DOI:10.22337/2587-9618-2023-19-1-41-54

COMPARISON OF PHYSICAL AND MECHANICAL TEST METHODS FOR COARSE AGGREGATE ACCORDING TO THE EGYPTIAN AND RUSSIAN STANDARD METHODS

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Abstract: Physical and mechanical test methods for coarse aggregate have been studied under the commercial program of Egyptian and Russian standard test methods comparison. Theoretical and practical research has been carried out using Egyptian raw materials from reputed occurrences. The research shows that the main part of tests is either the same or comparable, which can make the quality assessment easier for both sides provided that the converting rules are followed. Recalculating methods for important geometrical and mechanical properties are proposed. Converting tables, graphics and Russian standards are provided in order to assist Egyptian suppliers with participating in tendering for Al Dabaa NPP project.

Keywords: national specifications comparison, international standards, El-Dabaa NPP, physical and mechanical test methods, concrete aggregate characteristics, raw materials

СОПОСТАВЛЕНИЕ ФИЗИЧЕСКИХ И МЕХАНИЧЕСКИХ МЕТОДОВ ИСПЫТАНИЙ ДЛЯ КРУПНОГО ЗАПОЛНИТЕЛЯ ПО ЕГИПЕТСКИМ И РОССИЙСКИМ СТАНДАРТАМ

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Аннотация: В рамках выполненной работы по сопоставлению египетских и российских стандартных методов испытаний были проанализированы методы физико-механических испытаний крупного заполнителя. Теоретические и практические исследования были проведены на материалах, отобранных из наиболее распространенных месторождений Египта. Исследование показывало, что большинство испытаний сопоставимы или одинаковы, что может облегчить мероприятия по оценке качества по стандартам Египта и РФ, при условии соблюдения правил пересчета. Разработаны методы пересчета основных геометрических и механических характеристик. Результаты представлены в виде сопоставительных таблиц и графиков. Российские стандарты представлены для того, чтобы помочь египетским поставщикам участвовать в тендерах по проекту АЭС Аль-Дабаа.

Ключевые слова: сопоставление национальных стандартов, международные стандарты, АЭС Эль-Дабаа, физические и механические методы испытаний заполнителей, характеристики заполнителя для тяжелых бетонов, сырьевые материалы

INTRODUCTION

This study was motivated by the results of analysis and comparison of Russian and Egyptian test methods for fresh concrete, hardened concrete and its raw materials. Technical standards have been analyzed in 2020-2021 as a part of pre-operational work before the construction of the Al-Dabaa NPP.

According to project, fresh and hardened concretes have to be specified in compliance with Russian technical documents. At the same time, it is necessary to use local materials, which are produced and verified according to the Egyptian standards. Preparatory literature review showed only few works about specifications comparison, unfortunately, they are related to metal materials [1-3]. This is why at the pre-construction stage it is important to find a way to compare the specifications of raw materials for concrete (cement, coarse and fine aggregates, chemical and mineral additives) for such a significant project. A reliable recalculating method should be proposed if some of the characteristics cannot be compared without tests.

It was discovered that Egyptian specifications for cement, fresh and hardened concrete are harmonized with the international standards, meaning that the test methods in both countries are the same, which simplifies the quality estimation. The main difficulty appeared with the physical and mechanical characteristics of coarse aggregate. In Egypt, aggregates are still widely examined for compliance with ASTM [4], as it was ordered in ECP 203-2018 [5], despite the fact, that the updated in 2020 version of ECP 203[6] is based on BS EN standard specifications [7]. A transition from US to European standards will take some time for producer to adapt their production, even in 2021 it hard to find aggregates produced according to BS EN 12620. However it is worth mentioning, that distinction between foreign tests is not that big, as it is for Russian specifications. Investigation has shown that the main difference concentrated in the methods of physical tests which are tied up with the geometrical parameters of grains. This is the reason why in this study we have tried to develop a recalculating method for grain size distribution curves gained in accordance with the Egyptian test method. Another reason is that grains size distribution of coarse aggregates affect important characteristics, such as bulk and packing density and mechanical properties (Aggregate Crushing Value (ACV), Ten Percent Fines Value (TFV), Aggregate Impact Value (AIV), Los Angeles Abrasion Resistance).

