FROST-RESISTANCE TEST FOR COARSE AGGREGATES.

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ABSTRACT

The purpose of the investigation was to develop a suitable freeze/thaw-resistance test for aggregates for harsh climatic conditions. A comparison was made between a few frost resistance test procedures, using as variables the lengths and number of freeze/thaw cycles, the temperature range, and grain sizes of aggregates. A frost-resistance test method was selected, including two categories of grain sizes, i.e. 2,4-4,75 mm and 9,5-12,5 mm. The samples are saturated and tested in a 1% NaCl-solution, the length of each freeze/thaw cycle being 2,4 hours, the number of cycles 70 and the temperature range from -4°C to +4°C. The test result is calculated from the amount of the original sample which will pass through a specific sieve after testing. Outdoor testing in fresh water showed correlation with results of laboratory testing, although the breakdown (scaling) appeared to be approximately ten times less. Correlation was established between test results and field performance of experimental road sections. The frost resistance test method is mainly used on aggregates for cement concrete structures and asphaltic concrete.

Key words: *Frost resistance, Aggregates, Test-method, Asphalt, Concrete.*

1. INTRODUCTION

The Icelandic climate makes great demands on the properties of building materials, i.e. frost resistance. Geologically the country is young and mainly built up of basaltic lava layers. The basalts differ in chemical composition, alteration stage and porosity. Despite the young age of Icelandic aggregates, considerable alteration is abundant in places, especially where hydrothermal activity, due to central volcanism, has taken place. Porosity of Icelandic aggregates also varies and is dependent on the environmental and chemical conditions at the time of formation (solidification). Alteration stage and porosity are considered major parameters affecting the mechanical properties of the aggregates used as construction material.

Due to the global position of Iceland, climatic changes are frequent throughout the year and can vary from year to year. It may be stated that the changes in weather are greater and more frequent than in most other countries, and measurements show that a high number of freeze/thaw cycles occur /1/.

In 1985 it was evident that a need existed to study weathering resistance of Icelandic aggregates. Some research had been carried out earlier with the Magnesium sulphate soundness test (ASTM) and some non-standardised freeze/thaw-testing, but no correlation was found between the test results and aggregate durability /7/. A comprehensive survey of the sources available was carried out in order to find standardised test methods that could suit Icelandic aggregates and conditions. No suitable test methods were found however and it was decided to develop a new test and provide standard specifications and quality demand proposals. In fact the source survey indicated that a NaCl-solution has a decisive effect on aggregate breakdown under repeated freeze/thaw cycling /2/, and it was decided to use a 1 % NaCl-solution throughout the research programme. The research programme is restricted to evaluate the frost resistance of aggregates only and the connection with frost resistance of concrete is beyond the scope of this paper, but regarded as a future step in the research programme.

2. RESEARCH PROGRAMME

The research programme is divided into six sections:

- *Laboratory tests* carried out in steps, where certain parameters are changed from one step to another.

- *Outdoor testing* of samples under natural conditions to determine the correlation between breakdown of outdoor samples and samples tested in tbe laboratory.

- *Experimental road sections* were laid using aggregates of varying quality, to study the correlation between surface dressing durability and frost resistance test results.

- *Temperature and moisture measurements* in a pavement surface to establish actual climatic conditions and changes in a road surface over one year.

- *Hydrometer tests* were carried out on the broken down material to determine how much fine material was produced from the frost action.

- *Various side investigations* were made to prepare the frost resistance test method. The speed and nature of saturation was studied, both with subpressure and at atmospheric pressure. Also sample containers were designed and the effect of liquid quantity and sample size were studied.

3. LABORATORY RESEARCH

The laboratory work took place in five steps, each leading up to the next one. The main changes between steps involved altering the frequency of the freeze/thaw cycles and the temperature range. The five steps are discussed briefly below and the main results from each step presented. A further documentation of the types and sources of aggregates used in the research programme is given in reference /1/.

3.1 First step

- Test aggregates of known but different durability from 11 quarries.
- Run a total of 310 freeze/thaw cycles, but measure the breakdown after 10, 30, 70 and 150 cycles as well as after 310 cycles.
- Test three particle sizes, i.e. 0,6-1,2 mm, 2,4-4,75 mm and 9,5-12,5 mm. Sieve the breakdown from each sample using a sieve with half the aperture size of the smallest particle size of the sample.
- Run 5 freeze/thaw cycles per 24 hours with the temperature range of +10°C to -10°C.
- Test each material in duplicate immersed in a 1 % NaCl-solution.

Figure 1 shows the mean breakdown of two partial samples from 11 quarries in three grain sizes. It is evident from the figure that there is a distinct difference in breakdown, depending on aggregate source. Also, the figure shows that the smallest grain size suffers by far the least breakdown.

