QUALITY ASSESSMENT OF AGGREGATES FOR ROAD CONSTRUCTION

-Fragmentation, weathering and abrasion-

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1. INTRODUCTION

Samples from 20 Icelandic gravel pits and quarries, see location on Figure 1, were tested with 17 different test methods which all have in common that they measure degradation of aggregates. The samples were taken from gravel pits and quarries of varying quality from most provinces of Iceland to reflect the natural distribution in aggregate properties throughout the country. One purpose of this project was to evaluate the methods used for quality assessment of aggregates for use in road construction. The different test methods were classified and test results compared. The test methods are in many aspects different from each other and can be grouped into three mayor groups, i.e. fragmentation tests, weathering (durability) tests and abrasion tests, see Table 1.

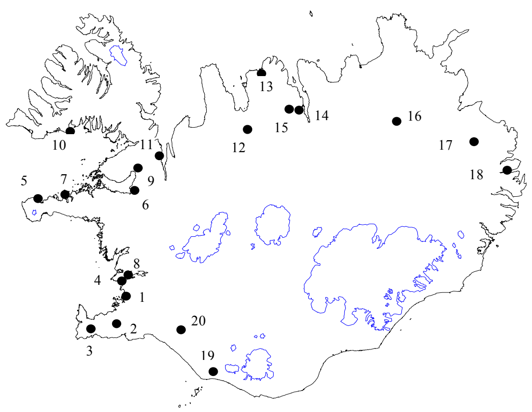

Figure 1. Location of quarries and gravel pits.

Another purpose of this project was to obtain Icelandic test results using the new European test methods for aggregates. The collection of data and knowledge of Icelandic aggregate performance is important in the process of implementing the European standards in Iceland (CEN-standards).

Table 1. Classification of the 17 tests into fragmentation, weathering (durability) and abrasion tests.

Fragmentation tests		
Impact tests	**Static tests**	**Other tests**
Sclagversuch	DSC 5mm test	LA test
AIV test, dry	TFV test, dry	
AIV test, wet	TFV test, wet	
Bg-mod index test		
Bg-stand. index test		
Weathering (durability) tests		
Freeze thaw tests	**Soundness test**	**Weathering product test**
Icelandic freeze/thaw	Magnesium Sulphate test	Methylene Blue Absorption test
Nordtest freeze/thaw		
Freeze/thaw index		
Abrasion tests		
Ball mill tests		
Nordic abrasion test (Studded Tire test)		
Micro Deval test		

LA:	*Los Angeles test*
SZ:	*Schlagversuch test*
Bg-stand:	*Standard Proctor Bg-index test*
Bg-mod:	*Modified Proctor Bg-index test*
TFV wet:	*Ten % Fines Value, wet material*
AIV wet:	*Aggregate Impact Value, wet material*
DSC 5 mm:	*Dutch Static Comp. test (5 mm sieve)*
Fr/Th-index:	*Freeze/thaw index test*
MSSV:	*Magnesium Sulphate test*
MBV:	*Methylene blue test*
Nordtest	*Nordtest Freeze/Thaw test*
Icel. Fr/Th.:	*Icelandic Freeze/ Thaw test*
STT abr.:	*Studded Tire test (Nordic abr.)*
Micro-Deval:	*micro-Deval test (abrasion)*

2. THIS STUDY

Aggregates samples from the 20 different sources were collected in large quantities with the purpose of running a number of tests on representative specimens. All of the aggregates had been prepared as base course material with grain size between 0 and 25 mm.

Figures 2, 3 and 4 give examples of the distribution of test result values for the 20 aggregates tested in this project.

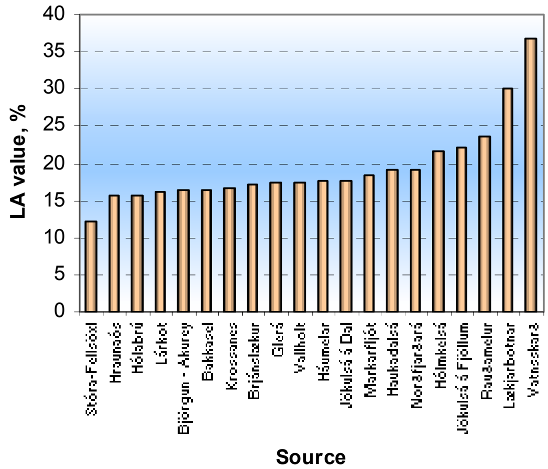

Figure 2. Fragmentation test results when using the LA value test-method.

Figure 2 shows that the distribution of values when using the LA method is not very wide, although the overall range is between 12 and 37 %. It can be seen that 14 of the 20 aggregates obtain values between 15 and 20 %, which is a rather small range and the aggregates would be considered rather strong in that range.