As an aside, it is important to notice, that the same work was also performed for special types of concrete, including heavy-weight, lightweight and serpentinite concrete for biological shielding. Consideration of these results is beyond the scope of this study.

MATERIAL AND METHODS

Test Methods

Physical and mechanical characteristics of coarse aggregates according to Russian specifications for normal-weight concrete [8] and Egyptian Code of Practice for concrete structures are presented in Table 1. Unlike international standards, the abovementioned Russian standards are available on the internet and it is possible to get familiar with them using machine translation tools. The links are provided in the References section.

According to recent updates the ECP 203-2020 is mainly focused on mechanical requirements for aggregate such as impact value (SZ) and resistance to fragmentation (LA). Recently mentioned ACV and TFV are no longer mandatory. Physical and chemical test methods, such as: water absorption, mean and bulk density and organic impurities have minor distinctions in both countries, due to its nature, and not presented in this study. More accurate information about EN and GOST test methods comparison described by Lyapidevskaya et al. [20]

Table 1. Main physical and mechanical characteristics for coarse aggregates required for both countries

Characteristic	Test method acc. ECP 203-18	Test method acc. ECP 203-20	Test method in Russia
Grain size distribution	ASTM C136-19[9]	EN 933-1:2012	GOST 8269.0-97[10] sec. 4.3
Materials Finer than 75-μm (No. 200) Sieve	ASTM C 117-17[11]	-	GOST 8269.0-97 sec. 4.5.3
Materials Finer than 63-μm Sieve	-	EN 933-1:2012[12]	
Los Angeles abrasion resistance	ASTM C 131/131M-20[13]	BS EN 1097-2:2020[14]	GOST 8269.0-97 sec. 4.10
Impact value	BS 812-112:1990[15]	BS EN 1097-2:2010	GOST 8269.0-97 sec. 4.11 (not obligatory)
Flakiness index	BS 812-105.1:1989[16]	EN 933-3:2012[17]	GOST 8269.0-97 sec. 4.7
Aggregates crushing value (ACV)	BS 812-110:1990[18]	Not carried out	GOST 8269.0-97 sec. 4.8
Ten percent value (TFV)	BS 812-111:1990[19]	Not carried out	Not carried out

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Grain Size Distribution

In both countries, grain size distribution curves are obtained after screening on control sieves. The main difference lies in the size and shape of sieve openings.

In Russia, grain is sized in accordance with GOST 8269.0-97, sec. 4.3, on sieves with rounded openings of the following sizes: ○ 25, ○ 20, ○ 15, ○ 12.5, ○ 10, ○ 7.5, ○ 5, ○ 2.5, and □ 1.25. After screening, the mass of **retained grains** is to be calculated on each sieve in percentage.

In Egypt, grain is sized in accordance with ASTM C136-19 on sieves with squared openings of the following sizes: □ 37.5, □ 25, □ 19, □ 12.5, □ 9.5, □ 4.75, □ 2.36, and □ 1.18. After screening, the mass of **passed grains** is to be calculated on each sieve in percentage. In EN 933-2 squared openings are also used: □ 31.5, □ 16, □ 8, □ 4, □ 2, □ 1, □ 0.5, □ 0.25, □ 0.125, and □ 0.063.

Materials Finer than 75-μm (No. 200) and 63-μm sieves

The wet sieving method is used both in Russia and Egypt where a control sample is washed on a sieve with a certain opening size. A percentage of passed particles is to be calculated as a difference between the mass of the sample before testing and after washing.

For this test, in Egypt there are following sieves: for ASTM the upper one, with the opening size of 1.18 mm (No. 16), and the bottom one (control sieve), with the opening size of 75-µm (No. 200) or for BS EN - 1 mm (upper sieve) and 63-µm (control sieve). In Russia – 1.25 mm (N125) and 50-µm (N005). In both cases, the upper sieve serves to protect the thin mesh of the control sieve against the pointy edges of coarse aggregate.

