COMPARISON OF BASALTIC AGGREGATES FROM ICELAND, WEST JAVA AND NORTHERN IRELAND

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1. Introduction

Basaltic rocks are among the most important of sources of aggregate in the world. They are the main type of aggregate used in Iceland, West Java and Northern Ireland for highway construction. The purpose of this paper is to compare some of the engineering properties of basalt aggregate to determine whether similarities occur between each of the different source countries. This is particularly interesting given the distance between countries and the different processes that have occurred since their formation.

Figure 1 shows the main plate boundaries of the earth at present and it can be useful to explain the different processes at work. Iceland is defined on the figure as a hot spot, situated at divergent plate boundaries, i.e. where two oceanic plates are drifting apart. This explains the active volcanism on the island, as well as the basaltic origin of the majority of the extrusive rocks. The drifting plate theory assumes that the North-Atlantic Ocean had started to develop some 60-65 million years ago and the Northern Ireland basalt formed at that time. That was long before Iceland had even started to form, but the oldest basalts in Iceland are about 15 million years old. Still, the relation between the two country's geological history is obvious.

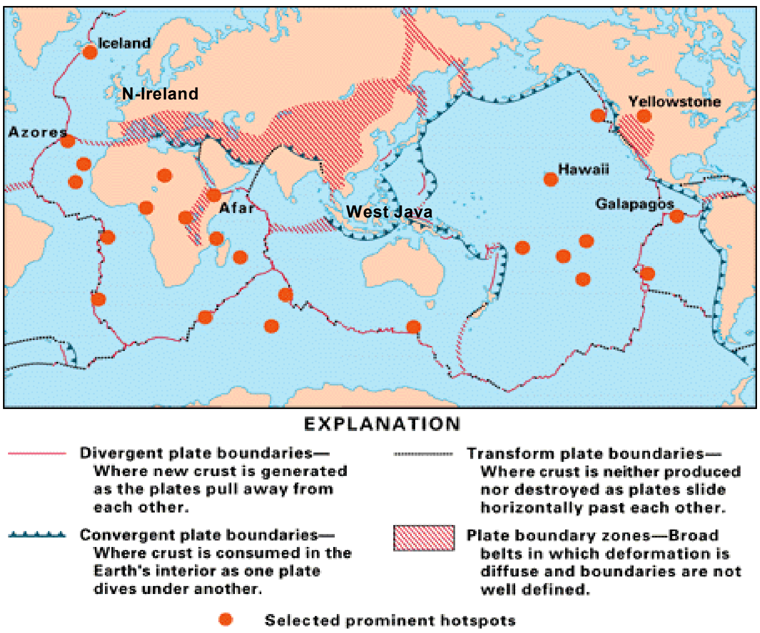

Figure 1 Plate boundaries of the earth's surface at present time (from USGS).

While both Iceland and Northern Ireland were formed on the same plate boundaries of two oceanic plates drifting apart, West Java is built up of different geological processes. In West Java, two plates meet and one is driven under the other, the so-called convergent plate boundaries. When one plate dives under another, the diving plate heats up under pressure and partial melting occurs. The molten material (magma) eventually erupts and is typically richer in silica than that produced on an oceanic rift zone. The extrusive material typically lies between basalt and rhyolite in chemical composition and is called andesite in geological terms.

It may seem questionable to compare “basalts” from such different geological sources as the oceanic basalts of Iceland and Northern Ireland on one hand and the andesitic convergent plate formations of West Java on the other hand. Still, as the appearance of the two rock types is quite similar and the two rock types have been classified together in the engineering context (see below), it seems reasonable.

2. Definition of the term basaltic construction aggregates

In this paper the term basaltic aggregate is used in its engineering context. In the United Kingdom use of the term basalt, to describe aggregate, dates from the early 20th Century, when it was recognised that there was the need for uniformity in a quarries output. This led to BS 63 – “Broken Stone for Chippings” being published in 1913 as the first British Standard specification concerning road making aggregates. This standard contained an Appendix, which simplified the classification of aggregates into 12 Trade Groups i.e. simple terms that the aggregate industry could understand. Each group was deemed by the Geological Survey to give similar levels of behaviour so as to provide a simplistic classification for road-making purposes rather than the somewhat confusing array of names and terms used by geologists. These are shown in Table 1. With a few minor changes, this original grouping still remains in widespread use within the British aggregate industry and elsewhere throughout the world.

