Studies on Grit Use in Asphalt Mixtures (II)

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It is a well-known fact that either pellets or granules used in sandblasting operations for cleaning/finishing metal surfaces of any kind, are subject over time to processes of either splitting or wear of the surface, thus diminishing their operational features, such as, for instance: the angularity and dimension. When being used in sandblasting operations, the granule size fractions that have lost their capacity of finishing surfaces are being sorted by sifting and eliminated. In industrial conditions, where very large surfaces are being sandblasted, the grit turns into a major problem, since it often requires large warehouse surface areas for storage. In that sense, this paperwork presents experimental data regarding the worn grit fractions management by using it in asphalt mixtures, conferring, beside an economic benefit, also that of environment protection, since those lightweight fractions oftentimes form very polluting air floating powder. By eliminating those fractions that are reusable in the process of sandblasting, on the remaining sort resulted from sifting through the 1.0 mm strainer granulation and bitumen behaviour studies were carried out. The analysis of proposed asphalt mixtures, holding a certain percentage of grit, highlighted the fact that the latter, by both the 0.4- 0.1 mm granule size and by the floatable particles of less than 0.2 mm granule size, allow for the replacement of natural quartz sand. The physical-mechanical features of studied mixtures were established on cylindrical probes made of bitumen, in which smashed silicone stone chippings were mixed, within standard required range of granule size, crushing sand and worn grit, in very well controlled mixing proportions. the results were compared to those derived from standard samples made of solely quartz crushing sand, alongside the other components that make up type BA8 asphalt mixtures, of a mere 6.5% bitumen of a 50/ 70 proportion, according to local standards. By comparing the two asphalt mixture type features (standard and experimental), it allowed for highlighting that worn grit may be very successfully used instead of crushed sand.

Keywords: grit, asphalt mixture, recycling, exploitation, environmental protection

The concept of sustainable development implies the restructuring of the fashion in which natural resources are being used, so that the economic activities get into balance with ecologic systems, for the purpose of avoiding the latter utter depleting. For that purpose, the corroboration between sustainable development policies of two companies, both great natural raw material consumers, yet one among them generating large quantities of waste, waste that may be capitalized by the other, by replacing one component as raw material, that may generate multiple economic and environmental impacts [1-7].

It is a known the fact that shipyards are large sandblasting material consumers, materials used for finishing metal surfaces in process, often making use of either quartz or fine chipping sand derived from quartz stone, raw material that requires, beside a potentially abundant natural source, also its processing, aiming at activating its sandblasting capabilities. There are, on the other hand, factories that produce bitumen-based asphalt mixtures, in whose mass they disperse quartz aggregates, the aforementioned factories being large raw material consumers, yet the latter susceptible of being replaced by grit sort that results from sandblasting. a great advantage presented by grit in such applications is its large floatable component mass concentration, that confers mechanical and climatic/chemical wear resistance, when utilized in asphalt blankets [1, 2].

Employing quartz sand sandblasting in cleaning maritime vessel parts, in both building, and restoring/ repainting old ships, allows for removing every surface impurity, in the form of corrosion byproduct, in existing paint cover, salt deposited by re-crystallizing, as well as deposits al algae, of gastropod/bivalve formations, etc. Quartz materials used for cleaning these metal surfaces are also known as grit, of a certain required granulation. The particle sharp edges are getting destroyed during sandblasting, moreover, most of them get smashed, thus continually changing the granule size ration , the strength and angularity features, resulting in quality sandblasting. In case the grit required characteristics are not met, metal surface cleaning is compromised [8].

The sandblasting operation performance is very much influenced by possible contaminants lying on the surfaces that are being cleaned, as well as by the abrasive particles quality, that shall confer optimal, standard-compliant roughness [9, 10].

Romanian shipyards, as well as those from abroad, beside their necessary of sandblasting material, are being confronted with procurement and processing issues, as well as issues related to the requirement for large areas for storing waste, and environment protection measures, since lightweight particles often create most harmful airborne powder [1, 2]. Moreover, by employing grit in sandblasting, the later is

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being converted in some sort of hazardous grit, as it contains traces of heavy metals, in the form of either skims or metal oxides, paint residue or other protective film layer generating element, of toxic constituents, such as polychlorinated biphenyl (PCB) [11, 12]. Given these circumstances, the naval sector pollution reduction, by heightening the level of using various sorts of waste, and their controlled storing, represents an environmental policy priority [1].