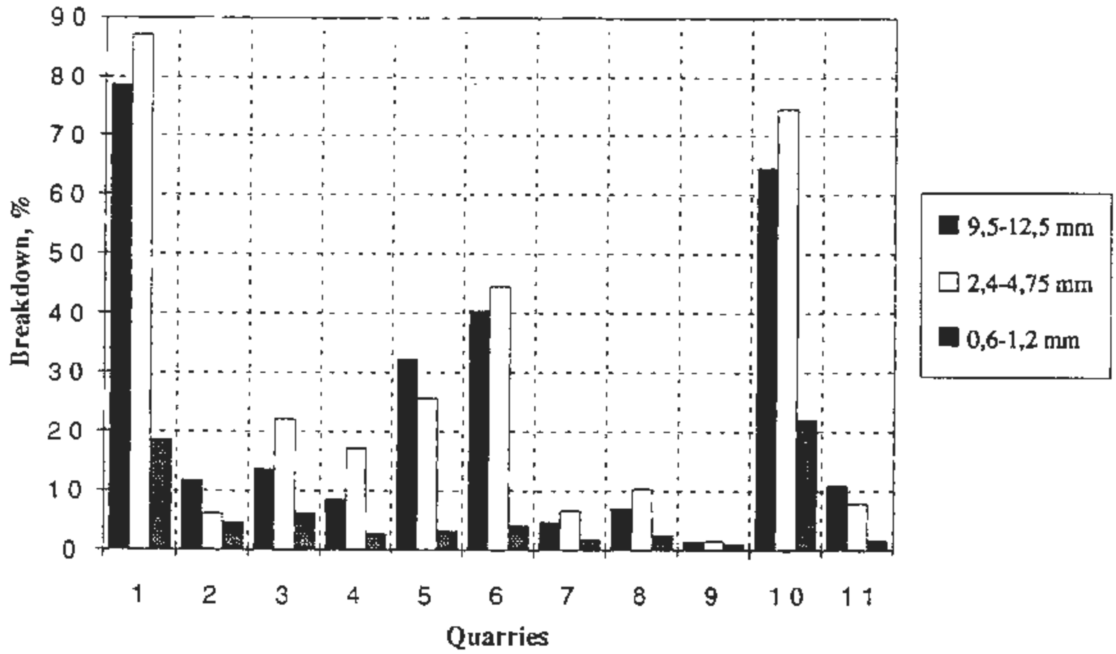

Figure 1. Freeze/thaw breakdown after 310 cycles in Step one.

This result shows that the freeze/thaw test as carried out in the first step discriminates between aggregates of different frost resistance. The breakdown of the two coarser grain sizes is up to 50-70 % after 70 cycles and the correlation is strong, as can be seen in Figure 2. Still, grain size 9,5-12,5 mm suffers approximately 25 % less breakdown than grain size 2,4-4,75 mm.

Figure 3 shows that the correlation between breakdown after 70 cycles and 310 cycles is strong, which indicates that the number of cycles can be reduced and hence the testing period.

On the grounds of the results from the first step the second step was designed. As can be seen in Chapter 3.2, the main aim of the changes is to reduce the testing period without affecting the quality of the test results.

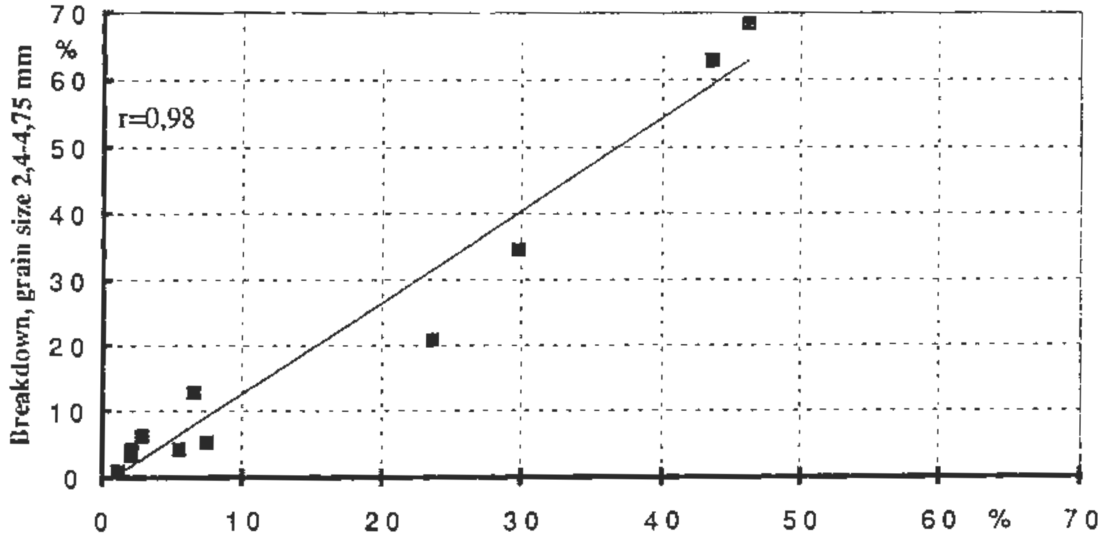

Figure 2. Freeze/thaw breakdown in two grain sizes after 70 cycles, Step 1.

