Construction aggregates: evaluation and specification

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ABSTRACT

Construction aggregate is a fundamental raw material for all countries. However, the testing and specification of aggregate is often overlooked or not considered. This has serious implications for the life and maintenance of buildings and infrastructure which can cost a lot of money in the future to repair or replace and at worst lead to structural failure and risk to human lives.

Geological materials have been used in construction since the dawn of time. This is still the case with construction raw materials accounting for the largest volumes of any known production process on the planet. Natural aggregate is the most ubiquitous construction material and is used in buildings, civil engineering projects and transport infrastructure such as roads, railways and airport runways.

The suitability of naturally occurring rock for the production of construction aggregate relies on its testing against national and international standards. Construction aggregate broadly comes in two main categories. Hard rock aggregate is typically sourced from igneous rocks such as granite, dolerite and gabbro, sedimentary rocks such as sandstone and limestone, and metamorphic rocks such as gneiss and marble. These are extracted in quarries by drilling, blasting and crushing. Sand and gravel aggregate is typically sourced from unconsolidated sediments of fluvial, lacustrine or marine origin. These are extracted in quarries by mechanical excavators. Both types of aggregate are washed and screened to create the required construction aggregate products.

The testing of aggregate not only ensures its suitability for different construction applications it is also the basis for consumer specifications and enables the ongoing assurance that it continues to meet the required properties.

INTRODUCTION

The construction aggregates sector is an important part of most modern developed economies. For example in the UK, aggregates account for approximately 85% of the non-energy minerals extracted. They are essential for constructing and maintaining what is literally the physical framework of the buildings and infrastructure on which our society depends (British Geological Survey (BGS), 2013).

To ensure that construction aggregates are fit for purpose and meet the requirements of the end-uses it is important to have an understanding of the geology of the resources, production processes, and standards and test methods used to evaluate their suitability. Construction aggregate is normally defined as being hard, granular materials which are suitable for use either on their own or with the addition of cement, lime or a bituminous binder in construction. Important applications include concrete, mortar, road stone, asphalt, railway ballast, drainage courses and bulk fill. There are three main types: natural aggregate (from mineral sources with nothing more than physical processing, often referred to as ‘primary aggregate’), manufactured aggregate (derived from industrial processes as a by-product, often referred to as 'secondary aggregate') and recycled aggregate (recovered from material previously used in construction) (BGS, 2013). This paper will focus on natural (primary) aggregate.

GEOLOGY OF AGGREGATE RESOURCES

Any naturally occurring geological material can be used as construction aggregate as long as it satisfies the requirements of the end-use specification. Primary aggregates are produced from two main sources, 'crushed rock' and sand and gravel. Crushed rock aggregate is produced from hard, strong rock formations including igneous (andesite, basalt, diorite, dolerite, gabbro, granite, rhyolite, tuff), metamorphic (hornfels, gneiss, quartzite, schist) and sedimentary (sandstone, limestone) rock (BGS, 2013).

Figure 1. Sandstone quarry, Yorkshire, UK

Most limestones and dolomites are hard and durable and useful for aggregate. The quality of the limestone resources and their ease and economy of working may be affected by a number of geological factors such as waste content, dolomitisation and degree of faulting and folding. The suitability of sandstone for aggregate use depends on its strength, porosity and durability (Figure 1). Many types of sandstone are too porous and weak to be used other than as sources of constructional fill. In general, older more indurated sandstones exhibit higher strengths and are suitable for more demanding aggregate uses. Igneous rocks tend to produce strong aggregates with a degree of skid resistance and are hence suitable for many road surfacing applications, as well as for use in the lower parts of the road pavement. The high strength and attrition resistance of certain igneous rocks results in their use as railway ballast (BGS, 2013).

Sand and gravel deposits are accumulations of the more durable rock fragments and mineral grains, which have been derived from the weathering and erosion of hard rocks mainly by glacial and river action, but also by wind. The term 'gravel' ("coarse aggregate") is used to define particles between 4 and 80 mm and the term 'sand' ("fine aggregate") for material that is finer than 4 mm, but coarser than 0.063 mm. The properties of gravel, and to a lesser extent sand, largely depend on the properties of the rocks from which they were derived. However, water action is an effective mechanism for wearing away weaker particles, as well as separating different size fractions. Most sand and gravel is composed of particles that are durable and rich in silica (quartz, quartzite and flint). Other rock types, mainly limestone, may also occur in some land-won deposits including deleterious impurities such as lignite, mudstone, chalk and coal (BGS, 2013).