Los Angeles Abrasion Resistance

In both countries, the abrasion resistance of coarse aggregates is measured using a shelf drum. A sample of aggregate is loaded into a shelf drum with steel or cast iron spheres (Ø 46…48 mm and m = 390…445 g), then the drum rotates at a constant speed of 30-33 rpm. The number of rotations and abrasion spheres is specified in accordance with the coarse aggregate grading. A percentage of mass loss is to be calculated as a difference between the mass of the sample before testing and after screening on a control sieve.

Both methods are close enough for coarse grades 5 to 10 mm and 10 to 20 mm according to GOST or 6.3 to 9.5 mm (grade C) and 12.5 to 19 mm (grade B) according to ASTM. In either way, the mass of the sample is 5 kg and the number of drum rotations is 500. The difference between the methods is in the size of control sieves' openings – 1.25 mm (N125) in Russia and 1.70 mm (No. 12) in Egypt. Equipment and test procedure according to BS EN is almost identical, except using 1.6 mm sieve as control.

Flakiness Index

Grains with the length three times greater than their width are to be counted as flaky according to the Russian standard. The quantity can be measured either using shell sieves or manually using a shape index caliper.

In Egypt, it was common to use the British approach to define the quantity of flaky grains. Its major difference lies in the alternative collection of samples and the definition of flakiness. Grains are to be considered as flaky if their width is lesser than 0.6 of mean fraction size (D_m) which is calculated as the average of two nearest sieves (Eq. 1):

$$D_m = \frac{d + D}{2}, \qquad (1)$$

where D_m is mean grain size of fraction (mm), d is bottom sieve opening size (mm), D is upper sieve opening size (mm).

For each fraction size, sieves with shell openings were designed. Control fractions and sieve shell openings according to the Russian and Egyptian test methods are presented in Table 2.

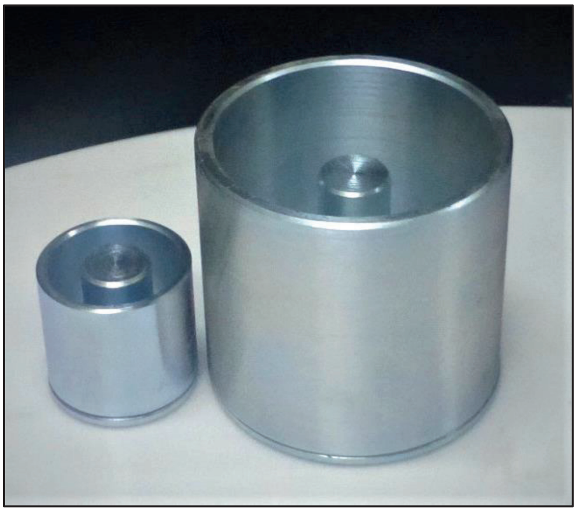
Latest version of Egyptian Code requires using BS EN 933-3 method, which is a bit simpler. Flaky grains are those with dimensions lesser than $D_i/2$. For each grain size there are certain d_i/D_i groups: 31.5/40, 25/31.5, 20/25, 16/20. 12.5/16, 10/12.5, 8/10, 6.3/8, 5/6.3, 4/5.

Table 2. Aggregate Size-Fraction and Shell Openings

Parameter	Russian method		Egyptian method		
Size-fraction, mm	5-10	10-20	6.3-10	10-14	14-20
Opening L x W, mm	10 x 2.5	20 x 5	30 x 4.9	40 x 7.2	50 x 10.2

Aggregate Crushing Value (ACV)

In both countries, the strength of coarse aggregate is measured after compression test in a special cylinder (Fig. 1).



a) Russian Cylinders Ø75 and Ø150 mm

b) BS 812:110 Cylinders Ø154 and Ø78 mm

Figure 1. Cylinders according to Russian and Egyptian standards

In Russia, ACV is determined using 5 to 10 mm and 10 to 20 mm size fractions. A test sample is put into a cylinder with the inside diameter of 150 mm and the height of 146 mm (Fig. 1a), then the sample is compressed under a 200 kN load at a loading rate of 1…2 kN per second. After the compression is over, ACV is calculated as a difference between the initial mass and the mass after screening on a sieve 2.5 mm for 10 to 20 mm fractions and 1.25 for 5 to 10 mm fractions.

