IAEG C-17 Aggregates, Technical report: Geological Information Aspects for Construction Industry

Information from ICELAND

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1. HOW TO INVESTIGATE AND PRESENT AGGREGATE RESOURCES.

Introduction: General aspects

Iceland is a young geological volcanic island containing mainly basaltic rock types. The extraction and processing of aggregates for structural purposes are exceptional in the country because of;

- a very high production of aggregates in tons per capita/year
- many small extraction sites, covering large areas around the country
- environmental conflicts due to extraction of rare volcanic and geological formations
- various information are not integrated in one national database
- there is no specially defined Geological Survey in Iceland

Aggregates (fluvial- and glaciofluvial sediments, sea-dredged aggregates and crushed rocks) are the major building materials in Iceland. Aggregates as a commercial product mainly came into use after Second World War, with a dramatic increase in concrete domestic house constructions, road construction, bituminous pavements and large hydropower dams and plants. Most structures, including domestic houses, roads, bridges and hydropower dams, are built with these materials, which are a necessity for the development of the country. Important amounts of valuables are invested in these structures and infrastructure. As a consequence knowledge of the properties of the aggregates, sustainability and quality of deposits are required in order to obtain a rational use of these materials.

Bedrock material resources

The bedrock is mainly volcanic igneous rock, especially basalt. The basalts are often porous and some are hydrothermally altered to different levels. Some 10.000-13.000 years old deposits from the last ice age cover the bedrock. The main aggregate production today in Iceland is from sand and gravel. In the different parts of Iceland, the abundance of sand and gravel is very variable, but in general it can be concluded that in the most densely populated areas, most of the good quality natural sand and gravel has already been used up. In these areas, lava, scoria and pillow lava is increasingly being utilised. In general, the Icelandic aggregates that are used in roads and other constructions are of sufficient quality, as far as materials requirements are concerned.

The use of Icelandic materials for ornamental stone has been increasing for the past few years. Initially only gabbro was utilised for tombstones and to less extent tiles, but now an increasing demand is also for basalt and rhyolite as claddings. These rocktypes are usually very fractured and difficult to find large intact bodies of the rock for cutting. The outcrops are scattered around the country but most of the gabbro outcrops are located in East Iceland.

The largest aggregate producer in Iceland for concrete aggregates has been quarrying sea-dredged aggregates from the bay Faxafloi near the capital region of Reykjavik since 1960. The material is glacio-fluvial deposits, formed by the end of the last glaciation period when the sea level was lower than present. Other producers in the capital region are producing aggregates by ripping pillow-lava and processing for further use in concrete- and roads structures.

Field investigations – methods

In the years of 1970 - 1985 when construction of many of the major hydropower plants took place, the National Energy Authority (NEA) conducted extensive research on aggregates and bedrock in Iceland. NEA use the map scale 1:20 000 to 1:100 000 and have completed large areas being investigated for planning of hydro- and geothermal power plants. The Icelandic Museum of Natural History and the Iceland Geodetic Society produce the official geological maps. The bedrock maps are in the scale 1:500 000 and 1:250 000 and some areas in a more detailed scale. The methods used are typical geological mapping methods (basic information such as geological age, origin, size and thickness of the formations). More specific methods are used based on the requirements in each case.

Geostatistics and spatial data analysis – No input

Exploration and environmental aspects

Legislation and environmental aspects

In Iceland, a number of laws and legislations are on the extraction and production of aggregates. The oldest ones are from 1923 and the most recent one is the Environmental Impact Law from 2000. These laws cover aspects such as protection of the environment, right of the government to use material for public interest and land planning in general.

Marketing and presentation of information

Structure of the aggregate industry

Aggregate production in Iceland has been and will long continue to be a local business based on easily accessible deposits. Most of the aggregate producers in Iceland operate in a different manner than in most other countries. Largest part, or 90% of the quarries are owned by farmers on a private land and they sell their product or lease the quarry to companies (contractors) which in 70-80% cases work for the Public Road Administration (PRA). These types of quarries are scattered around the country close to the roads and a total number of 3000 quarries and gravel pits in Iceland have been registered. These quarries are often local river deposits or various talus deposits in foot of cliffs. Of these, only 60-70% are in constant use. The largest aggregate producers are in the capital region of Reykjavik and the south part of Iceland (40-50 % of the market) and they sell only about 20% of their products to the PRA. These are producers of aggregates for concrete production and exporters of pumice.

The Association of aggregate producers in Iceland was formed in 2002.