PRODUCTION OF CONSTRUCTION AGGREGATE

Primary aggregates are produced from two main types of quarrying operation, crushed rock and sand and gravel. They are typically extracted by surface quarrying with underground mining of aggregates relatively rare. Any overburden is removed using a combination of hydraulic excavators, ripping and blasting. Crushed rock aggregate is produced from quarries that are much larger and deeper than sand and gravel pits. Crushed rock aggregate is normally extracted using blasting whereas sand and gravel is usually extracted by front end loaders, bull dozers with rippers or self-elevating scrapers. The excavated material is delivered it to a production plant in a form suitable for processing (Mitchell, 2007).

Figure 2. Gyratory crusher, Leicestershire, UK

Production of crushed rock aggregate involves screening (scalping) to remove fines and waste material followed by crushing and screening to produce material with specified size grades. Crushing is carried out to reduce the size of the excavated material from large blocks (up to a metre across) to a size finer than 20 to 50 mm (Figure 2). Production of sand and gravel involves washing and scrubbing to remove clay, separation of the sand fraction by screening, grading of the gravel, sand classification and dewatering, and crushing of any oversize gravel to produce a saleable product. Washing removes silt and clay (material finer than 0.063mm), which is present either as surface coatings or as clay-bound agglomerates that need to be broken down (Mitchell, 2007).

STANDARDS AND TEST METHODS

The testing of construction aggregate is carried out to international standards. The quality of quarry products used in the UK is controlled by the European Standards for Aggregates for concrete, mortar, asphalt and road construction. The key parameters for aggregates are particle size and shape, physical and mechanical properties and durability. The laboratory evaluation of construction aggregate ranges from simple and low cost to sophisticated and expensive testing. A useful manual for the testing of construction materials, including aggregate, was published by the British Geological Survey in 1994 (Harrison & Bloodworth, 1994).

Particle Size Distribution (Grading)

The particle-size distribution, or ‘grading’, is a fundamental property for all construction aggregates and often defines the product. Grading is usually carried out by sieve analysis (Figure 3). The sample is passed through a sieve stack (wet or dry) and the weight proportion retained on each sieve is determined. The cumulative percentage finer than each sieve size is plotted to produce ‘grading curves’. Aggregate should be clean (free of clay, silt and dust) to ensure effective binding of cement or bitumen. Sedimentation methods may also be used to determine the grading of fines.

Figure 3. Grading of sand and gravel

Particle Shape

The shape of aggregate particles is a product of the rock type, depositional environment and quarrying and production process. For example, hard, tough or brittle rocks will often generate more flakes, whereas softer rocks produce more fines. Angular, cuboidal aggregate is usually preferred. Flat, flaky or long, thin particles will not interlock well and result in weak road stone or concrete products. Also, poorly-shaped aggregate has a high surface area and has a high demand for binder.

Aggregate shape is determined using petrographic analysis and can be classified as: rounded, cuboidal, irregular, angular, flaky, or elongated. Flakiness and elongation are the key measures of poor particle-shape. The ‘flakiness’ of an aggregate is measured as the weight proportion passing a specially designed slotted sieve. A limit of 35% flaky particles is imposed for general purpose construction aggregate whereas a stricter limit of 25% flaky particles is imposed for wearing course road stone.

Density Testing

The bulk density of construction aggregate is expressed as the weight per unit volume for example kilograms per cubic metre (kg/m^3). The bulk density can be calculated for loose and compacted aggregate, the latter simulates the density of aggregate after transportation. Measurements are carried out using calibrated containers of known volume. The density of fine aggregate can be determined using a pycnometer bottle.

Aggregate strength testing

Strength tests are used to assess the suitability of aggregate for use in road stone or concrete. They are indicator tests, measuring the likely rather than the actual performance of aggregate.

- Aggregate Impact Value (AIV) – this is the measurement of the aggregates resistance to repeated and sudden force. A test specimen of aggregate (14 – 10mm) is hit 15 times with a standard weight dropped from a fixed height. The proportion of material passing a 2.36mm sieve is the AIV (mean value of two tests). The lower the AIV the stronger the aggregate. It is a simple, cheap test giving precise results. An AIV less than 30 is usually required.
- Aggregate Crushing Value (ACV) – this is the measurement of the resistance of aggregate to crushing by compressive force. A test specimen (10-14mm) is compressed (up to 400 kN) and the proportion of material passing 2.36 mm is the ACV (mean value of two tests). The higher the value the weaker the aggregate. An ACV greater than 35% indicates that aggregate is too weak for most construction uses. A variation is the Ten Per Cent Fines Value (TFV) which is expressed as the load required to produce 10% fines. TFV ranges from 10 kN (very weak rock) to greater than 400 kN (very strong rock).
- Los Angeles Abrasion Value (LAAV) – this is a measurement of the resistance to attrition. A test specimen (5kg) is loaded into a hollow steel container with 6 – 12 steel balls which rotates at 33 rpm. The weight proportion finer 1.6 mm after testing (determined by screening) is the LAAV. LAAV is a preferred method for evaluating aggregate.