Table 1 British trade names of road-making rocks (BS 63, 1913).

Granite	Basalt (including basaltic whinstone)	Grit
Gabbro	Hornfels	Limestone
Porphyry	Schist	Flint
Andesite	Quartzite	Artificial

The andesite and basalt trade names were later combined in BS 812 to form the Basalt Group. This included andesite, basalt, basic porphyrite, diabase, dolerite, lamprophyre, quartz-dolerite and spilite i.e. a range of volcanic rocks that were fine to medium grained of intermediate and basic composition.

However, individual sources of aggregate within each of these groupings do not perform in similar ways. This type of simple classification must also recognise that differences occur at a local level. Rather than use the collective terms such as basalt a much better level of immediate understanding would be achieved if knowledge of local problems and performance capability were available.

There are many other types and variations of igneous rocks, which would not be considered as general road construction material, such as tuff, breccia and pyroclastic rocks. Those types will not be compared in this paper and to eliminate such material, only aggregates with water absorption less than 5 % are considered. The rocks in concern are typically dark in colour with their crystals visible in some cases, although fine-grained samples may be microcrystalline and some varieties may contain phenocrysts, i.e. large isolated crystals. A small crystal size indicates that the molten rock was either silica-rich and/or cooled relatively quickly which is a feature of extrusive and shallow intrusive igneous rocks.

3. Composition of basaltic rocks

The main mineral constituents of basaltic rocks include calcic plagioclase and augite, with different accessory minerals determining their exact petrological name. In engineering terms, these mineralogical differences are not usually important except in the way they influence alteration. For example, olivine is a high temperature mineral and is more susceptible to alteration than augite. Thus olivine basalt is likely to be more altered than olivine free basalt. Other factors of significance to the engineer are the variations in the physical properties of the rock, in particular grain size, texture, porosity, discontinuities and other variation in quality.

Typically the minerals that form basaltic rocks are elongated and form an interlocking network that is held together by the groundmass. In lava, quick cooling may give a microcrystalline or even glassy texture. The resultant rock is hard and has no preferred planes of weakness. Where glassy or microcrystalline minerals form the majority of the rock mass, it often breaks with a glassy fracture and produces a flaky aggregate.

Discontinuities in the rock mass may form during the process of cooling. The most common feature is jointing caused by shrinkage. The resultant pattern gives a columnar structure with spacing in the range of 20-500 mm. Lava flows may also contain small holes or vesicles, particularly in the upper and lower part. These are caused by the process of cooling and gas escaping from the molten mass. The holes or vesicles are often filled with secondary materials in older basalts. Discontinuities and vesicles provide a path for water to penetrate into and throughout the rock. This will then start the process of chemical or hydrothermal alteration, which will eventually convert the rock to a soil.

Basaltic rocks may vary considerably in their visual appearance. One of the main factors for this is the degree of alteration that they may have been subjected to during their geological life. Crushed aggregate may vary from apparently fresh, through to highly altered material that has been substantially chemically or hydrothermally altered. This alteration causes i.e. the formation of secondary swelling clay minerals, which can cause frost susceptibility of aggregates. Handling can easily break down altered material and if used in highway construction it may quickly degrade, particularly when wetted. This degradation is particularly serious if swelling clay minerals are present in the rock.

There are different stages of alteration. The presence of highly altered material within a bulk sample can complicate the testing of these materials and makes interpretation of the resulting data very difficult. The presence of such material may be detected by petrological examination. In West Java for example, if more than 33% of the particles are altered, the aggregate is viewed with caution. Similar guidelines are in use in Iceland, where very altered basalt is viewed with caution when more than 5 to 25 % are altered (depending on end use).