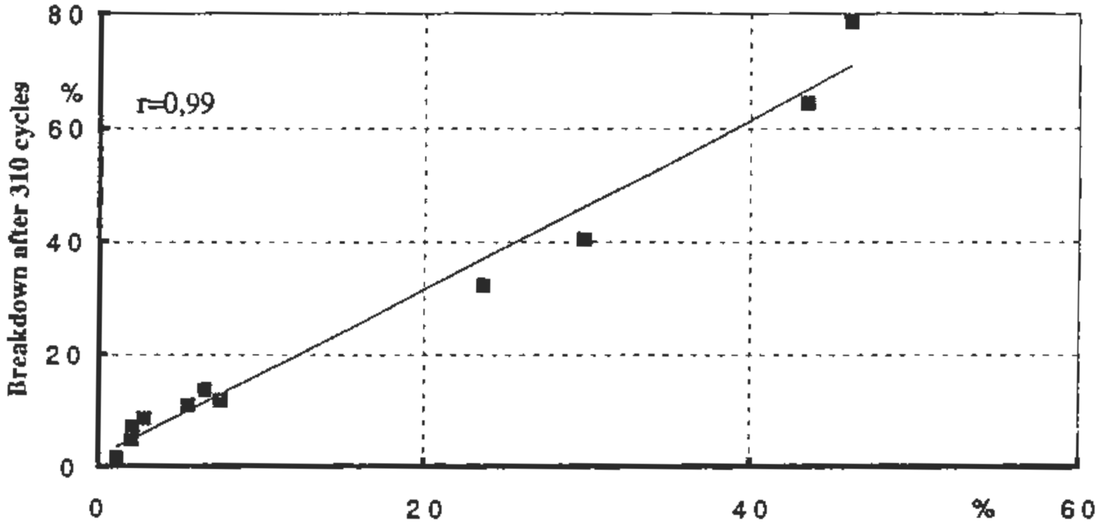

Figure 3. Breakdown after 70 and 310 cycles in grain size 9,5-12,5 mm, Step 1.

3.2 Second step

- Select 6 types of aggregate for testing instead of 11.
- The smallest grain size, i.e. 0,6-1,2 mm was discarded due to the small amount of breakdown in the first step.
- The number of freeze/thaw cycles was reduced from 310 to 150 due to a good correlation in the first step. Intermediate sieving was carried out after 10, 30 and 70 cycles.
- The frequency of freeze/thaw cycles was increased from 5 to 10 every 24 hours and the temperature range was reduced from +10/-10°C to +5/-5°C. This was done to study the effect of reducing the testing period and is in fact the only physical change from the first step.

The main result from this step is that the breakdown is less in step two than in step one. In grain size 2,4-4,75 mm the difference is about 15 % and in grain size 9,5-12,5 mm the difference is about 25 %, see Figure 4. Despite this difference, the correlation between breakdown in steps one and two is satisfactory.

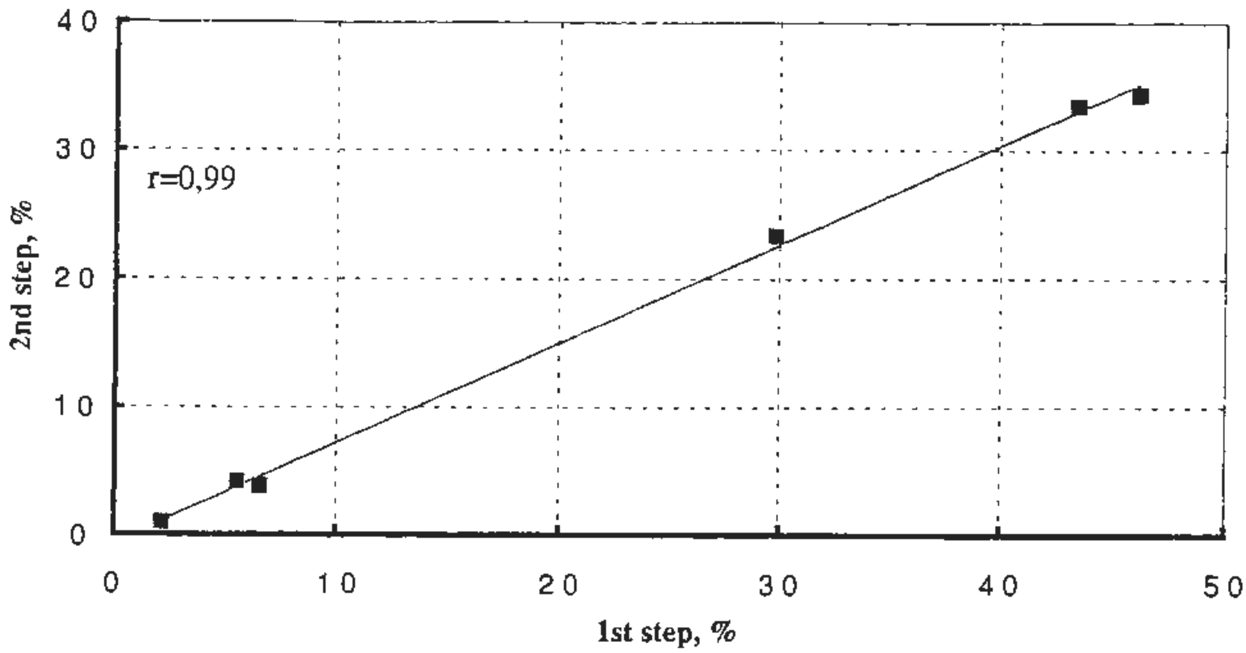

Figure 4. Correlation between breakdown in steps one and two, 9,5-12,5 mm

These results indicate that either the cycle length or temperature range (or both) have a decisive effect on breakdown under ruling conditions. To find out which parameter affected the amount of breakdown, the third step was carried out with one of the parameters changed back to what it was in the first step.