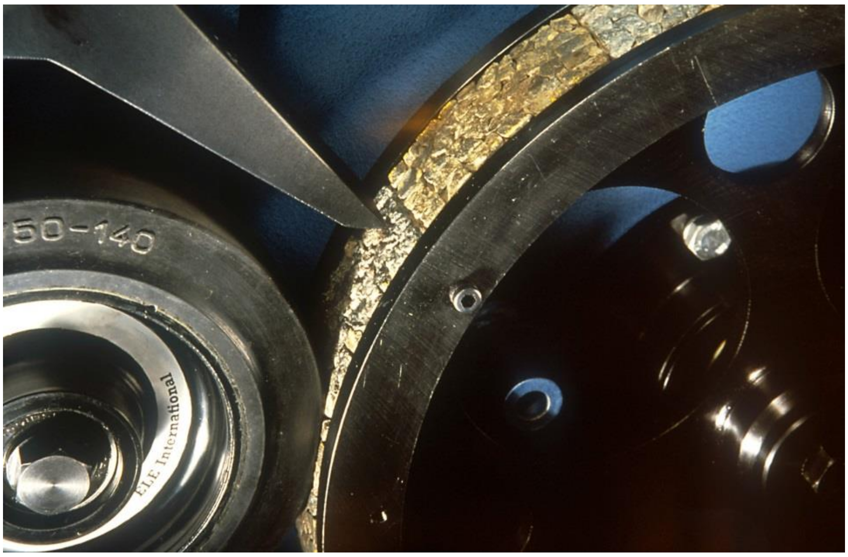

Figure 4. Polished Stone Value (PSV) testing

<u>Aggregate durability testing: wear</u>

Durability testing determines the resistance to wear and decay of aggregate. This testing is divided into two types: mechanical deterioration ('wear') and physico-chemical disintegration ('soundness')

- <u>Aggregate Abrasion Value</u> (AAV) – this is an estimate of the surface wear of road surfacing aggregate and is an indicator test for abrasion resistance. Aggregate particles (10-14mm) are mounted in resin mould and abraded using a specially designed machine. The percentage loss of the test specimen is the AAV. The lower the result the more the resistant the aggregate (limestone is typically 8-15% and sandstone typically 3.5-12%).
- <u>Polished Stone Value</u> (PSV) – this is a measure of resistance to the polishing action of tyres (Figure 4). It is increasingly important as skid-free roads are recognised as safer. It is a complex test involving preparation of test specimens similar to AAV and polishing in an accelerated polishing machine. The higher the value the greater the resistance to polishing, poor resistance 20-30, moderate resistance 55-60 and high resistance greater than 65.

<u>Aggregate durability testing: soundness</u>

Soundness testing is used to identify those aggregate that may be prone to degradation in saturated moisture conditions, elevated temperatures or freezing conditions.

- <u>Magnesium Sulphate Soundness Value</u> (MSSV) – this measures the breakdown of aggregates following accelerated physical weathering by salt crystallisation. Repeated cycles of immersion of aggregate (10-14mm) in magnesium sulphate solution and oven drying simulate the expansion of water on freezing. The weight loss proportion is calculated as the MSSV.
- <u>Methylene Blue Absorption Value</u> (MBV) – this measures the clay content of aggregate. Methylene blue is an organic dye absorbed by clay minerals and the amount absorbed is proportional to the clay content.

- Alkali Silica Reactivity (ASR) Testing – ASR is a reaction between reactive silica and alkalis in cement which can cause expansion and cracking in concrete. Reactive silica may be present in rocks such as rhyolite, rhyodacite & dacite; lithified tuffs, ignimbrites and other pyroclastic rocks. Reactive silica can be identified using petrographic analysis.

CONCLUSIONS

To ensure that construction aggregates are fit for purpose and meet end-use requirements it is important to have an understanding of the geology of the resources, the production processes, and the standards and test methods used to evaluate their suitability.

Primary construction aggregate can be produced from any source of rock as long as it meets the specification of the end-user. Production of construction aggregate is a well-known process of extraction, size reduction and screening to produce graded products.

The testing of construction aggregate is carried out to international standards. The particle size distribution ('grading') is the key defining characteristic of construction aggregate and is often used as a product classification. Particle shape, density, strength, mechanical wear and chemical soundness are important criteria for evaluating the suitability of aggregate for use in construction.

ACKNOWLEDGEMENTS

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