In turn, asphalt mixture plants, beside the fact that they are large energy consumers, are also large pollutants, yet presenting the advantage that many of the filling sorts, derived from natural raw materials, may be successfully replaced by waste derived from sandblasting, or by ceramic plant remnants [9, 10].

Road construction asphalt or bituminous mixtures generally employ as natural aggregates pre-washed river ballast, mixed up with quartz sands (extracted from either riverbeds or ballast pits), and chippings (removed from quarries following crushing and stone selecting processes) or crushing sands (the finest fraction of quarry chippings). All these products suppose high extraction and processing costs, that shall add up to the final asphalt mixture cost [13-15].

In this sense, the present paper shows experimental data obtained by utilizing asphalt mixture worn grit. Thus, past eliminating fractions reusable in sandblasting processes, the remaining sort, sifter through the 1,0 mm strainer, was analyzed from the granule size viewpoint, and also based on its behavior to bitumen dispersion process, in the form of asphalt mixture for the road wear surface (roads, lanes and pavements on industrial plant buildings).

Experimental part

Materials and methods

Since grit resulted from metal surfaces sandblasting in the process of either building ships, or restoring/repainting old maritime vessels, is characterized by a wide range of granule size and a most varied inorganic and organic impurity content, including soluble salts resulted by the re-crystallization of seawater, and that it is before being utilized in experiments, it was subject to washing operations/processes, for the purpose of removing soluble components.

Thus, our study made use of grit origination from the Galaţi Shipyard, where we collected 10 statistic samples, 5 from the surface on different layers, and 5 from various depth layers, that were subsequently mixed, dispersed in distilled water and heated while stirred up to 75...80°C, for 5-10 minutes, followed by decantation and filter washing until chloride free, for eliminating soluble salts.

After drying, the material is separated in fractions, using a system of jigging screens made of 4.0, 2.0, 1.0, 0.65, 0.4, 0.2, 0.1 and 0.065mm strainers. From among these, we separated for the experiment the sort deemed as residue alone, excepting the sort that may be reused in sandblasting, made of greater than 2.0 mm fractions, oftentimes utilized in asphalt mixtures recipes (SR EN 933-1/2002). Besides the sort (fractions remnant on the 1.0, 0.65, 0.4, 0.2, 0.1 and 0.065mm screens) the study also utilized a sort made of crushed silica rock chippings, of granule size between 6.0 and 2.0 mm, and a sort of crushing sand made of granule size made of 1.0, 0.65, 0.4, 0.2, 0.1 and 0.065mm fractions. From the worn grit were therefore removed fractions greater than 2,00 mm, that also contain impurities (skims, burr, shell and snail fragments, algae, etc..); All these are being sent to useless waste landfill.

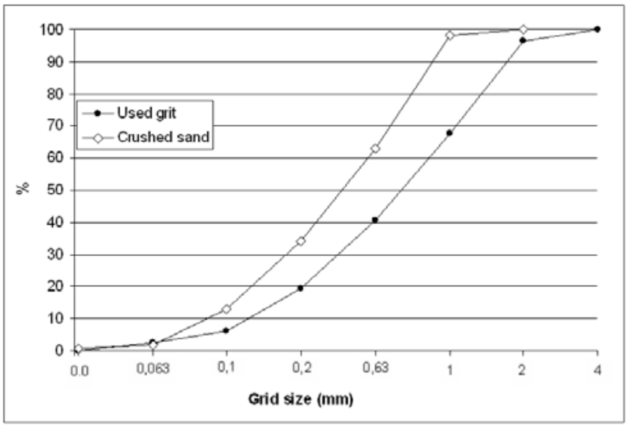

Fig.1- The percentage distribution of the fractions filtered through the jigging screens

For starters, the fine granule size sorts were analyzed for granule size, aiming at highlighting, by comparing distributions, their suitability for being used in mixes and their behavior at bitumen dispersion.

Figure 1 presents the fraction obtained following the granulation analysis, and the distribution of granulation curves based on fractions that had passed through the sorting system screens, according to standards SR EN 933-1/2002 and SR ISO 3310.