Production of aggregates in Iceland

A special study was made in the year 2002 to establish a more accurate overview of the yearly production of aggregates in Iceland and the utilisation of the materials. In an attempt to reach the correct values, various approaches were used. Some 19 aggregate producers were asked to fill out a questionnaire, describing their aggregate production both qualitative and quantitative for the year 2001 (see table 1). The Public Roads Administration collected information of all their materials used in the year of 2001. Additional information has also been gathered from other sources in Iceland.

Table 1: Questionnaire sent to Icelandic aggregate producers: **Aggregate production 2001**

Aggregate type	Fraction	Origin	Use	Volume 1000 m^3/year	Method of processing
e.g. concrete sand bound aggregate.	e.g. 0-8 mm, 0-10 mm, 0-25 mm, etc.	**(A)** Sediment **(B)** Rock - (B.1) Lava - (B.2) Pillow lava - (B.3) Other **(C)** Pumice/ scoria **(D)** Other	**(A)** Concrete **(B)** Roads **(B.1)** Base course **(B.2)** Subbase **(B.3)** Wearing course **(B.4)** Gravel wearing course **(B.5)** Subgrade **(C)** Mortar aggregates **(D)** Landfills **(F)** Other (specify)		
…filled out by producer	….	….	….	….	….

One of the main problems while making a quantitative overview of the production and use of aggregates, is how to define aggregates. Aggregates with defined size-fraction (processed aggregates), as building materials in concrete and road structures are quite clear. However, large amounts of unsorted sand, gravel and rock fragments are also used in the construction of f.ex. roads, harbours, power plants and airfields. Here all these definitions are included in the total amount of aggregates used in Iceland per year.

A previous estimate of aggregate production in Iceland was made by the PRA in 1998 and indicated a consumption of approximately 5,2 million m^3/year, or 18 m^3 per person. This is due to the low population density, where a minimum of roads and other constructions are needed, independent on the population.

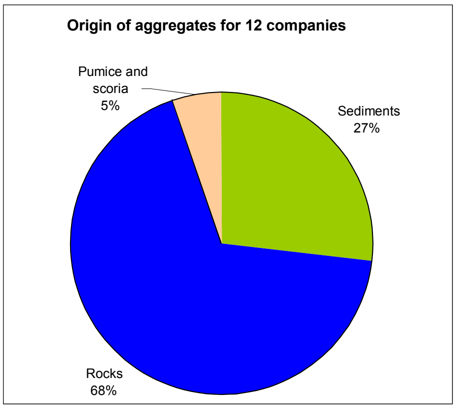
The following is the estimate of the different application in 1998 by the PRA:

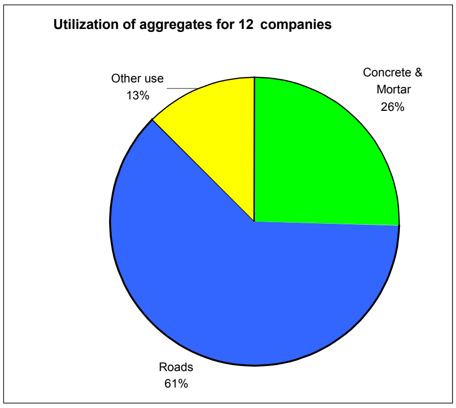
- Roads 58 %
- Streets & foundations 18 %
- Airfields & harbours 6 %
- Power-plants 8 %
- Concrete 10 %

In relation to this study, the PRA made an overview of purchased aggregate materials in 2001, giving the following numbers:

Subgrade	Base course and subbase	Wearing course	**Total aggregates in road construction 2001**
2.800.000 m^3	1.300.000 m^3	300.000 m^3	**4.400.000 m^3**

12 of the 19 aggregate producers participated in the survey. These produced a total volume of 1.400.000 m^3, and the origin and utilisation of the aggregates are presented in figures 1 & 2. By estimating volume for the rest of the producers, we can estimate a total volume of approximately 2.300.000 m^3.





Figures 1 & 2. Origin and utilisation of aggregate for 12 aggregate producers with a total production of 1.400.000 m^3 in the year 2001.

Some difference is detected between the numbers from PRA and the producers. The PRA volume numbers include the subgrade while the producers register the volumes in base course, subbase and wearing courses where the processed material is used. Therefore the subgrade material is excluded from the quantity of the aggregate producers and accounts for the difference in quantity stated by these two sources of information.

Information on the use of Icelandic materials for ornamental stone was obtained from five major producers in the Reykjavik area. The estimated total use for the year 2001 is some 2.000 m^3.