3.3 Third step

- Test the same aggregates from six sources as in step two.
- Test grain sizes 2,4-4,75 mm and 9,5-12,5 mm in duplicate.
- Run 150 cycles with intermediate sieving after 10, 30 and 70 cycles.
- Run the test with a temperature range of +5/-5°C (as in step two) and change the frequency of cycle to 5 per 24 hours (as in step one)

The results of step three are that the breakdown obtained is similar to the breakdown in step one, see figure 5. It may be reasoned therefore that the cycle frequency rather than the temperature range has a decisive effect on breakdown under ruling conditions.

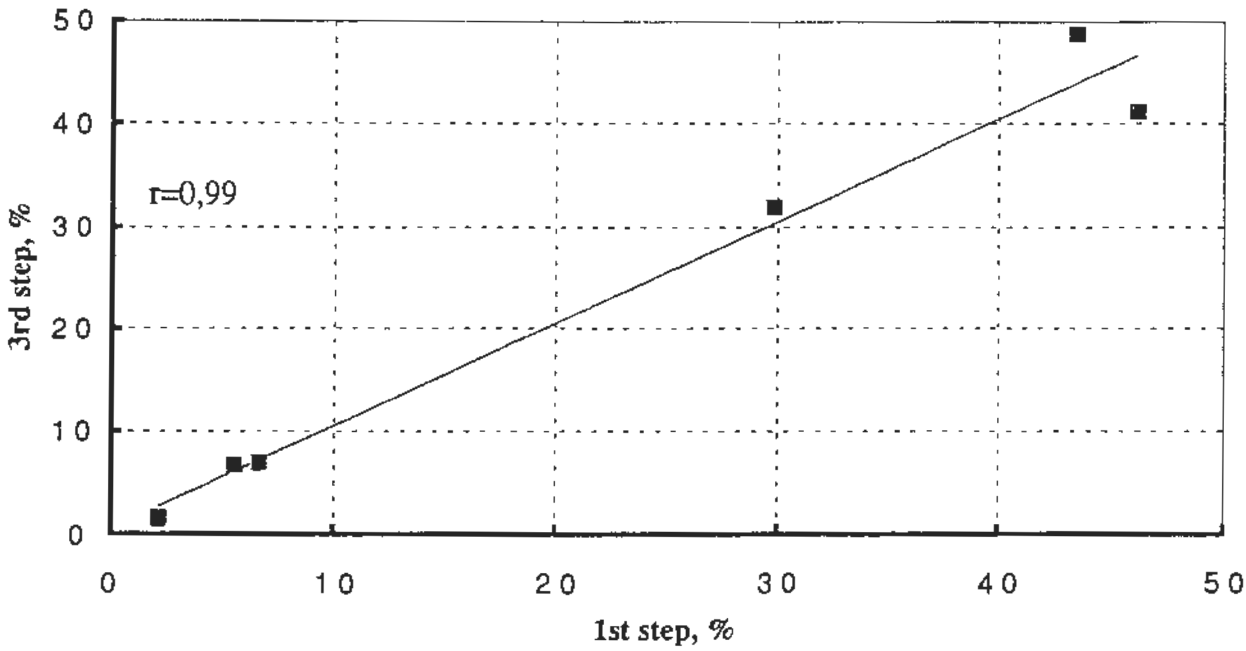

Figure 5. Correlation between breakdown in steps one and three, 9,5-12,5 mm

3.4 Fourth step

On the grounds of the test results of the first three steps, standard proposals for step four were made. The results of the associated research, i.e. temperature measurements, durability of experimental road sections, outdoor testing etc., were kept in mind (see chapter 4).

- Test 16 types of aggregates with a known durability.
- Use a total of 70 freeze/thaw cycles.
- Test grain sizes 2,4-4,75 mm and 9,5-12,5 mm.
- Run 10 freeze/thaw cycles per 24 hours, with the temperature range of +4°C to -4°C.
- Test each sample in duplicate, i.e. 2 x 500 gr.
- Test the samples immersed in a 1 % NaCl solution.

This testing procedure is in fact very similar to the procedure used in the second step. The only difference worth mentioning is that 70 cycles were run instead of 150 cycles, on the grounds of a strong correlation between breakdown after 70 and 150 cycles. By reducing the number of cycles, the freeze/thaw test is completed in 7 days.

The main results of step four are connected with results of the associated research and will be discussed in chapter four. The positive connections led to the conclusion to run a similar test again to evaluate the precision of the test method.

3.5 Fifth step

- Test aggregates from ten of the sixteen sources tested in step four.
- Use the same testing procedure as in step four.
- Decrease the sample quantity from 500 gr. to 400 gr.

The main results from this step is that the breakdown is very similar in steps four and five, the correlation coefficient, r, being 0,98 for ten materials, see Figure 6.