Among these sorts, the study made sole use of those deemed non-reusable in sandblasting, namely the fractions that passed the 4.0 mm sift.

Therefore, from among the fractions separated by the set of jigging screens, shown in figure 1, according to SR EN 174-1/2009 and SR EN 933-1:2002, we focused on granule metric fractions that have passed the 8 jigging screens (4.0, 2.0, 1.0, 0.65, 0.4, 0.2, 0.1, 0.065mm respectively).

Besides the worn grit, chippings and crushing sand, the recipes for the asphalt mixture also made use of limestone filler - sort of 0.063 and 0.100mm granule size (according to STAS 539-79).

Road bitumen type D 50/70 was used as binder for asphalt mixtures, according to standard SR EN 12591:2009, which possesses a great capacity for intake and aggregate by making monolith of divided solids. That bitumen moreover offers stability over time and resistance to water and other external elements (light, frost-defrost, mechanical wear, etc). Another characteristic that shall be considered in the study is that that the asphalt mixture thus obtained should present little flexibility at temperatures over 50°C, namely, it should neither soften, nor become very rigid at temperatures below 0°C.

Achieving an optimum asphalt mixture recipe implies selecting a rigorously analyzed mixture, made of either silica or aluminum- silica aggregates, filler and bitumen, for greater durability.

Setting the recipe

The experimental study was carried out in the road testing laboratory of Tancrad company, Braila quarters, based on a cooperation agreement signed on Nov. 4 2012, whose objective was establishing the physico-mechanical characteristics of new asphalt mixture recipes, based on worn out grit. This, instead of classic, chipping-based aggregate (4.0...8.0mmsort), and crushing sand (0.0...4.0mm sort), from Revărsarea quarry (set of standard probes), a mixture of chipping (sort 4.0...8.0mm) and crushing sand (sort 0.0...4.0mm) and grit originating from the Galaţi Shipyard landfill. On the two recipes, calcareous

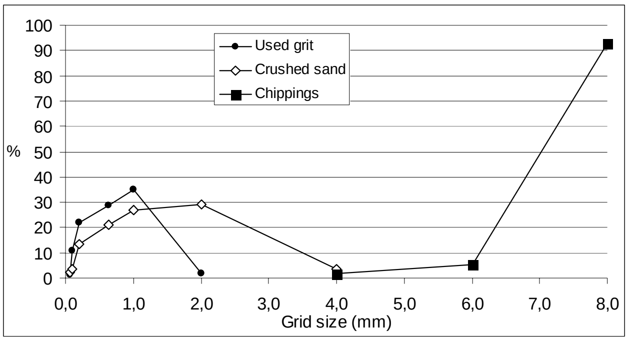

Fig. 2. The curves of the granulometric distributions of the fractions remained on the riddle

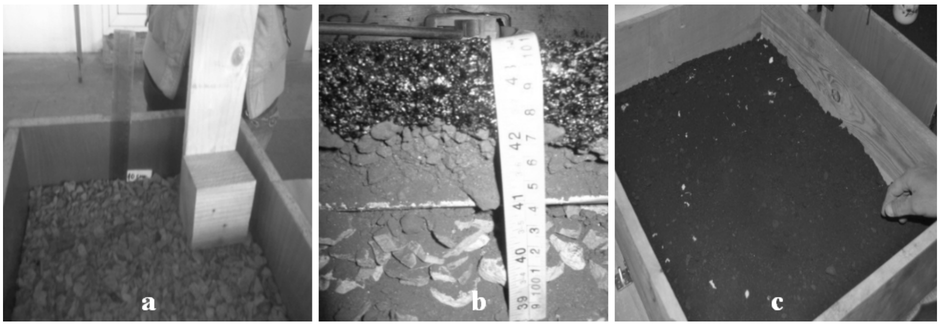

Fig. 3. Road blanket casting by means of asphalt mixture type BA8, for experiments: a - base layers compacting phase, b - driving layers structure, asphalt blanket, c - asphalt mixture before compacting

filler was added, obtained from dry grinding very fine limestone from Holcim, whereas the binder was type 50/70 road bitumen, according to SR EN 12591/2009, whose softening point had been calculated prior to its use. According to local national standards, three versions of bitumen composition were initially used: 6.2, 6.5 and 6.8%,, out of which, according to the experiments connected to the Marschall test, the optimum composition was selected, in accordance with BA8 standard for mixtures.