The estimated amount of aggregates for concrete used in 2001 is 470.000 m^3. This is based on the total amount of cement sold during that year.

The Icelandic Maritime Administration's (Siglingastofnun Íslands**)** most important tasks involve responsibility for state-sponsored coastal protection and harbour projects, research, and planning for the development of coastal protections and harbours. According the 2001 annual report of the transport ministry of Iceland, the total use of aggregates in breakwaters and coastal dams was close to 400.000 m^3.

During the last years there has been an increase in import of aggregates from Norway, both for use in road surface layers, and more recently as concrete aggregates. Granite and quartzite from Norway, used for bituminous pavements, were in 1995 about 22.500 m^3. In the year 2000, the total import of aggregates from Norway was estimated to approximately 60.000 m^3.

The export of lightweight volcanic aggregates did increase significantly during the years 1990 – 1995, when the export of pumice reached over 400 thousand m^3. This has decreased during recent years and in 2001 only some 130 thousand m^3 of pumice were exported. The export is mainly to the German market.

Summary of information

Estimated amount of aggregates used in Iceland for the year 2001 is as follows:

- Roads 4,4 million m^3
- Streets & foundations no information yet
- Airfields & harbours 0,4 million m^3
- Power-plants no information yet
- Concrete 0,5 million m^3
- Other 0,1 million m^3

Total estimated for 2001: 7-8 million m^3 (based on ratios from the PRA for 1998) and this corresponds to some 50 tons/person/year.

2. Case studies and research in a context.

Material properties

Basalts are very different in both physical and chemical properties. A significant amount of the aggregates used for structural purposes are quite porous and/or have been altered to different degrees, which requires specific Icelandic research. During the last 20 years, a classification system for aggregates has been developed in Iceland, which differs from international standardised systems[1,2]. The system is based on a petrological classification. The aggregates are divided further into three subclasses based on the alteration stages and porosity. In classifying rocks for roads and pavements, extensive work has been carried out to compare and relate the classification to other test results like fragmentation, strength tests, wear resistance tests and abrasion tests[3]. Therefore, the classification is based on research and is generally accepted as a first approach to the evaluation of a new material. This correlation based on research is lacking for concrete and the classification of aggregates for concrete is based on experience rather than actual test results.

Alkali aggregate reactivity has caused extensive damage in Iceland, particularly in domestic concrete houses. Cement manufactured in Iceland from 1958 is of high-alkali type. However, the blending of silica fume into the cement after 1979 seems to have hindered further problems. The rock types of andesite, dacite and rhyolite are considered the most damaging in Iceland, but quartz-normative basalt has also the potential of reactivity.

In Iceland freeze-thaw durability is a very important property of aggregates, due to the many freeze-thaw cycles and the wet climate. The stage of alteration, and to a lesser degree porosity, seems to govern freeze-thaw durability of Icelandic aggregates.

Tests for construction acceptance

Special national standards, except the petrographic classification, have not been used in Iceland, but the ASTM standards as well as specific Nordtest methods and other Nordic national standards (such as Swedish, Norwegian etc.) were used until present. The change is towards the CEN methods as Iceland is part of the CEN co-operation and is obliged to use the standardised test methods such as of CEN TC-154 for aggregates.

[1] Rannsóknastofnun byggingariðnaðarins, 1989: "Berggreiningarkerfi Rb, 3. útgáfa", Reykjavík (In Icelandic with English abstract).

[2] Helgason, Þ.S., 1990:"Characteristics, properties and quality rating of Icelandic volcanic aggregates", Proceedings of the 43. Canadian Geotechnincal Conference in Quebec, October 1990.

[3] The Icelandic Aggregate Committee Symposium, Reykjavík, March 1994.

The petrographic description is according to the national petrographic description, based on the alteration stage and porosity of the rock. This standard has now been added to the CEN EN 932-3 as special guidelines that enables Icelandic aggregates to be evaluated in details according to their alteration stage and porosity.

A “wet mix test” has been developed at IBRI for measuring adhesive properties, and a “BG Modified Proctor” method is used for measuring strength of unbounded aggregate layers, to name a few. A Nordtest method – Frost resistances test with salt – has been developed at IBRI. It has been emphasised the necessity to include this test method in the future European standard, and the method is now in a working process to be adopted.

Validation – case studies

In the years from 1994 – 2001 a major co-operation programme in the field of road research (BUSL) was carried out in Iceland. The programme was administrated by the Public Roads Administration, Public Works – Municipality of Reykjavik, Icelandic Building Research Institute and the University of Iceland – Faculty of Engineering. Many others institutions and companies participated in the research. Many reports from the programme are dealing with various properties of aggregates and the resistance to fragmentation, weathering and abrasion in both unbound- and bituminous bound road construction.