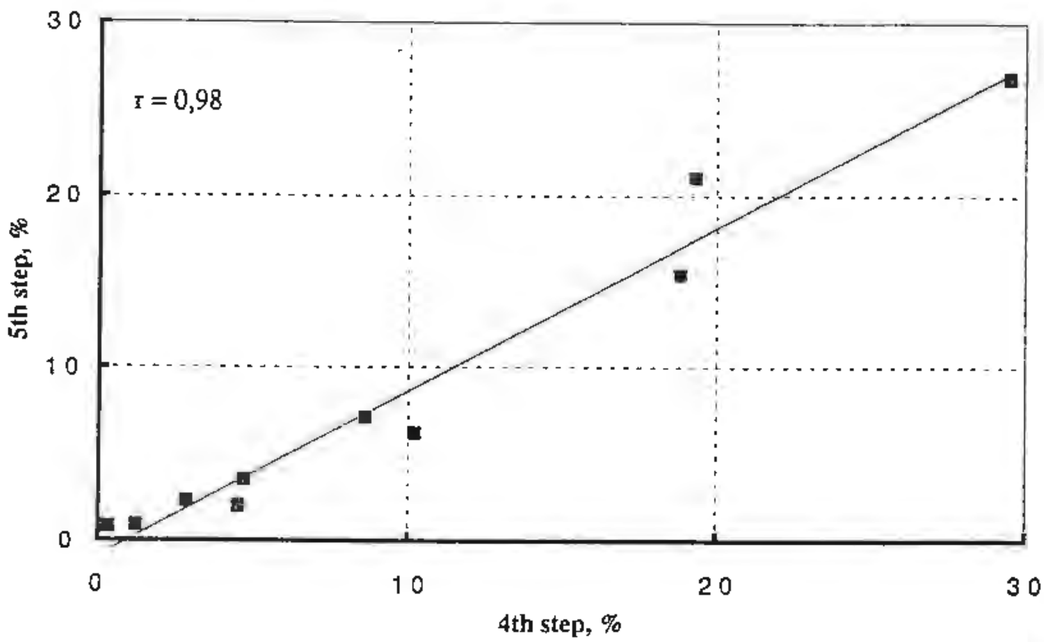

Figure 6. Correlation between breakdown in steps four and five, 9,5-12,5 mm

4. ASSOCIATED RESEARCH

As mentioned in Chapter 2 the laboratory research was associated with various side investigations. The main results are listed here below. When comparing laboratory test results with investigations, the results from step four are used, after 70 freeze/thaw cycles in grain size 9,5-12,5 mm.

4.1 Experimental road sections

The aggregates used in laboratory step four had a known performance in the Aggregate Committee's experimental road sections using surface dressing. The durability of these aggregates was estimated in two ways:

- By counting crumbled aggregate in a frame in the wheel track. A significant correlation exists between the amount of crumbled aggregate and laboratory freeze/thaw test results, see Figure 7.
- General mapping of the experimental road sections and quality rating from 1 (best) to 6 (worst) gives significant correlation with the freeze/thaw test-results, see Figure 8.

It should be mentioned that although a correlation exists between the durability of a surface dressing and the aggregate's frost-resistance, other properties have an effect on the durability and show a correlation, such as abrasive strength /3/. A correlation does exist between abrasion value (Dorry) and frost resistance.

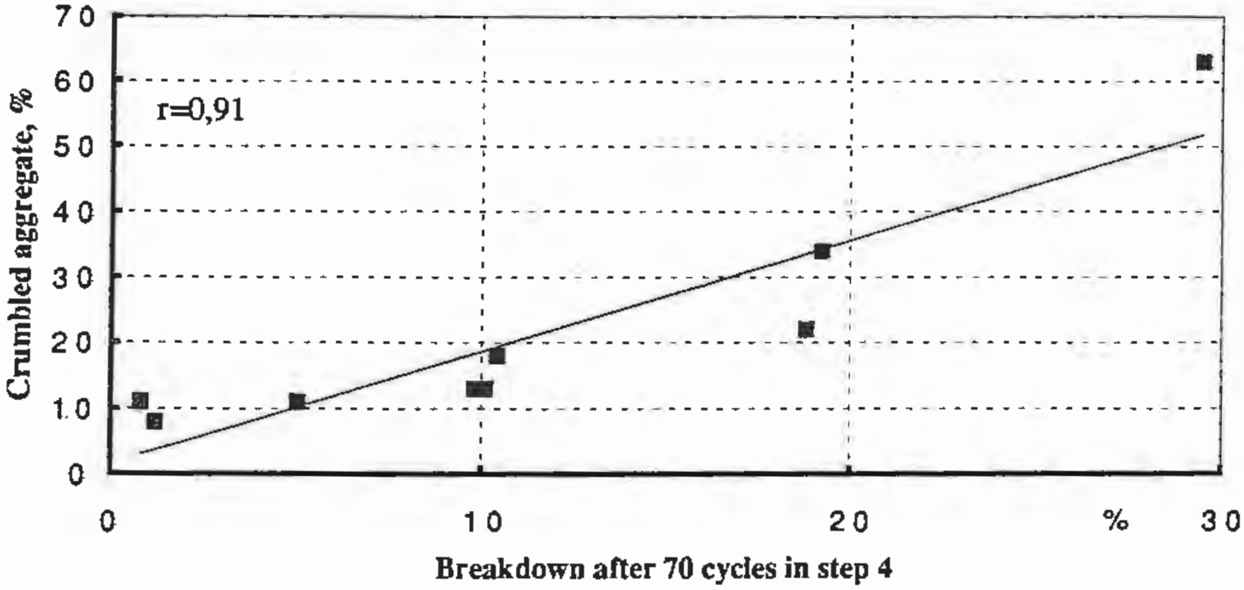

Figure 7. Correlation between frost-resistance and crumbled aggregate.