4. Extraction of basaltic aggregates

Basaltic aggregates may be quarried as a conventional bedrock quarry (usually homogeneous rock type) or dug as gravel from pits (usually heterogeneous material of a variety of rock types). Its composition can vary both within a quarry, a pit and between pits. This affects the overall quality of the aggregate produced. The variation is a reflection of the structure and composition of the original rock and also of its alteration history.

5. Sources of basaltic aggregate in Iceland

Iceland is a relatively young island, the oldest rocks being about 15 million years old. It is situated on the North Atlantic Ocean rift zone, where two oceanic plates drift apart. Therefore, the source of magma is basic and primitive, originating in the earth's mantle. About 80-90 % of the Icelandic bedrock is of basaltic origin, but in places where central volcanism has been active, acidic rocks can be found, mainly rhyolite and granophyres. In such areas, hydrothermal processes have generally resulted in very altered basalts.

Generally speaking, the oldest rock formations in Iceland are to be found at the far east and west side of the island and the youngest lava flows are being formed at a N/S zone in the centre. As volcanism is still quite active in Iceland, new sources of aggregates are being naturally produced at present. Figure 2 shows a schematic classification of the sources of aggregates used for road construction in Iceland.

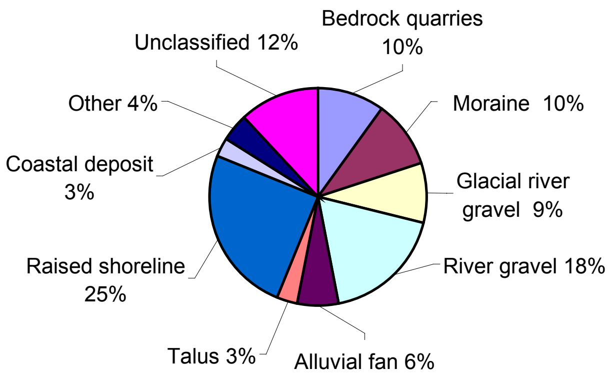

Figure 2 Classification of Icelandic aggregate sources.

The figure shows that only about 10 % of all aggregate sources in Iceland are from rock quarries. Most of the quarried aggregates are from loose gravel deposits, such as river- or raised shoreline gravel. Usually, there is a mixture of rock types, as well as difference in porosity and alteration stage of the gravel aggregates. Therefore, basalts are classified (using simplified petrography) mainly on the grounds of porosity (dense, porous, very porous) and alteration (fresh, altered, very altered). All samples are classified with this respect and in that way general information about the expected performance is obtained. So, each sample (for example river gravel) has x % fresh, dense, y % fresh, porous, z % altered, dense basalt, etc. Other factors, such as shape and cleanliness are also observed. Scoria, pyroclastic, pumice and other such petrological types are not classified as basalt in this manner.

6. Sources of basaltic aggregate in West Java

Road aggregate quarries are found through out the West Java region of Indonesia. Van Bemmelen (1970) divided West Java physiographically and structurally into four East-West trending belts:

- The southern mountains of West Java were sub-divided into the Djampang Stage and the Tjimandiri Complex. The volcanism was predominantly pyroxene andesitic, with occasional outbursts of dacitic tuffs. The pyroxene andesitic eruptions reached their climax during the Djampang Stage (lower Miocene). The Tjimandiri Complex was formed in the middle Miocene and consists mainly of marine sediments with minor amounts of volcanic constituents.
- The Bandung Zone is a depression 25-50 km wide, slightly convex to the North, located between the Bogor Range and the southern mountains. The Bandung Zone was formed at the end of the Neogene.

Verbeek, White and Blattmann (1938) state that some rocks in this zone are basaltic, whereas the younger products are mainly andesitic (pyroxene andesites and hornblende-pyroxene andesites).

- The Bogor Zone in Bantam forms the western part of the Neogene geosynclinal basin of West Java. The Neogene and older Quaternary strata taper out westward so that in Bantam they are separated by many unconformities and disconformities caused by oscillatory movements of the basement complex. Volcanism began in the Lower Pleistocene forming olivine basaltic to pyroxene andesitic volcanoes.
- The lowland plain of Batavia is an alluvial and marshy area that forms the northern part of West Java (Batavia). This lowland extends from the west to the east of the coast. The coast steadily shifts northward due to the silt load of the rivers flowing into the Java Sea.