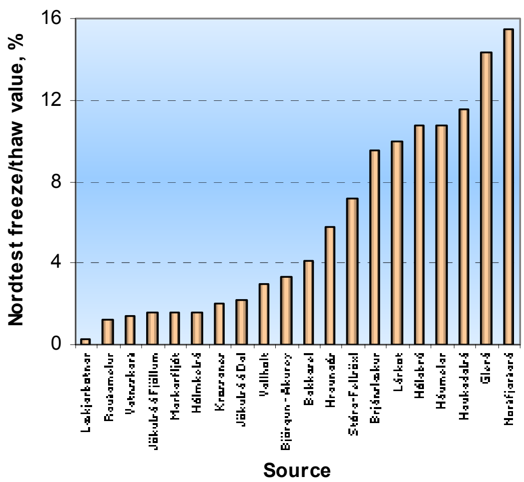

Figure 3. Frost resistance test results when using the Nordtest treeze/thaw method.

Figure 3 shows a wide distribution of test results for the 20 aggregates, when testing with the Nordtest method, with values between 0,3 and 15,5 % loss. This fact, among others, has helped in the process of recommending requirements based on the test results using this test method.

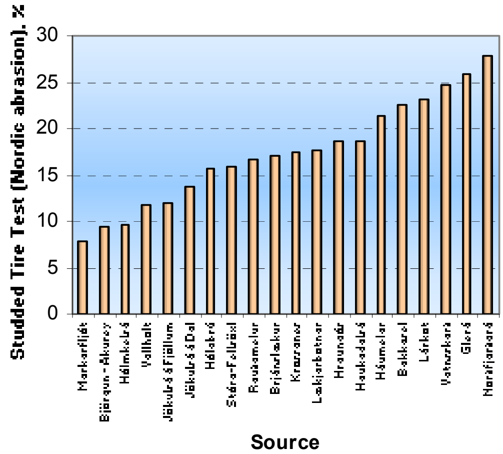

Figure 4. Abrasion test results when using the Nordic abrasion test-method.

Figure 4 shows a rather wide distribution of test results for the 20 aggregates, when testing with the Nordic abrasion method, with values between 7,8 and 27,8 % loss. These results have given Iceland information to support the categories in the European product standards regarding abrasion from studded tires.

It is established that there is good correlation between test results within the three test groups but lower correlation between the groups, see examples of strong correlation in Figures 5, 6 and 7. This is confirmed with regression analysis, see Tables 2 and 3.

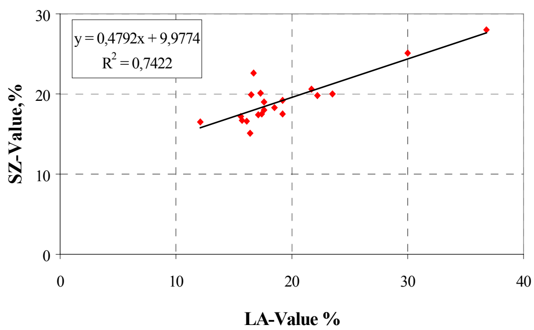

Figure 5. Correlation between two fragmentation test results.

Figure 5 shows the correlation between the two fragmentation tests that have now been taken up as European standards, i.e. the Los Angeles test (LA) and the German Schlagversuch test (SZ). There is a strong correlation between the two methods and

Table 2 indicates that strong correlation is obtained between all the fragmentation test results obtained in this research project. As shown in Table 1, most of the fragmentation tests are impact tests or static compression tests, but the LA test is different, using a drum and steel spheres to fragment the sample.

Table 2. Correlation coefficients (r) between fragmentation tests.

Test	SZ	Bg-stand	Bg-mod.	TFV Wet	AIV wet	DSC 5mm
LA	0,86	0,75	0,87	0,77	0,86	0,93
SZ		0,86	0,96	0,82	0,85	0,87
Bg-stand.			0,90	0,87	0,82	0,73
Bg-mod.				0,86	0,86	0,89
TFV-wet					0,79	0,80
AIV-wet						0,80

Figure 6 shows the correlation between two frost resistance tests.

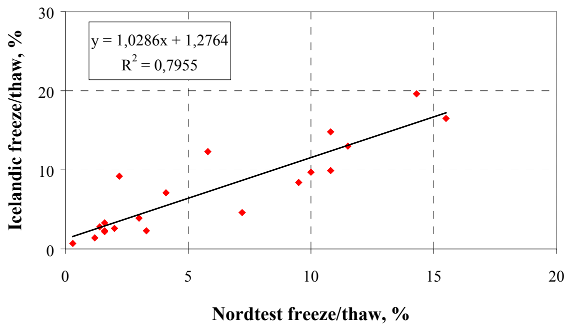

Figure 6. Correlation between two frost resistance test results.