In Egypt, the British test method, which is more concerned about preparation of control samples than the Russian one, was adopted. According to the British method, the main fraction size is 10 to 14 mm. A test sample is put in a cylinder with the inside diameter of 154 mm and the height of 125…140 mm (Fig. 1b), then the sample is compressed under a 400 kN load at the loading rate of 0.67 kN per second. After the compression is over, ACV is calculated as a difference between the initial mass and the mass after screening on a 2.38 mm sieve.

According to Appendix A to BS 812-110:1990, it is possible to use fraction sizes other than 10 to 14 mm. For example, to test 10 to 6.3 mm fractions a small cylinder with the inside diameter of 78 mm, the height of 70…85 mm and compression under the load of 100 kN is used. However, a notable difference remains compared to the Russian method: the load is 50 kN and the height of the test cylinder is 150 mm.

Raw Materials

Control samples for this study were taken from the following occurrences:

- Suez, Attaka (dolomite);
- Matrouh, New Alamein (limestone);
- Matrouh, Al Dabaa (limestone);
- Giza, El Fayoum (basalt).

The chosen occurrences are the main sources of coarse aggregates for civil construction in Egypt. Dolomite aggregates from Attaka, Muhafazah Suez, are considered as the most qualitative due to their stable composition and low alkali reactivity. Then comes moderate limestone from El-Alamein occurrence, Muhafazah Matruh, extended along Wadi-El-Natroon Road. The most changeable physical and mechanical properties are common for limestone from Al-Dabaa region, Muhafazah Suez.

Apart from other materials, there stand igneous rocks rarely used in Egypt as a coarse aggregate for concrete. However, these materials are

essential for the critical structures of nuclear power plants, such as the reactor core containment. Basalt produced in the occurrence near El Fayoum oasis is the most available material in Egypt for this purposes.
Size 67 (4.75 – 19.0 mm), also known on the Egyptian market as Size 1, was chosen as the main grading according to ASTM [4]. The decision was made due to the Al-Dabaa NPP project requirement not to use grains larger than 20 mm. Along with Size 1, Size 2 similar to Size 56 (9.5 to 25.0 mm) is also produced.

THEORETICAL INVESTIGATION

Some characteristics described in Table 1 can be compared based on the theoretical analysis of test methods, e.g. fines content (< 75-μm) and Los Angeles abrasion test.

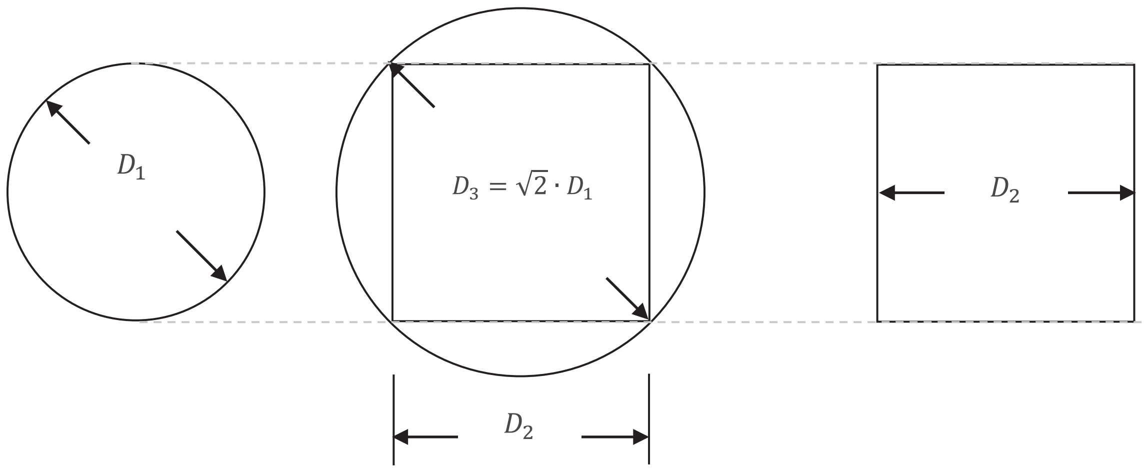
Materials Finer than 75-μm (No. 200) and 63-μm sievesAs mentioned before, the main difference between the two methods is the size of control sieves' openings. In Egypt, particles less than 75-μm or 63-μm in size are measured, which means that their content will be a bit higher or identical to the value that could be obtained according to the Russian method. Considering the genesis of aggregates in Egypt, it is more likely that fine particles are formed mostly from crushing operations. In case of coarse aggregate, grain size distribution curves are flatter in the 50 to 75 μm range, and the difference is not as crucial as it can be for sands and soils.
As a first estimation, it is recommended to use the results according to the Egyptian standard method from quality certificates without converting them. First, with the Egyptian method, the results could be only a bit higher than with the Russian one, so the project restrictions will not be violated. Second, this approach does not break the ranging of suppliers in accordance with their product quality. Third, control tests according to the Russian and Egyptian standards are to be carried out for the most potential suppliers.
Control examination should be carried out in accordance with the Egyptian method, but using an additional 50-μm sieve (No. 35) from the ASTM E11 [22] set. Since a residue on each sieve is known, it is possible to define the content of particles according to both methods without parallel tests. Furthermore, this approach will give additional information for the rating of aggregates since water demand highly increases after 50-μm rather than 75-μm.