In West Java some 40% of the aggregate quarried is bedrock material with 53% comprising unconsolidated gravels. As shown in Figure 3 these materials consist of differing geological types.

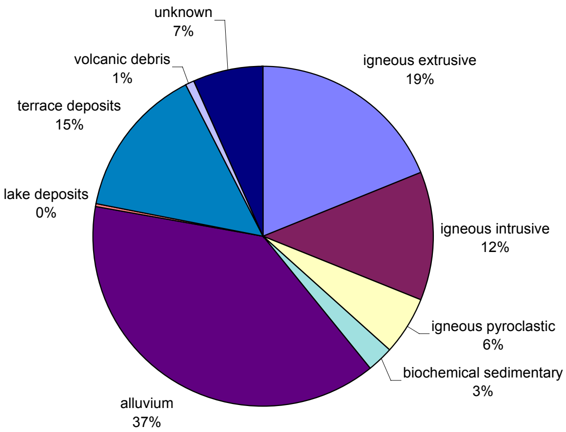

Figure 3 Different types of material quarried in West Java.

The dominant source for both the bed rock and unconsolidated alluvial gravels is either andesite or basalt with an estimated 260 million m^3 of reserves thought to exist in West Java.

7. Sources of basaltic aggregate in Northern Ireland

The main types of aggregate quarried in Northern Ireland and their production figures for 1999 are shown in Table 2. In terms of quantity produced, Tertiary basalt is the most important with 33% of the total production. This is followed by limestone, sand and gravel and Silurian greywacke. Basalt is the main source of aggregate in Northern Ireland and occurs across an area of approximately 4000 km^2 in Counties Antrim and Londonderry. It was formed approximately 60 million years ago when two major cycles of sub aerial volcanic activity resulted in the accumulation of a thick lava pile known as the Tertiary Antrim Lava Group.

Table 2 Northern Ireland aggregate statistics (Dep. of Economic Development, 1999).

Rock type	Quantity (tonnes)	% of total
Tertiary basalt	9,538,000	32.87
Silurian greywacke	3,615,000	12.46
Carboniferous limestone	8,771,000	30.22
Sand and gravel	5,517,000	19.01
Others	1,579,000	5.44
Total	29,020,000	100.00

The basalt quarried would be comparable to the bedrock type from West Java and typically consists of olivine rich basalt with smaller amounts of tholeiitic types (Lyle 1980, Woodward 1997). All of the basalt quarried is from crushed rock sources. Unlike Iceland and West Java there is no basalt gravel used in construction in Northern Ireland. Although there are a few pits were basalt gravels are present, its quality has been affected by severe alteration deeming the gravel unacceptable for use.

Woodward (1997) proposed a simple classification to describe the different types of basalt quarry present. This was based on their formation processes and subsequent post-formation conditions that may have subsequently affected the uniformity of aggregate quality between quarries. The main factors that have impacted this variation include:

- The degree of weathering (alteration).
- Geographical location in relation to the eruptive source.
- Vertical position within the volcanic pile.
- Presence of faulting, jointing and dykes.
- Thickness of flow.
- Depth of weathered (altered) profile.
- Presence of weathered (altered) ash-fall or bole.
- Whether the flow was single or compound.
- Influence of geologically recent events such as removal of weathered (altered) flow-tops during the last ice age.

Based on these factors, the 5 basic types of quarry proposed are shown in Table 3. Although quarries may have been located in all of the 5 types, the need to improve quality and recognition of potential soundness related problems has meant that Type1 and 4 are now the predominant types followed by Type 2. There are now no Type 3 quarries in production as the multiple and compound flow types gave aggregate of variable composition in terms of soundness.

Table 3 Basic classification of basalt quarries in N. Ireland (Woodward, 1997).

Type of basalt quarry	Description
Type 1	Typically 1 thick flow
Type 2	Typically 2 or 3 thick flows
Type 3	4 to 7 thin or compound flows
Type 4	1 thick flow where the upper weathered (altered) portion has been removed to expose good basalt at surface
Type 5	Any of above effected by faulting, dykes etc.