Both freeze/thaw tests are performed in a 1 % NaCl solution and the figure shows a strong correlation between the two test results. Table 3 shows a strong to medium strong correlation between the weathering (durability) tests and also with abrasion test results.

The weathering (durability) tests that have been used in this project can be classified into two groups. One group is actual freezing and thawing in a special freeze/thaw cabinet under prescribed conditions. The number of freeze thaw cycles, the frequency of cycles and maximum and minimum temperature can be different from one method to another. Also saturation and type of liquid can vary. This group can be considered as the actual weathering tests. In the second group of durability tests is a chemical test, the Magnesium Sulphate Soundness test (MSSV), which is supposed to imitate the action of freezing and thawing. The method involves soaking aggregate samples in a liquid, which crystallizes when dried, and hence expands in the pores of the aggregates, resulting in disintegration.

Table 3. Correlation coefficients (r) between weathering (durability) and abrasion test results.

Test method	MSSV	MBV	Nord-test	Icel. Fr/Th	STT abr.	Micro Deval
Fr/Th ind.	0,64	0,69	0,94	0,89	0,61	0,82
MSSV		0,63	0,70	0,73	0,68	0,73
MBV			0,65	0,68	0,58	0,82
Nord-test				0,89	0,61	0,79
Icel. Fr/Th.					0,64	0,77
STT abr.						0,87

The Methylene Blue test (MBV) is a dye test developed to trace harmful fines, i.e. swelling clay. It is therefore not a durability test, but gives valuable information on weathering products of aggregates.

Figure 7 shows the correlation obtained between the two abrasion tests, which were included in this research.

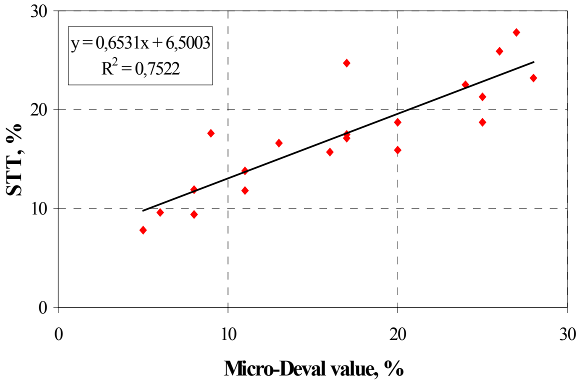

Figure 7. Correlation between the Studded Tire test (Nordic abrasion) and micro Deval test.

The abrasion tests show a strong correlation as might have been expected, as they are rather similar in procedure. Both methods involve testing aggregate samples along with steel spheres immersed in water. In both cases the testing instrument is a hollow drum, which rotates around a horizontal axis. The main difference between the abrasion tests is that the drum for the Studded Tire test has three ribs, which can cause fragmentation of weak aggregates, but the micro Deval drum is smooth and causes little fragmentation.

3. RESULTS

All the test results were put through a Factor analysis calculation using Varimax rotation. The results are presented in Figure 8.

Factor analysis is a statistical technique used to identify a relatively small number of factors that can be used to represent relationships among sets of many interrelated variables. Observed correlation between variables result from the sharing of these factors. The factor analysis identifies the not directly observable factors based on a set of observable variables. The variables must be related to each other for the factor model to be appropriate.

If the correlation between variables is small, it is unlikely that they share common factors. It is important and fulfilled in the study described in this paper that all the materials have been tested with all the test methods so there is no gap in the data. The results can be presented as x – y co-ordinates and plotted on a graph as in Figure 8**.** The co-ordinates are between 0 and 1 and the outer circle is a circle of unity.

Test results that measure the same or related properties tend to group together in a Factor analysis graph. The closer to the circle of unity the tests plot the better they describe the material property or as described above they share a common factor. A 90° difference on the Factor Analysis plot between groups of tests indicates a maximum difference in the underlying factors. It should be pointed out that although the points I and J appear close to –1 on the x-axis they are closely related to the group of points close to +1 on the same axis. The difference simply lies in the numerical presentation of the test result itself, i.e the higher numerical value in TFV-value, the stronger the aggregate is, which is the other way around for the other fragmentation test results.

The factor analysis confirms the result of the regression analysis that these are different test groups that measure different quality of aggregates, i.e. fragmentation tests, durability tests and abrasion tests. The results have been compared with a petrographic analysis of the aggregates. For Icelandic basalt the durability test results and the abrasion test results seem to be dependent on the degree of alteration while the fragmentation test results are dependent on porosity, see points O and P on the graph.. It follows this conclusion that in order to measure all factors of aggregate strength the aggregates have to be tested with at least one test method of each group. Since there is a high correlation between most of the test results within each class, it is not necessarily important which of the test methods is used.