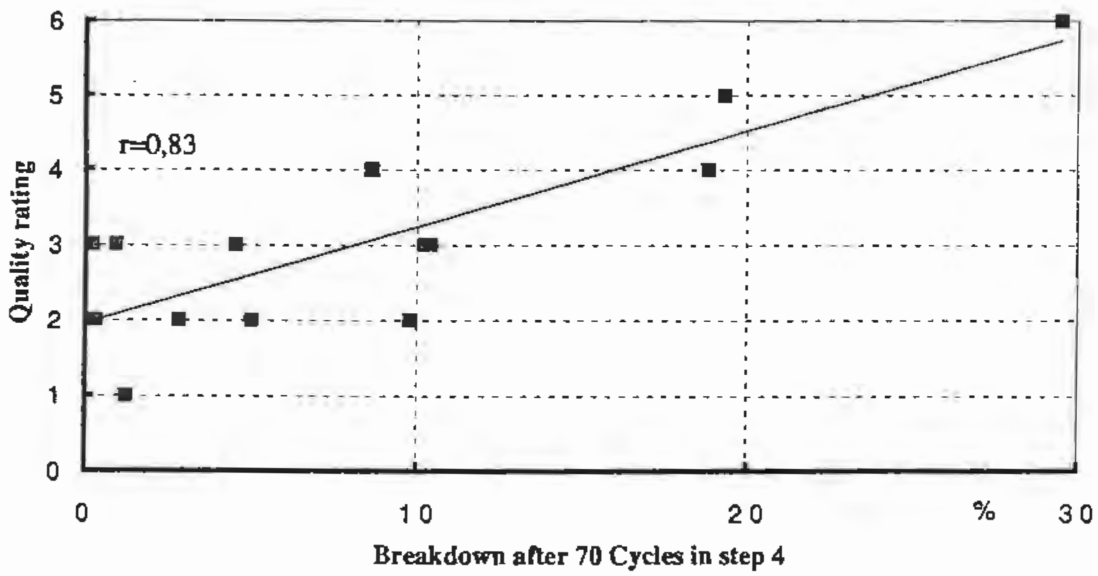

Figure 8. Correlation between frost-resistance and quality rating.

4.2 Outdoor testing

The outdoor testing was carried out to examine the natural breakdown of aggregates due to frost action and to see its correlation with laboratory test results. Aggregates, which had been tested with the freeze/thaw test, were placed in sample containers with fresh water and left untouched outdoors during one winter. Then the breakdown was sieved away as in the freeze/thaw test. A correlation was observed between breakdown in the outdoor test and the freeze/thaw test, although the breakdown from the outdoor testing was approximately ten times less, see Figure 9. Still it is apparent that the natural frost action causes breakdown of aggregates, depending on their source. This indicates that one may assume that aggregate frost resistance has a marked effect on the durability of structures which they are used in.

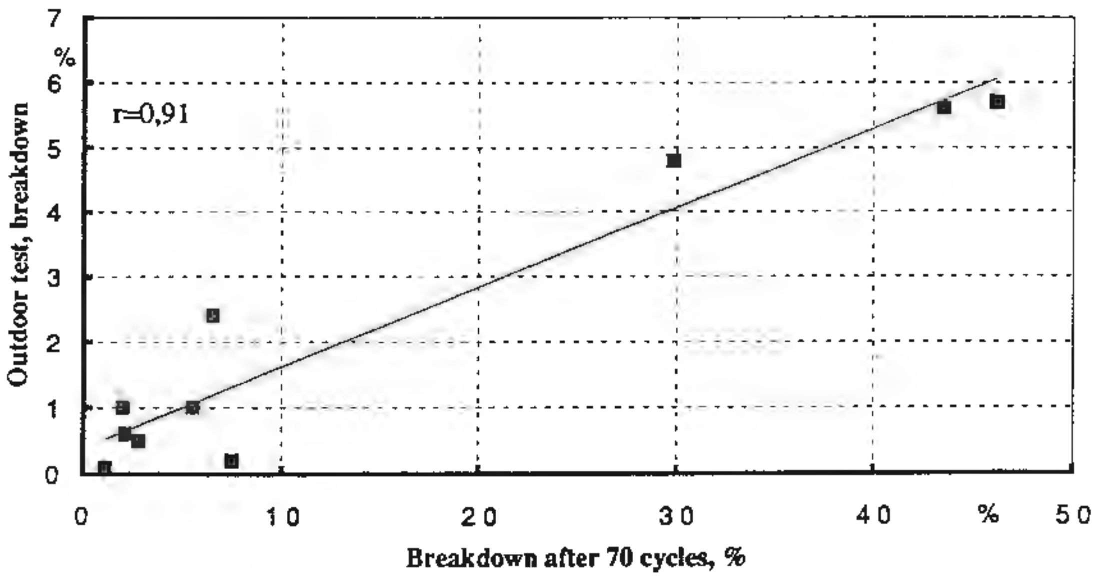

Figure 9. Correlation between frost resistance and outdoor testing.

4.3 Temperature and moisture measurements

It was decided to measure the actual temperature changes and moisture content of a street surface in Reykjavik, by placing a thermometer and hygrometric sensors in the surface of asphaltic concrete. The moisture measurements indicated that the street surface remained damp or wet for approximately 80 % of the year 1988. Temperature measurements on the street surface showed between 80 and 100 freeze/thaw cycles occurring in one year. Most of those cycles had a minimum temperature between -1°C and -7°C, see figure 10. It can be stated therefore that the freeze/thaw test-method, with its 70 cycles and minimum temperature of -4°C, has some similarities with real conditions in a street surface. On the other hand it should be pointed out that there are also differing or unmeasured factors involved. For example it is rare to have more than one cycle per 24 hours under natural conditions. Also, the salinity of the street surface was not measured, nor the frequency of salting.