8. Test results

The source of the West Java aggregate data is taken from a Road Material Inventory carried out by the Institute of Road Engineering (IRE), the Agency of Research Development and the Ministry of Public Works in Indonesia. The Northern Ireland data was taken from a study by Woodward (1995). The Icelandic data has been taken from research projects carried out in the BUSL co-operation and mainly funded by the Public Roads Administration.

8.1 Correlation of Specific Gravity and Water Absorption

Figure 4 shows the relationship between Water Absorption and Specific Gravity determined on a saturated surface dry basis.

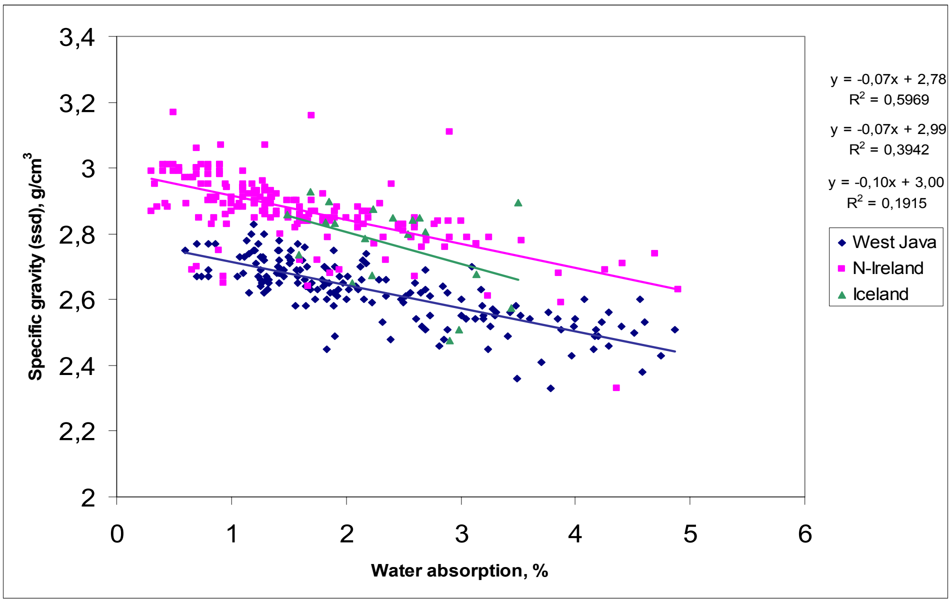

Figure 4 Relationship between Water Absorption and Specific Gravity determined on a saturated surface dry basis.

It can be seen that both the Icelandic and the Northern Ireland aggregate are denser for a given Water Absorption than the West Java aggregate. This relates to the predominant type of basaltic material found in each country i.e. the less dense andesite in West Java and denser olivine rich basalts from Iceland and Northern Ireland. Good correlation exists between the two variables for all three aggregate sources i.e. Specific Gravity tends to decrease as Water Absorption increases. Only aggregates which have a Water Absorption value less than 5% are plotted, as stated in Section 2. It is interesting to note that the Water Absorption values for all the Icelandic basalt are above 1,5 %, but for West Java and Northern Ireland basalts, Water Absorption values as low as 0,5 % are measured. This difference could be explained with the difference in geological age of the basalts, at least in the case of the North Atlantic basalts. The relatively young basalts of Iceland have a more open texture than the older Northern Ireland basalts. Another factor affecting water absorption is the degree of alteration. Typically the presence of altered minerals containing absorptive clays will result in lower densities and higher Water Absorptions. Indeed, the Water Absorption in the UK is used as a quick indicator of soundness were Water Absorption values greater than 2 % require a Magnesium Sulphate Soundness test to be carried out. Chemical composition could be a part of the explanation for different Water Absorption values in the case of the West Java basalt, as andesitic materials tend to be microcristalline and therefore less space is available between crystals for water absorption to occur.