Figure 2 shows a comparative granulation distribution of crushing sand and worn grit in relation to the chipping sort utilized in the two recipes, the standard and the experimental, whose shape proves that the fractions of worn grit assume a granulation disposition resembling that of crushing sand, the latter being often utilized in asphalt mixtures composition.

For creating a driving layer in the laboratory, we utilized a formwork in which we simulated by layer an asphalt blanket for light traffic and for industrial buildings pavements (fig.3), using the same elements as in the field (asphalt mixture, adherence layer, and base/support, layer). After compacting and cooling, the asphalt mixture alone was removed, and from it, r = 5cm, h = 7cm cylindrical samples were extracted (fig.4).

The components used in obtaining the new asphalt mixture under study, except for the bitumen, were initially analyzed as granulation using classifying jigging screens (SR EN 933-1:2002), having meshes of: 8.000, 4.000, 2.000, 1.000, 0.630, 0.200, 0.100, 0.063mm.

Initially, based on data from the specialized literature according to the road work standards SR 174-1/2009 (Part 1- Technical Conditions for Asphalt mixture), the optimal relation between the bitumen used in standard networks of asphalt mixture (hydrocarbon concrete mixture BA8) based on broken quartz sand, 0.0-4.0mm category. In this study of optimization of the bitumen composition the Marshall test was used which determines the *stability* (S) of the bitumen layer in traffic conditions.

The Marshall tester is schematically drawn in figure 5.

For trial purposes, Marshall test tubes of 10 cm in diameter and 6.3 cm in height are used. The principle of the test is the determination of the breaking strength of the test tube, under a force applied on a generator. The trial is made on a test tube in a mould at a temperature of 60°C by Marshall characteristics are presented in table 1test.

According to this trial, the Marshall *stability* (S) is the charge expressed in kN reached when the test tube breaks at a temperature of 60°C. The minimal Marshall stability, according to STAS 174-1/97, for fine asphalt mixture ranges from 5.0…9.0kN, depending on the road traffic and category. For hydrocarbon concrete mixture BA8 a Marshall stability of at least 6.0kN is recommended.

The *flowing rate* (I) is the deformation reached by the vertical diameter of the test tube at the breaking time and is expressed in mm. The flow rate or the creep may vary from 1.5 to 4.5mm. Generally-speaking, for the Marshall test the result spreading is pretty large.

Furthermore, the trial uses two other characteristics: apparent density and water absorption or degree of moisture.

Apparent density (g/cm^3), is the mass of the volume unit of compact asphalt mixture including voids. This is determined based on the sample mass/volume formula, according to the relation:

Fig. 4. Asphalt mixtures cylindrical probes subject to analysis: a – standard, b - experimental

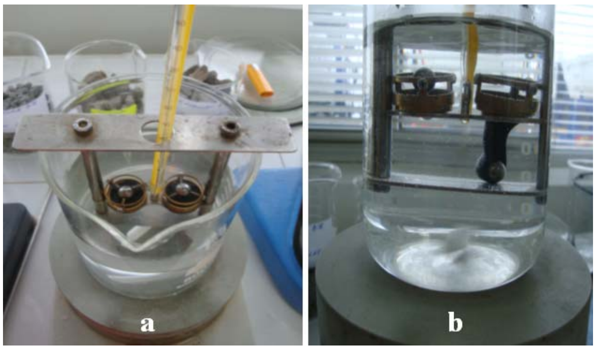

Fig. 5. Device for the determination of the sagging point: a. configuration of the device, b. ball crossing the sample when the sagging point is reached

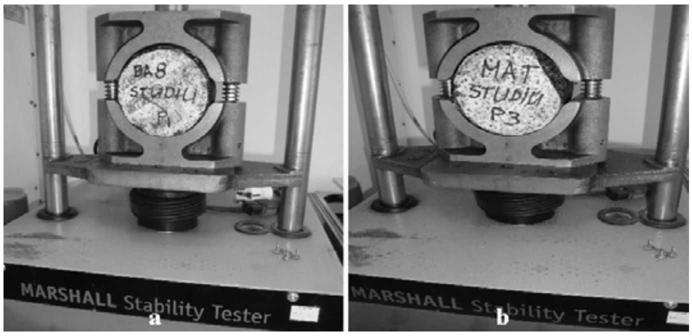

Fig .6. Device with samples under study using the Marshall test: a – witness sample, b - experimental sample

$$\rho_a = \frac{m_u}{V}\ \left(\frac{g}{cm^3}\right)$$

In which, for the standard sample, we have:

- ρ_a is the apparent density of the hydrocarbon mixture, (g/cm^3);
- m_u is the sample mass weighting 1137.4g when dry according to the analytical scales;
- V is the volume of the cylindrical sample with a diameter of 10cm and the height of 6.3cm and its value is 494.5cm^3,

for which an apparent density was achieved:

$$\rho_a = \frac{1137.4g}{494.5cm^3} = \frac{2.30g}{cm^3}$$

Therefore, for asphalt mixtures the apparent density should have at least the value of 2.330g/cm^3 according to SR 174-1/09. This allows for the evaluation of the compacting degree of the samples submitted to the Marshall test.

The water absorption (%) was determined by evaporation after being immersed in water, using the thermal method in a static regimen. Initially, after getting the sample out of water, it was mopped up with a cloth to remove surface and gravitational water excess. The moist sample was introduced in a drying closet with automated heat and water adjustment control, where it got dried up at a temperature of 60°C and UR under 2.5%. The heating was made at a constant mass. The water absorption or the moisturizing capacity is expressed in percentages from the initial mass of the sample and the moisturized mass. Water absorption in volumetric rates is calculated according to the relation:

$$A_a\,\% = 100(m_f/m_i) = 100(2047.3/1137.4) = 1.8$$

where :

- m_i is the initial mass of the sample, 1137.4g;
- m_f is the final mass of the sample after being moisturized, 2047.3g.

The sagging point of bitumen in achieving the asphalt mixture was determined by the method of heating in cold water, using a ball device that automatically records the temperature of the sample when crossed by the ball that falls on a metal lamella, fixing the sagging temperature on the thermometer (fig.5).

The configuration of the device of the figure 5 comprises a Berzelius glass of 800mL, 2 standard balls, 2 rings, each with three ball centering levers, ring holder, metal lamella for letting out the ball and stopping the thermometer, the clamping plate for ring and thermometer holders.

It is dipped in cold water so that the water level is about 50 mm over the level of the bitumen rings. The balls are laid in the middle of the rings on the impression or in the centering device, taking care that between balls and bitumen air bubbles are not formed. During heating, the bath should be sheltered from draughts. The temperature at which the ball reaches the lower plate of the tester is considered to be the sagging point (fig. 5b).

The sagging point for the bitumen used in experiments determined by means of the ball device is 56°C (fig. 5b).

To determine the optimal bitumen percentage, cylindrical samples of asphalt mixture were made with a bitumen content of 6.2, 6.5 and 6.8%. They were submitted to the Marshall test (fig. 6). The compaction was made by impact using the Marshall hammer, hitting both faces of the sample. The samples were tested in the Marshall tester at a temperature of 60°C, when were obtained parameters information about the Marshall stability (S) and creep (I).

Using these analysis methods, it was aimed at optimizing the standard bitumen composition that needed to be as similar as possible to those used in asphalt factories and to enable the determination of some characteristics that differentiate the experimental samples based on grit from the standard ones.

Results and discussions

With regards to composition, granulation and morphology of particles, grit, crushed sand and chippings resulting from the crushing of silica rocks, within the framework of Romanian regulations [16-20], meet the standards SR 174-1/2009 (base course), SR 7970/2001 (base course) and STAS 10473-1/1987 (stabilized ballast) and the standards NE 026/2004 (field: road works, hot bitumen coating).

The composition of the nets used in manufacturing standard samples or reference samples and of the experimental ones was determined based on a preliminary study made in an accredited lab, observing the technical conditions required by the regulations pertaining to asphalt mixtures and hot bitumen coating (NE 026/2004).

The samples under study were submitted to lab trials to check if they possess the physical and mechanical characteristics corresponding to the STAS 730/1989 [17], that requires quality technical conditions for natural aggregates, such as the Romanian standard SR 174-1/2009 [21], for the BA8 mixture. The compliance of these samples with the Romanian regulations is presented in table 1 and figure 7.