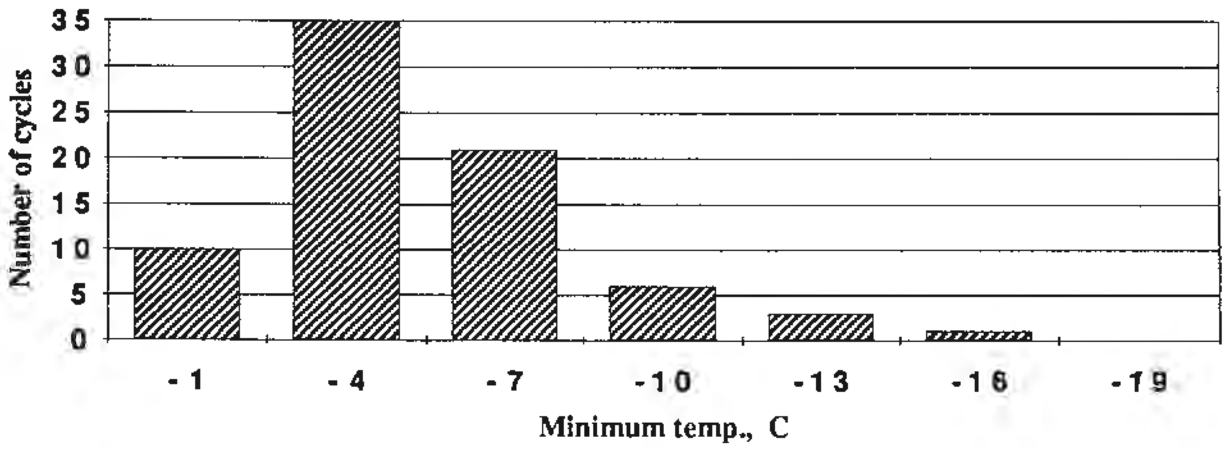

Figure 10. Frequency of minimum temperatures in asphaltic concrete

4.4 Hydrometric tests

Hydrometric tests were carried out on material that broke down from the grain size class 2,4-4,75 mm in the first step, i.e. to determine the grain size distribution of material passing the 1,2 mm sieve. Sufficient quantity was obtained from 10 samples. The main conclusion was that the breakdown is of relatively coarse grain sizes, see figure 11. About 90-97 % of the material is coarser than 0,075 mm and 40-60 % is coarser than 0,6 mm. These results explain why such a small amount of breakdown occurred in the smallest grain size in the first step. The results also justify the dry sieving of samples after the freeze/thaw test, because it is not likely that a considerable amount of fines will adhere to the retained material and thus influence test results.

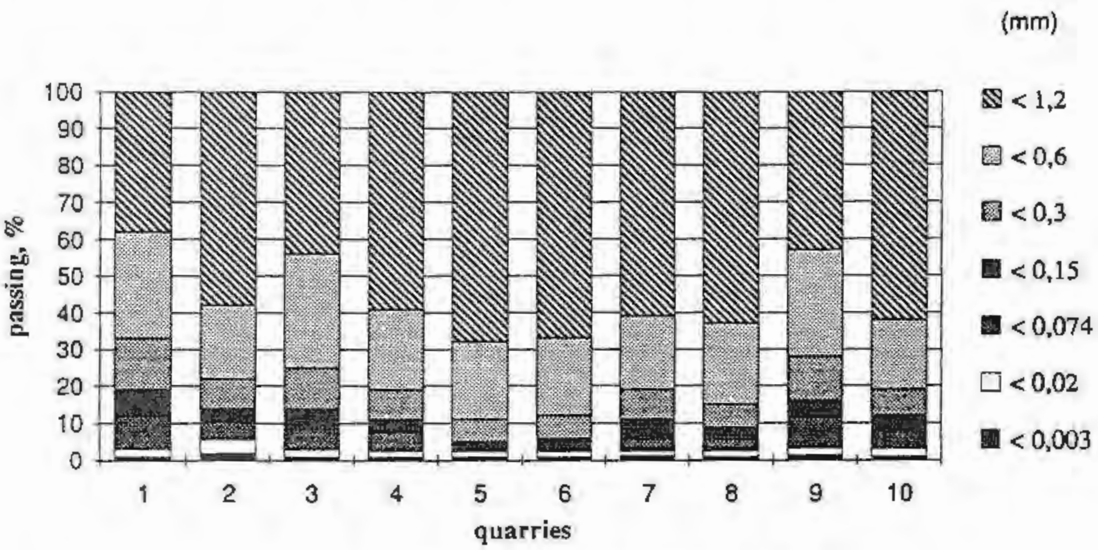

Figure 11. Grain size distribution of the aggregates breakdown

4.5 Various side investigations

Some other side investigations were carried out to help prepare the frost-resistance test and to strengthen the base of the test. The speed and nature of saturation was studied, both with subpressure and at atmospheric pressure. Also sample containers were designed in order to obtain maximum heat exchange, see figure 12. The effect of liquid quantity and sample size were studied. These investigations will not be discussed here, but they all helped in the process of developing a frost resistance test for harsh climatic conditions /1/.