Los AngelesAabrasion Resistance
In both countries, aggregates abrasion resistance is determined using a shelf drum (Los Angeles machine). The drum construction, dimensions, weight of grinding spheres and drum velocity have minimal differences and are within reasonable tolerance limits.
Recalculating is not necessary, however, it is worth to mention that the Russian method requires a sieve with 1.25 mm openings against 1.70 mm or 1.60 mm in Egypt. It is recommended to use an additional sieve No. 16 (1.18 mm) from the standard sieve set [4] for more accurate results.

PRACTICAL INVESTIGATION

The remaining characteristics have to be compared according to practical examination due to the basic distinctions of the test methods, e.g. grain size distribution, flaked and elongated grains content, aggregate crushing value (ACV). However, some results can be converted.

Grain Size DistributionIn Russian and in Egypt, the results of tests are presented graphically as a grain size distribution curve. Between two nearest sieves, the distribution curve is considered continuous. Hence, it is possible to measure the mass of grains for every sieve size inside this interval by means of interpolation. However, this statement is only adequate when the sieve openings have the same shape, otherwise, if the openings are of the same size the screening area will be different. This means that in order to develop a recalculating method an experimental correspondence between squared and rounded sieve openings should be found.



a) Rounded opening with size D_1

b) Diagonal of square opening with size D_2 supposed to be equal to diameter of new rounded opening D_3

c) Squared opening with size D_2

Figure 2. TR 103 Interpretation of Correspondence between Squared and Rounded Openings

In Russia, it is possible to use Technical recommendations [23] to recalculate the results from squared to rounded sieve openings (sec. 4.3.4, Table 2). The correspondence between sieves is established geometrically (Fig. 2b) as an equality between the square's diagonal (D_3) and the corresponding diameter of the rounded opening. However, this method didn't pass experimental verification and cannot be used.

Since the geometric approach was not confirmed during experiments, it was decided to establish a new correspondence between sieves based on the data of sieving materials' samples (see 2.2). Tests were carried out first on Egyptian sieves, then – on Russian. It became possible to establish a new correspondence between the sieves knowing actual grains distribution from the same test samples (Fig. 3).

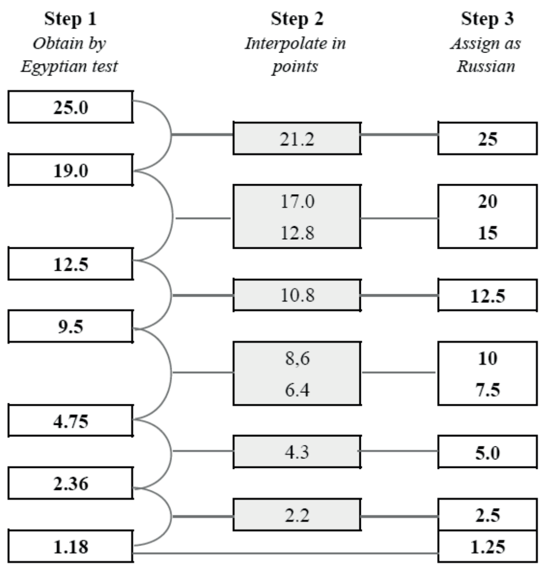


Figure 3. Scheme of Recalculating Results from Egyptian to Russian Sieves

The order of recalculating is as follows:

1. Measure the mass of «passed grains» on Egyptian squared sieves.
2. Convert the obtained values of «passed grains» into «retained grains» via Eq. 2:

$$A_n = 100\% - W_n, \qquad (2)$$

where A_n is the total percentage of retained grains on n-sieve, W_n is the total percentage of passed grains on n-sieve.

3. Find the corresponding points on the curve by means of interpolation using the principle of grain size distribution curve continuity (Fig. 3).
4. Draw a new grain size distribution curve corresponding to Russian rounded sieves.

Fig. 4 (a, b, c, d) presents the actual and recalculated results. As it seems from the graphs, it was not possible to level the error between the different shapes of sieve openings completely. The largest discrepancy is about 10%; however, on the bright side, the curves follow each other's trajectory. The biggest gap can be observed in Fig. 4g showing the results for basalt from El Fayoum with the highest percentage of flaky grains, which most likely increases the discrepancy. In all other cases, the curves are quite close to each other.

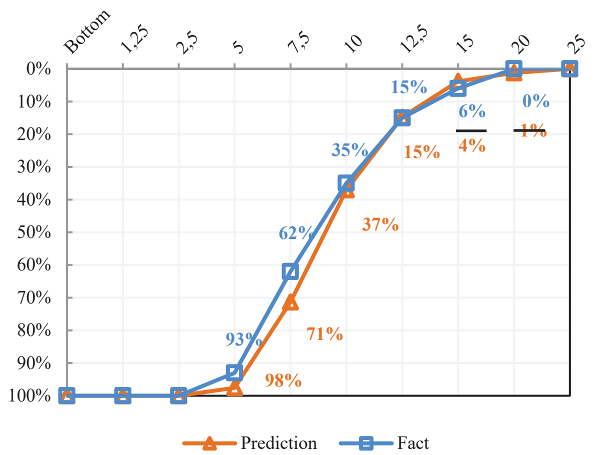


Figure 4a. Suez, Attaka grain size distribution curves

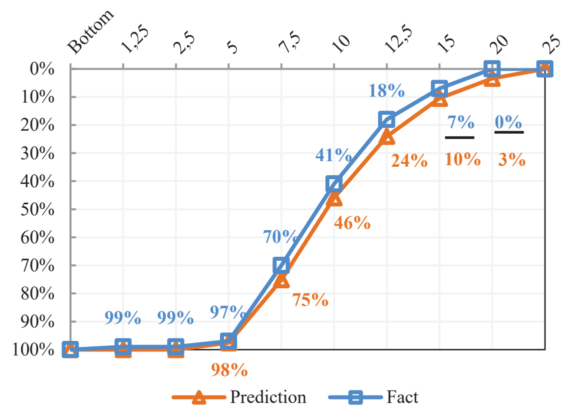


Figure 4c. Matrouh, Al-Dabaa grain size distribution curves

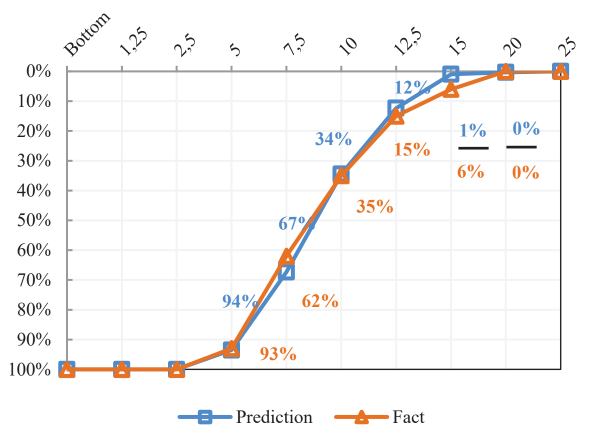


Figure 4b. Matrouh, New Alamein grain size distribution curves

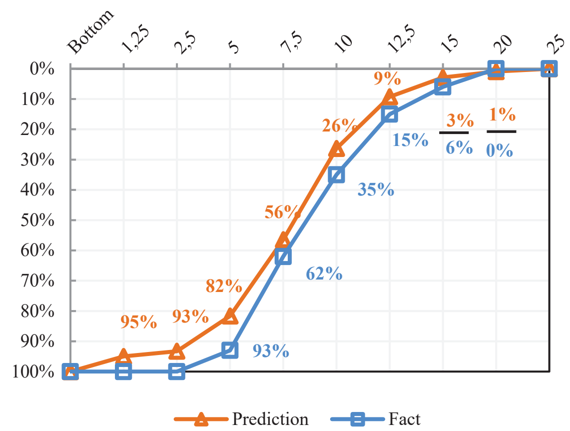


Figure 4d. Giza, El Fayoum grain size distribution curves

Based on the recalculating method results, the following requirements to the interpretation of Russian grain size distributions have been proposed (Table 3).

Table 3. Grading Requirements according to Russian[21] and Egyptian Standards

	Grading	Percentage of passing						
		25.0 mm	19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm
Russian	5.0 to10.0 mm	...	...	100	94 - 100	8 - 23	0 - 5	0
Russian	10.0 to 20.0 mm	100	94 - 100	37 - 65	8 - 22	0	...	...