As the shapes of the granulation curves of the grit and of the crushed sand are similar and close as value, both being within the limits required by the standards, it is practically allowed to replace the crushed sand with the waste grit (fig.7). Moreover if obtaining leaching fractions is meant, under 0.200mm, the grit presents a series of advantages:

Table 1
COMPOSITION ON GRANULATION FRACTIONS OF THE TWO NETWORKS FOR THE DRIVE SURFACE BASED ON ASPHALT MIXTURE TYPE BA8 (STANDARD SAMPLE AND EXPERIMENTAL SAMPLE) AS REQUIRED WITH UPPER AND LOWER LIMITS ACCORDING TO [21]

Recipe		Dimension of the jigging screen(mm)								Total (%)
		0.063	0.100	0.200	0.630	1.000	2.000	4.000	8.000	
Composition of the witness sample	Chippings, 4.0…..8.0mm	0.0	0.0	0.0	0.0	0.0	0.0	3.1	30.4	33.5
	Crushed sand, 0.0…4.0mm	1.30	1.85	6.65	10.50	13.50	14.50	1.70	0.0	50.0
	Filer, SR EN 13043/2003	1.90	8.10	0.0	0.0	0.0	0.0	0.0	0.0	10.0
	Bitum, D50/70	-	-	-	-	-	-	-	-	6.5
Total granulometry for the witness sample/ recipe		**3.20**	**9.95**	**6.65**	**10.50**	**13.50**	**14.50**	**4.80**	**30.40**	**93.5**
Composition of the experimental sample/ recipe	Chippings, 4.0…..8.0mm	0.0	0.0	0.0	0.0	0.0	0.0	3.1	30.4	33.5
	Crushed sand , 0.0…4.0mm	0.65	0.92	3.33	5.25	6.75	7.25	0.85	0.0	25.0
	Grit, 0.0…2.0mm	0.33	2.72	5.47	7.23	8.80	0.45	0.0	0.0	25.0
	Filer, SR EN 13043	1.90	8.10	0.0	0.0	0.0	0.0	0.0	0.0	10.0
	Bitum, D50/70	-	-	-	-	-	-	-	-	6.5
Total granulometry for the experimental sample/ recipe		**2.88**	**11.74**	**8.80**	**12.48**	**15.55**	**7.70**	**3.95**	**30.40**	93.5
Superior limit SR 174-1/09		**10.0**	**15.0**	**20.0**	**25.0**	**30.0**	**35.0**	**40.0**	**50.0**	**-**
Inferior limit SR 174-1/09		**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.0**	**5.0**	**10.0**	**-**

Table 2
THE PHYSICO-MECHANICAL CHARACTERISTICS FOR THE ASPHALT MIXTURE TYPE BA8, WITH CRUSHED SAND, IN THREE VARIANTS OF BITUMEN CONCENTRATION

No.	The characteristics obtained on the cilindrical samples obtained through the MARSHALL TEST	U.M.	Bitumen concentration variant (%)			References/ Standards SR 174-1/09
			I	II	III	
			6,2	6,5	6,8	
1	Stability(S) determined at a 60°C temperature	kN	7.7	**7.8**	7.1	min. 6.0
2	Flowing index (I)	mm	3.5	**3.8**	4.6	1.5...4.5
3	Report S/I	kN/mm	2.2	**2.1**	1.5	1.3...4.0
4	Apparent density	g/cm³	2.330	**2.354**	2.326	min 2.300
5	Water absorption	%	2.1	**1.8**	1.6	1.5…5.0