8.2 Correlation of Water Absorption and Los Angeles Abrasion data

Figure 5 shows the correlation between Water Absorption and the Los Angeles test.

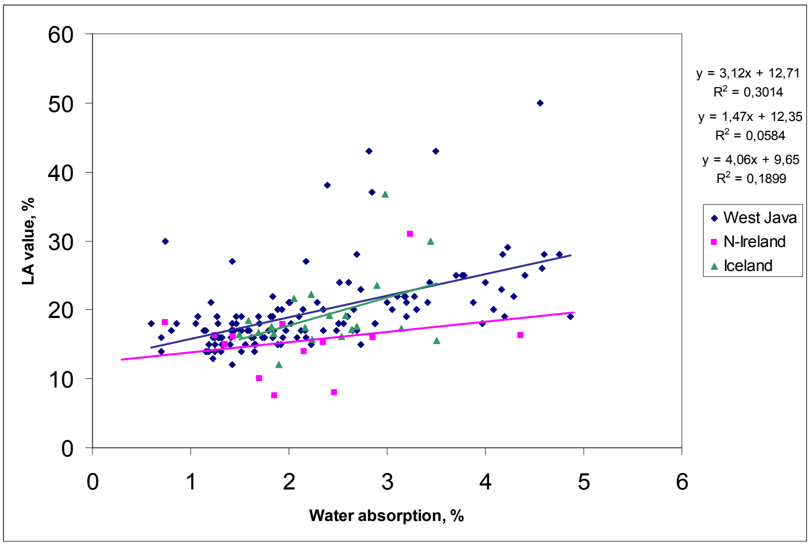

Figure 5 Correlation between Water Absorption and the Los Angeles test.

The Iceland and Northern Ireland data was determined using the CEN test method EN 1097-2 whereas the West Java data was obtained using the ASTM C-131 method. Despite this difference, Figure 5 shows the trend that increasing Water Absorption causes a decrease in the value of Los Angeles i.e. high Water absorption aggregates will suffer more degradation. This is related to the degree of alteration where higher values of Water Absorption indicate a weathered unsound aggregate that is prone to degradation. For Icelandic basalts this also relates to vesicles and open texture, which result in a high Water Absorption value as well as a high LA-value.

8.3 Correlation of Water Absorption and Aggregate Impact Value data

Figure 6 shows correlation between Water Absorption and the Aggregate Impact Value.

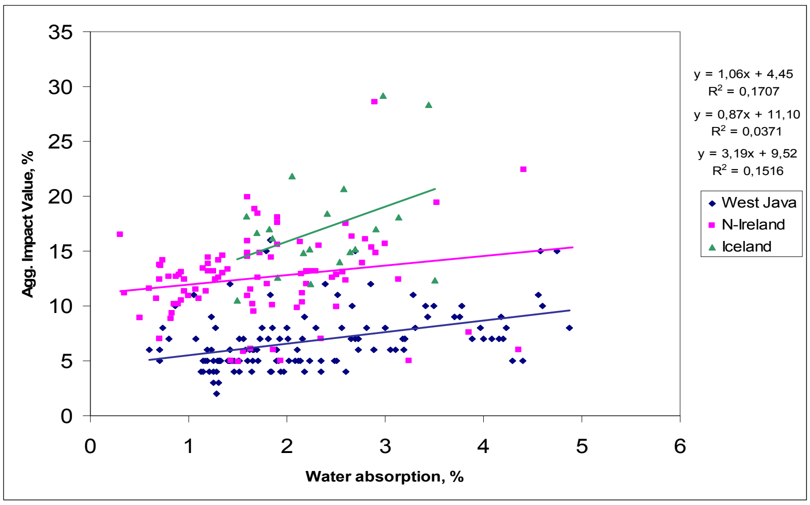

Figure 6 Correlation between Water Absorption and the Aggregate Impact Value.

The figure shows that increasing Water Absorption values of aggregates from all countries correspond to poorer Aggregate Impact Values i.e. poorer quality aggregate.   For a given value of Water

Absorption, the West Java andesitic aggregate is generally more resistant to sudden impact than the Iceland and Northern Ireland olivine basalts. This may be connected to the coarser and more fragile crystalline texture of the Icelandic and Northern Ireland olivine rich basalts in comparison to the microcrystalline andesitic basalts of West Java.