Russian	5.0 to 20.0 mm	100	94 - 100	54 - 78	32 - 58	3 - 14	0 - 4	0
Egyptian	19.0 to 4.75 mm (No. 67 or Size 1)	100	90 - 100	...	20 - 55	0 - 10	0 to 5	0
Egyptian	25.0 to 9.5 mm (No. 56 or Size 2)	90 - 100	40 - 85	10 - 40	0 - 5	0 - 5	...	...

Field aggregate examination was carried on ASTM sieves; however described recalculating method is also applicable for BS EN sieves. For recalculating additional 22.4 and 11.2 sieves are required from basic group plus sieve set. Recalculating method was used in Voronezh State University on prepared samples in accordance with GOST 32703-2014, which is harmonized with EN 933-1; results are presented in Fig. 4e.

Flakiness and Elongation Indexes

Grains with the length 3-times greater than their width are to be considered in Russia as flaky with no strict differentiation from elongated grains. In Egypt, flaky and elongated grains are to be were determined according to the British standards using mean grain size between two nearest sieves. Grains longer than $0.6 \cdot D_m$.are to be called flaky.

However, no relation between the methods was found after doing the tests due to the significant difference between fractions and mean grain sizes (Table 2). Table 4 shows the results of the tests.

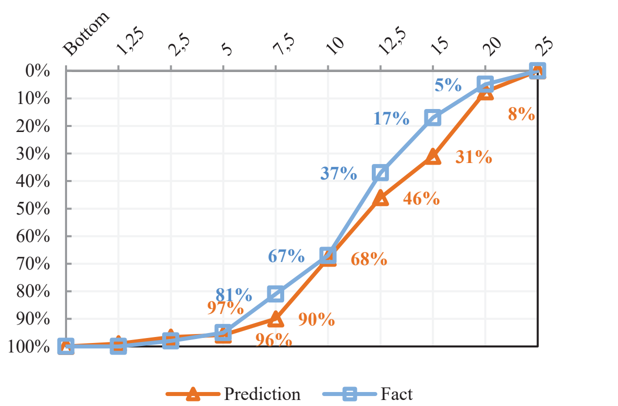


Figure 4e. Experimental EN 933-1 grain size distribution curves

Table 4. Flaky Grains Content Test Results

Region	Grains content (Egyptian method), %		Content of flaky grains (Russian method)[6], %
	Flakiness index[9]	Shape index	
Suez, Attaka (dolomite)	~ 9…12	~ 9	8…10
Matrouh, New Alamein (limestone)	~ 38	~ 22	22…24
Matrouh, Al-Dabaa (limestone)	20...25	12…16	18…22
Giza, El Fayoum (basalt).	~ 38	~ 17	40…46

Aggregate Crushing Value

In Egypt and Russia, ACV is determined by mass loss after compression test in a special cylinder (Fig. 2). Despite the same physical concept and similar testing equipment dimensions, sample preparation and compression force are essentially different.