Various research projects at IBRI have been dealing with the properties of concrete aggregates and the utilisation in structures. A microscopic investigation on the quality of concrete in over one hundred houses/ buildings in the city of Reykjavik was carried out in 1993[4]. The properties of concrete made with different types of basalt were examined in 1995[5]. It was found that the properties of the concrete depended strongly on the aggregate types that interact differently with the cement paste. The water-cement ratio of concrete as determined with fluorescence technique is heavily dependent on the type of the aggregate.

[4] Sveinsdóttir, E.L. and Guðmundsson, G.(1993) :"Condition of hardened Icelandic concrete. A microscopic investigation". Proceedings of the Fourth Euroseminar on microscopy applied to building materials, 3.-5. June 1993 in Visby, Sweden, ed. Jan Erik Lindqvist and Bo Nitz, 11 p.

[5] Sveinsdóttir, E.L. and Guðmundsson, G., (1995):"Properties of concrete made with different types of basalt". Proceedings of the Fifth Euroseminar on microscopy applied to building materials, 14.&15. Sept.´95 Leuven, Belgium, ed. Jan Elsen, pp. 9-15

3. Quality control and statistical evaluation of aggregate products and production.

Introduction

There is an increased need for higher quality aggregates in Iceland as the primary foundation of the main road system now has been nearly completed, and the needs now are more concentrated upon aggregates for bituminous pavements. New developments in the concrete industry (e.g. self-compacting concrete) require aggregates with more homogenous properties. As a consequence, it is realised the need to optimise the extraction and processing of aggregates, and use the right quality of aggregates for the right structural purposes.

The federation of Icelandic Industries, together with the major national civil structural owners, have recently introduced a campaign were they require a more formal use of quality control systems in the years to come. This will have impact also upon the aggregate sector.

Quality control systems in Iceland

Only one of the aggregate producers today has developed a quality control system according to the EN ISO 9002: 1994. Most aggregate producers in Iceland do not have a standardised quality control system, but operate according to their own, different systems of internal production control – often supported by a third party inspection. Their clients, either the concrete producers or contractors for road buildings, have different demands for specifications of the product they purchase.

For concrete production the European standard EN 206 is active for Iceland. This implicates that aggregate producers need to develop more accurate and formal procedures for quality control. The only legislative requirements for concrete aggregates according to the Icelandic Building Regulation are that aggregates must be innocuous with regard to alkali-silica reactions in concrete and include less than 0,06% NaCl for reinforced concrete (less than 0,02% NaCl for pre-stressed concrete).

For road building contracts the regulation by the Public Road Administration (Alverk ´95) is active. It includes specifications for the different layers of the road structure, but does not include any requirements for quality control system of the aggregates produced.

A project accomplished in 2000[6] was dealing with the development of quality control systems for the Icelandic aggregate industry, in general based on ISO 9002. It was emphasised the need to develop systems that would work in real life of

[6] Wigum, B.J. & Holmgeirsdottir, Þ., 2000: Aggregate quarries quality and environment – Part 3 (In Icelandic). Rannsóknastofnun byggingariðnaðarins (IBRI), Report No. 00-04, 27 pages.

extraction and production and not only as fine words in the manuals. Suggestions for development of such systems were based upon the Norwegian experience during the past decade. A handbook for developing quality systems for aggregate producers was published.

Production control – Certification

Today the Icelandic Building Regulation from 1998 is active. The requirements made there regarding aggregates for concrete are that an independent test house that has been approved by the Ministry of the Environment shall perform quality control. The only requirements for the aggregates are concerning alkali-silica reactivity and NaCl content as previously described.

No certification is claimed for these products today – but this will change with the implementation of the new European standards.

Statistical evaluation of the production

Most Icelandic aggregate producers are conducting sieve analysis of their production. However a very few of them are using the collected data as a governing parameter in the daily production to adjust the configuration of the processing machinery. No central body in Iceland is collecting these data.

Laboratory work

Only a few producers are performing other aggregate tests. Most of the aggregate producers are sending samples for further testing to the Icelandic Building Research institute (IBRI) or to various engineering companies.

Conformity criteria – Test results versus requirements

In Iceland, the building regulation is based on that the requirements are met by the control of the borough surveyor in each community.

For larger building projects, conformity criteria and test results versus requirements will be controlled by third parties control bodies which in many cases will be represented by engineering companies.