8.4 Correlation of Los Angeles and Aggregate Impact Value data

Figure 7 shows the correlation obtained between LA test results and AIV test results. Only Icelandic and West Java data is plotted here but Northern Ireland data was not available.

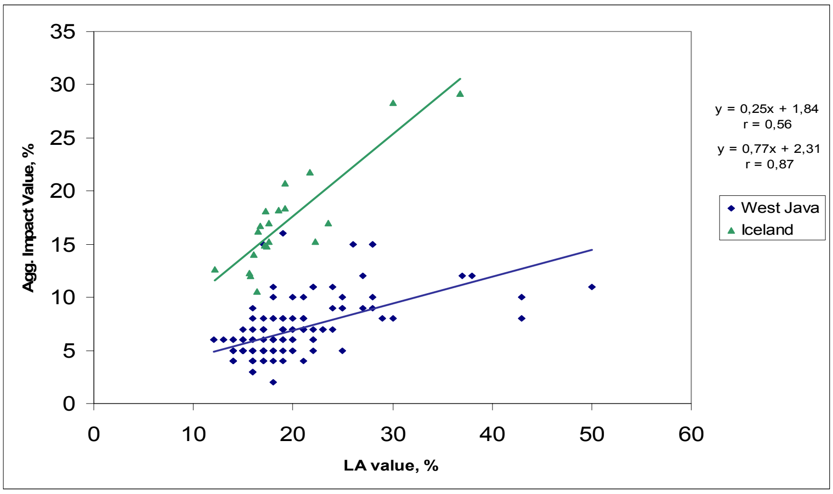

Figure 7 Correlation obtained between LA test results and AIV test results.

The figure shows clearly that the Aggregate Impact test results are considerably higher for Icelandic aggregates than West Java aggregates for a given Los Angeles value. When the LA value obtained is between 15 and 20 %, as commonly observed, the AIV value is approximately ten units higher for the Icelandic basalts than the West Java aggregates. The trend line for the Icelandic aggregates also shows a stronger correlation than the trend line for the West Java aggregates. This confirms that the West Java aggregate appears to be generally more resistant to sudden impact than the Icelandic and Northern Ireland olivine basalts. Figure 7 also clearly indicates that test results for different rock types can show different correlations between test methods.

9. Discussion

Basaltic types of rock (BS 812, engineering context) are the main source of aggregate in Iceland, West Java and Northern Ireland where they are regarded as a valuable resource. Although grouped under the engineering term "basaltic", there are distinct differences within the specific types present in each of the countries considered in this paper i.e. mainly andesite in West Java and basalt in Northern Ireland and Iceland.

In all countries the geological history of the basalts has influenced the aggregate properties. West Java on one hand and Northern Ireland and Iceland on the other hand have different climates at present i.e. West Java is a tropical climate and Northern Ireland and Iceland are regarded as cold regions. However, the Northern Ireland basalts were all formed in a tropical climate some 60 million years ago and the same can also be said about the oldest Icelandic basalts, which started forming some 15 million years ago. Therefore, the North Atlantic basalts have many of the typical altered profiles associated with tropical alteration conditions. Furthermore and more importantly, regional conditions (such as hydrothermal activity in Iceland) have influenced the rock properties and alteration products.

Correlation of physical and mechanical data indicates that the Northern Ireland and Icelandic basalts are typically of higher density and yet not as resistant to impact as the West Java andesite. The difference in Specific Gravity values for aggregates from West Java on one hand and N-Ireland and Iceland on the other hand is explained partly by the chemical composition of the material, but also by geological age, geological history and climate.

It is evident that individual sources of aggregate within rock type groupings do not perform in similar ways. A simple classification must therefore recognise that differences occur at a local level. It is also doubtful whether it is appropriate to include different rock types when correlations are made between different test methods. Rather than use the collective terms such as basalt a much better level of immediate understanding would be achieved if knowledge of local problems and performance capability were available.

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