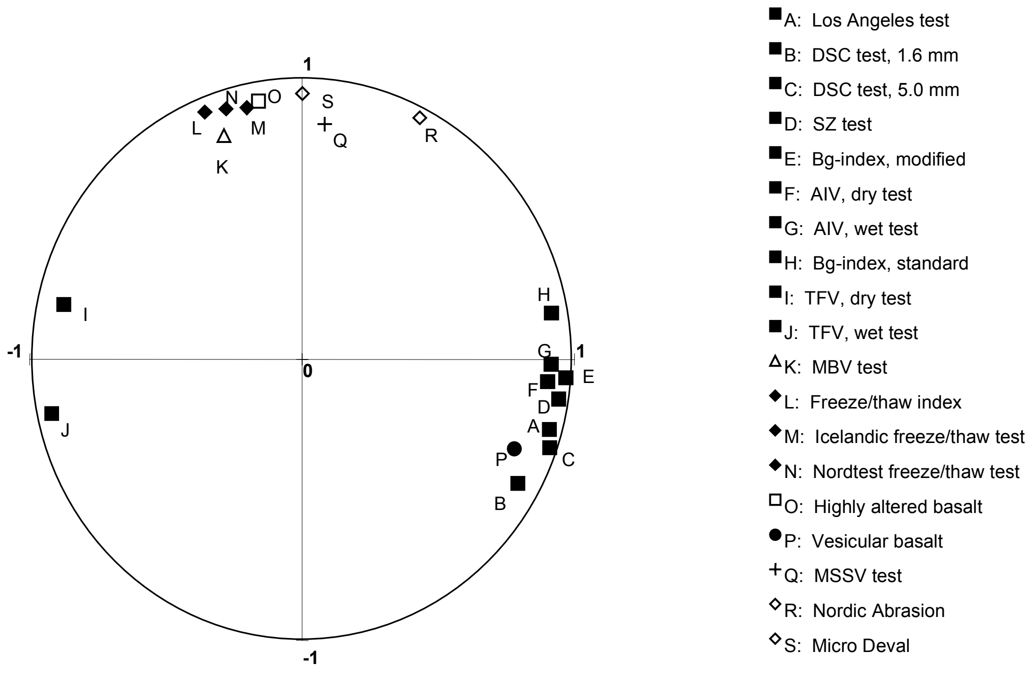

Figure 8. Factor Analysis showing the interrelationship between test results.

Knowledge of the interrelation between the test methods makes it possible to estimate with a certain degree of accuracy, what a test result from one method means in the terms of another method. It is however important to keep in mind the fact that other factors also influence the degradation of aggregates. It is also important to remember that the regression analysis and factor analysis are based on results from the testing of Icelandic and predominantly basaltic aggregates.

On the grounds of this research requirement proposals have been put forward for different road layers (surface dressing, asphalt concrete, unbound surface, base course and subbase). Table 4 gives an example of requirements proposed for upper base course layer. The requirements are dependent on road class in this example.

Table 4. Example of requirements proposed for upper base course layer.

	Road class			
Test method	**C3-D**	**C1- C2**	**B2-B3**	**A-B1**
Petrogr. anal.	≤ 15	≤ 15	≤ 10	≤ 7
Bg-Index	≤ 12	≤ 10	≤ 8	≤ 8
LA test, %	≤ 30	≤ 25	≤ 20	≤ 20
Freeze/thaw, Nordt.,	≤ 19	≤ 15	≤ 12	≤ 9
Flakiness, FI, %	≤ 35	≤ 30	≤ 20	≤ 20
Crushed and broken	≥ 30	≥ 40	≥ 50	> 50

It should be pointed out that for road surfacings, requirements regarding resistance to abrasion (Nordic abrasion test) are also included. Those requirements, as well as requirements for resistance to fragmentation (LA test), shape (Flakiness Index) and percentage crushed and broken surfaces, are all in harmony with the European Standards. The petrographical classification and Bg-Index requirements are only used in Iceland so far. The Nordtest frost resistance requirements are also Icelandic, but the test method is at present being processed within CEN TC154 as an alternative test method to EN 1367-1 for Nordic regions.

4. CONCLUSIONS

This paper has mainly focused on comparing different test methods and different quality of different materials. It is however important to remember that the regression analysis and factor analysis are based on results from the testing of Icelandic and predominantly basaltic aggregates. Testing of materials from other countries and other origin, such as testing of aggregates from sedimentary rock, plutonic rock or metamorphic rock might prove to give different results.

The results presented here have made it possible to put forward requirement proposals for Icelandic aggregates for specific end use in road construction (surface layers, basecourse etc.).

Iceland will be required to use the CEN standard tests in the near future. The results from the research project described in this paper and the correlations, that the project has established, will contribute to that transition.

5. ACKNOWLEDGEMENTS

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