4.6 Standardisation

It should be mentioned that the Aggregate Committee has assisted the Icelandic Council for Building Standardisation in following the development and progress of standardisasion of test methods within CEN/TC154 ("Aggregates"). In this connection the Committee gave a negative response to the proposed CEN freeze/thaw test method on loose aggregates using fresh water /4/. This was the case because Icelandic research had shown that the "fresh water" method does not discriminate between aggregates of differing frost resistance /5/. The relevant task group (TG9) within TC154 has drafted another frost resistance test method, which is based on the Icelandic method in all major respects /6/. It has still to be seen, whether that draft will proceed within CEN, but more precision data is needed at the moment for that purpose.

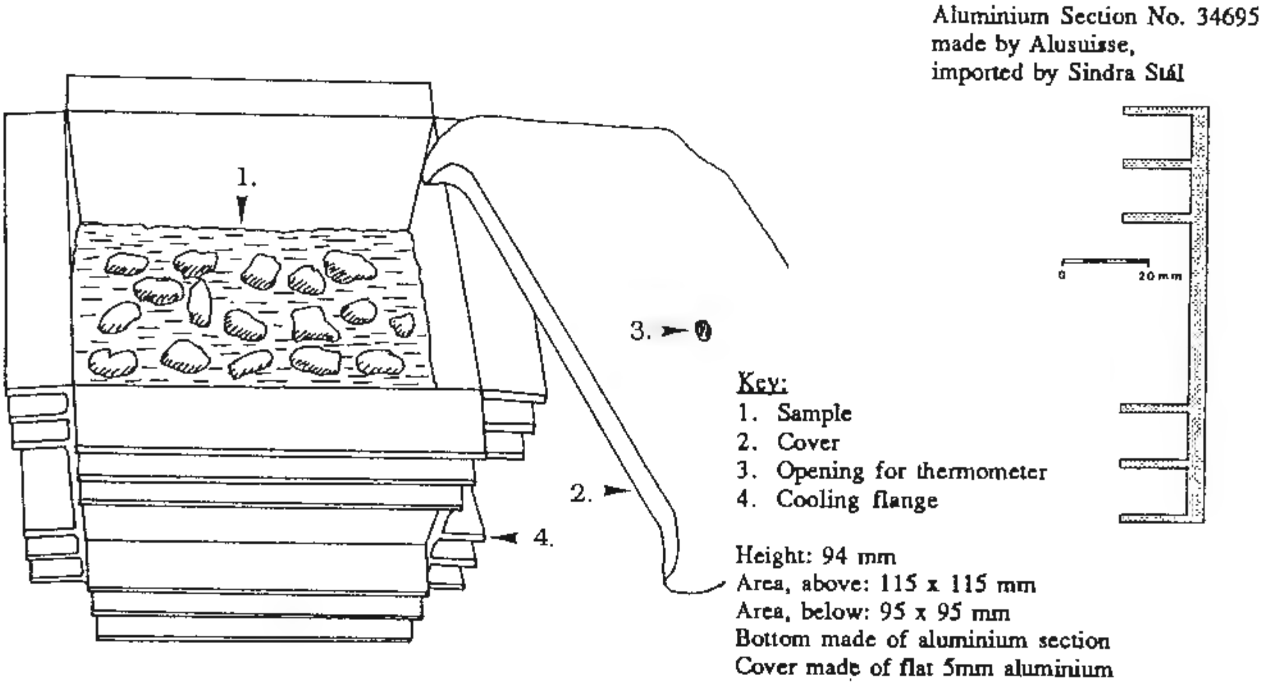

Figure 12. A schematic drawing of a sample container

5 CONCLUDING REMARKS

A testing programme has been run in five steps on various aggregates, associated with some side investigations. The results presented in this paper indicate that a correlation in breakdown exists:

- between 310 cycles and 70 cycles [r=0,99, n=11].
- for particle sizes 2,4 to 4,75 mm and 9,5 to 12,5 mm [r=0,98, n=11].
- when the temperature range is reduced from +10/-10°C with 5 cycles per 24 hours to +5/-5°C with 10 cycles per 24 hours [r=0,99, n=6].
- when the sample quantity is reduced from 500 g to 400 g [r=0,98, n=10].
- between samples tested outdoors in fresh water and laboratory tested samples in a 1 % NaCl- solution [r=0,91, n=10]. The breakdown was approximately ten times higher in the laboratory test.
- and durability of experimental road sections of surface dreessings.

On the basis of the research work carried out and described above, the frost resistance test standard was drawn in accordance with step five, see Chapter 3.5. The materials requirements that have been in use in Iceland are as follows (9,5-12,5 mm):

- Breakdown <3 %: very frost resistant aggregate
- Breakdown 3 to 5 %: frost resistant aggregate
- Breakdown 5 to 10 %: medium frost resistant aggregate
- Breakdown 10 to 20 %: poor frost resistant aggregate
- Breakdown >20 %: very poor frost resistant aggregate

It is believed that an accurate frost resistance test method has been developed for harsh climatic conditions, which has a correlation with actual performance of structures. Still, it has to be stated that the reproducibility of the method has not yet been established. There is also a lack of information about the correlation between frost resistance test results and durability of concrete structures. Yet, it is reasonable to presume that such a correlation does exist, especially in cases where aggregate properties are responsible for concrete failure.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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