Results according to the Egyptian method are not comparable with the Russian. However, it is acceptable to convert values using mass loss percentage obtained by Los Angeles machine test. This correspondence is presented in GOST 26633-2015 (see Table A.3). Fig. 5 shows its visual interpretation.

The tests were carried out on the samples described in this study. The results confirmed the adequacy of the correspondence, see Table 5.

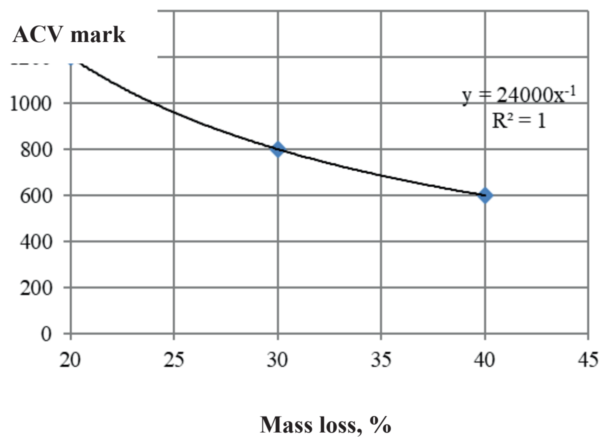


Figure 5. Correspondence between ACV and Percentage of Mass Loss by LA Test

Table 5. LA Machine Test and Russian ACV Test Results

Region	LA mass loss, %	Russian ACV mark	
		expected	actual
Suez, Attaka (dolomite)	19…21	M1200	M1200 (mass loss 9…10%)
Matrouh, New Alamein (limestone)	23…26	M1000	M1000 - 1200 (mass loss 10…12%)
Matrouh, Al-Dabaa (limestone)	35…40	M600	M600 (mass loss 16%)
Giza, El Fayoum (basalt).	~ 16	M1400	M1400 (mass loss ~ 8%)

CONCLUSIONS

The analysis of Egyptian standards as well as their comparison with the Russian technical documents was carried out. It has been found that the standards for fresh and hardened concrete and cement materials are harmonized with international standards in both countries. Main differences appear between coarse and fine aggregates test methods. This study covered only main physical and mechanical tests of coarse aggregate. Experiments have shown that the test methods and their results can be compared provided that the rules of conversion are followed. Most attention must be paid when evaluating the geometric parameters of coarse aggregate grains.

Based on the results of the work it is possible to make the following statements:

- a correspondence between square and round sieves is proposed. However, the prediction accuracy is affected by the content of flaky grains: a higher content increases the gap between the curves. For this reason, the method is recommended only for the initial assessment via quality certificates or when adjustments to crushing processes in production are needed.
- flaky grains content values cannot be converted from Egyptian to Russian method results. The control groups and sizes of shell sieves have essential differences which do not allow avoiding parallel tests.
- an identical approach is used to determine the abrasion resistance. Due to this, it is possible to estimate the aggregate strength (ACV) based on mass loss values obtained by attrition in the Los Angeles machine. Based on the results of the work, the relevance of this dependence was confirmed.

This article can be used as a guidance for Egyptian materials suppliers when it is required to draw up terms of reference or a commercial proposal. Tables for converting requirements and graphical illustrations have been prepared to serve for this purpose.

ACKNOWLEDGES

Presented in this work results were prepared on the basis of experimental investigations, which were carried out in laboratories accredited in accordance with GOST ISO/IEC 17025-2019:

- Housing and Building National Research Center (HBRC), Egypt, Cairo;
- JSC "Institute Orgenergostroy", Russian Federation, Moscow;
- Center of collective usage named after Professor Yu.M. Borisov in Voronezh State Technical University, Russian Federation, Voronezh, partly supported by the Russian Ministry of Science and High Education, Contract No.075-15-2021-662.

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