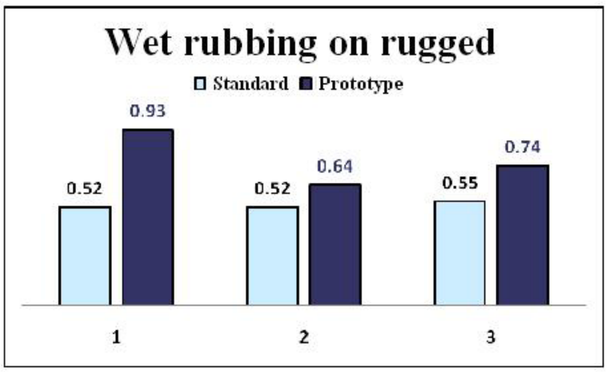

Fig. 7. Static friction coefficient on a rugged tire under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2.

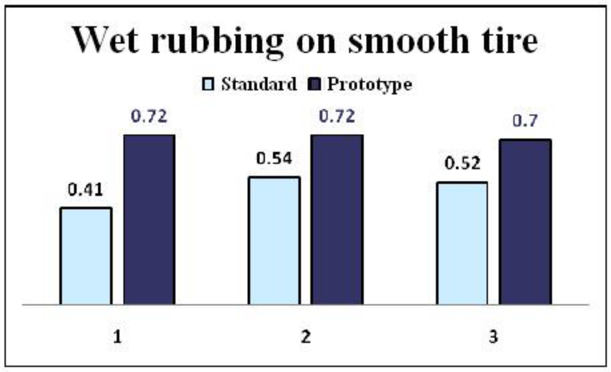

Fig. 8. Static friction coefficient on a smooth tire under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N

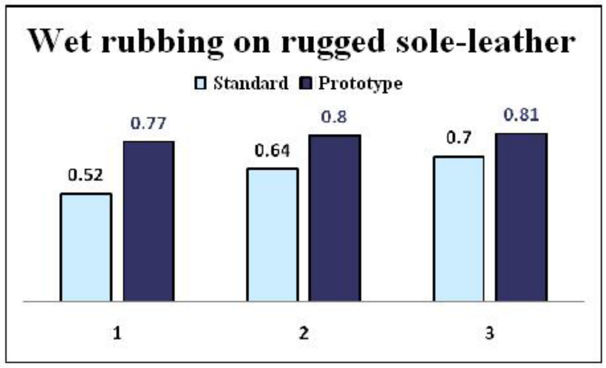

Fig. 9. Static friction coefficient on a rugged sole-leather under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N,

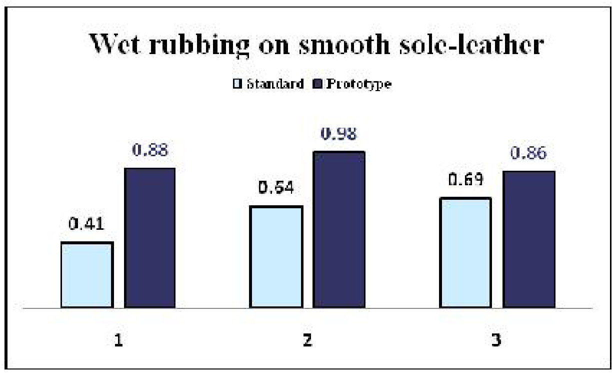

Fig. 10. Static friction coefficient on a smooth sole-leather under load: 1 - 19,4 N; 2 – 38,8 N; 3 – 58,2 N.

dependence of mass wear on the number of friction cycles. A greater wear is found for the standard (the „old“ paving stone) when compared to that of the new prototypes.

The linear wear intensity represents the ruptured thickness of the material per unit of a friction path.

The resulting magnitude is non-dimensional. The absolute wear resistance is the reciprocal value of the linear wear intensity.

The coefficients of static friction with respect to different anti-rolls (rugged tire, smooth tire, smooth sole-leather and rubbed sole-leather) are established at different loads under dry and wet conditions.

The dependence of the mass wear on the number of friction cycles was established (Tables 6, 7).

Table 6. The prototype and standard abrasive wear.

Number of cycles	0	400	800	1200	1600
Friction path S, [m]	0	92,96	185,9	278,9	371,8
Standard (old samples), mass [g]	10,57	10,56	10,54	10,53	10,52
Wearing, [mg]	0	4,5	8,2	9,8	11,6
Prototype (new samples), mass [g]	9,477	9,473	9,468	9,466	9,464
Wearing, [mg]	0	4,3	8,6	10,2	12,1

Table 7. Parameters of abrasion wear of the prototype and standard.

Number of cycles	0	400	800	1200	1600
Friction path S, [m]	0	92,96	185,9	278,9	371,8
Standard, mass [g]	10,57	10,56	10,56	10,56	10,56
Mass wear [mg/m]	0	0.038	0.044	0.035	0.031
The linear intensity of wear *i*	0	0.046	0.042	0.033	0.03
Absolute wear resistance I	0	21.81	23.94	30.05	33.85
Prototype, mass [g]	9,477	9,473	9,468	9,467	9,465
Mass wear [mg/m]	0	0.038	0.044	0.035	0.031
The linear intensity of wear *i*	0	0.049	0.049	0.039	0.034
Absolute wear resistance I	0	20.48	20.47	25.89	29.08

CONCLUSIONS

On the basis of sedimentary rocks from the village of Svetlen, Targovishte in Bulgaria after a complex semi-industrial research in the “Rodna Industriya” Ltd., Popovo from plastic mass and thermal treatment at 1100±5°C were produced prototypes of “yellow paving stones” with equivalent yellow colour to the standard from the street floor in the center of Sofia. The resulting pavers are characterized by a higher coefficient of static friction with respect to different counter bodies in a dry and wet environment and a lower abrasion wear compared to the reference pavers.

The new samples were characterized by better mechanical and operational performance. They had a lower surface porosity by about 80 times and a lower water absorption by about 19 times when compared to those of the original pavement. The prototypes had a compressive strength of 2900 kg/cm^2 - 3000 kg/cm^2, a wear resistance of 0.05 g/cm^2, micro-hardness of 760 kg/mm^2 - 800 kg/mm^2, thermal resistance of 30°C (from 500°C to 20°C).

The 3D computer tomography analysis of samples from the original pavement showed the presence of “defects” in the form of darker spots of the registered image. This proved the non-uniform structure of the standards. The tomographic analysis of the new prototypes showed no presence of defects proving in turn the homogeneous nature of the structure of the material of no cavities and cracks.

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