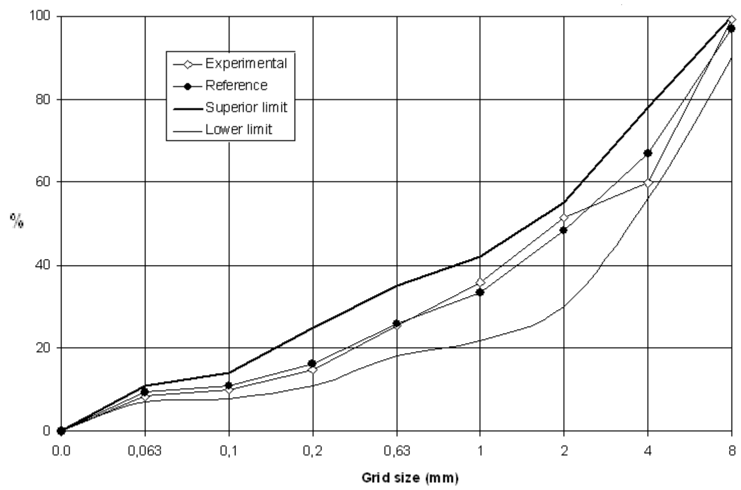

Fig. 7. Granulation curves for basic/ experimental recipe

high capacity of binding together with bitumen, high compatibility at inclusion in bitumen and elimination of airborne dust in storing dumps. These aspects are confirmed by a series of studies. Thus, J.B. Sousa et al. [21] observed that the sizes of aggregates play an important part in the behaviour of asphalt mixture at fatigue. They state that the finer the aggregates in the pavement, the higher the resistance to fatigue Furthermore, with regard to the shape of the granulation curve there is another study [22] that shows that asphalt mixtures with a steady granulation curve are highly fatigue-resistant.

These two studies confirm our results. Furthermore, analyzing the classification of the granulation curves of finer aggregates of the two nets, for the standard sample and for the experimental sample, these range in-between the upper and lower limits as required by [21] (fig. 7), the shape of the granulation curve of the grit being close to the crushed sand.

Table 2 presents the physical-mechanic characteristics obtained for the standard sample manufactured using a recipe of asphalt mixture BA8 (light-vehicle road drive surface and floors for production premises), in which crushed sand and bitumen with the sagging point of 56°C were used, in the three work variants, varying only in the bitumen component.

Analyzing the data in table 2 based on standards, the optimal bitumen concentration of 6.5% was chosen both for the standard sample and for the experimental one.

No.	Characteristics	U.M.	Witness	Experiment	References/ Standards SR 174-1/09
1	Specific weight (Monolith obtained through melting)	kg/m³	2.372	2.398	-
2	Apparent specifically weight(porous sample)	kg/m³	2.330	2.354	min 2.300
3	Water moistening capacity	%	1.80	1.60	1.5...5.0
4	Drying speed	mg/min per vol. unity	75.00	78.00	-

Table 3
PHYSICO-MECHANICAL CHARACTERISTICS FOR ASPHALT MIXTURES TYPE BA8, WITH THE STANDARD RECIPE AND THE EXPERIMENTAL RECIPE WITH THE BITUMEN CONCENTRATION OF 6.5%

The bitumen used in the three variants of the standard recipe from the stands of Marshall penetration test and sagging point, are classified as road bitumen type 50/70.

Table 3 presents a series of psychico-mechanical characteristics for asphalt mixture type BA8, in which a bitumen concentration of 6.5% was used for the standard and for the experimental samples.

Analyzing the data of table 3 from the stand of standards, the asphalt mixture based on grit (25%) and crushed sand (25%) is superior to the standard or reference one adding a series of advantages resulting from the use of grit as noxious industrial by-product for humans and animals around storing dumps.

Conclusions

At a comparative analysis of the two asphalt mixtures BA8, based on 6.5% bitumen type 50/70, a standard one and a reference one (optimized by the Marshall test), having the composition: 33.5% small-sized crushed silica rock, with a granulation from 4.0 to 8.0mm, 50% crushed sand, with a granulation from 0.0 and 4.0mm and 10% limestone filler and the other the experimental one, having the composition: 33.5% broken stone with the same characteristics as in the standard recipe, 25% crushed stone and 25% grit, resulting from sanding, with a granulation from 0.0 and 2.0mm and respectively 10% limestone filler, it was noticed that:

- the granulation of grit close to that of crushed sand and ranging of granulation curves within the limits required by standard, enables the partial replacement of the natural quartz sand of the recipe;
- leaching components with a granulation of less than 0.2mm, of the grit improve greatly the characteristics of the asphalt mixture;
- the analysis of some characteristics as required by national standards enables the determination of the doses for analyzed asphalt mixtures with a optimal behaviour at fatigue;
- the use of the grit in the recipe, besides the improvement of the wear-and-tear strength, adds value, such as its use, as it is a noxious industrial by-product for humans and animals in the area of the storing dumps.

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