AGGREGATE TESTS

Why do we need to test rocks?

Have you ever wondered why stone quarries tend to be found in hilly and mountainous regions of the country? Hills and mountains exist because they are composed of hard rocks resistant to erosion. That's why quarrymen look to these areas to find suitable rock to quarry. Valleys often form in areas of weaker rocks that are more easily eroded away.

It is essential that aggregates used in construction purposes are strong and durable. Think of bricks, blocks, concrete, coated materials – the largest single component in all of these construction materials is aggregate. It would be disastrous to construct houses or bridges or roads with building materials made with weak rock.

This is why quarrymen need to test the rocks that they quarry – they need to know if the rock is strong and suitable for the end-use it is to be put to. They need to know if there are any weak strata (rock layers) in the quarry that would be detrimental to the quality of the stone.

For instance, where basalt lavas are being quarried, the quarryman needs to take care to exclude any soft red rock that is often found between lava flows. He also needs to avoid any basalt that has weathered, or that contains excessive amounts of vesicles (gas cavities formed during the emplacement of the flow), or amygdales (cavities filled with soft white minerals called zeolites). In gritstone quarries, bands of soft shale have to be excluded from aggregate production.

'Soft' rocks

The following are some rock types that are generally too soft, friable (crumbly) or fissile (composed of weak platy layers) for use as aggregates in construction:

- Marl (calcium carbonate bearing clay)
- Mudstone
- Shale (fissile)
- Slate (fissile, though some slates are strong enough for roofing)
- Weakly cemented or clay bound sandstones
- Weathered or vesicularised basalt
- Mica schists
- Argillaceous (clay bearing) limestones

Although soft, shale can be quarried for the production of cement. To make cement, shale is finely crushed and mixed with ground limestone. The blended powder is then calcined (fused by great heat) in large rotary kilns to form a hard clinker. The clinker is ground down to make cement powder. Cement is used in an incredible range of building materials such as mortar, paving blocks, engineering brick and concrete.

'Hard' rocks

The following are the main rock types that are generally tough and hard**,** and therefore suitable for use as aggregates in construction:

- Unweathered basalt
- Dolerite
- Gabbro
- Granites
- Massive limestone
- Well cemented sandstones
- Greywacke (a type of sandstone)
- Massive gneiss
- Hornfels

However, even if a rock is hard and tough, it may still not be suitable for certain purposes. For road construction, there are several very important considerations as to whether a rock is suitable or not. Aggregate used in the surface course (running surface) of roads MUST be resistant to the polishing action of vehicle tyres, otherwise the road can become slippery, especially when wet. For bitumen coated road materials, it is also important that the rock type is compatible with the bitumen. Bitumen, though very adhesive, sticks well only to certain types of aggregate, such as basalt, limestone and gritstone. It does not stick at all well to quartz bearing rocks such as granite, flint, quartzite and schist, although this can be overcome by the addition of adhesion promoting agents to the bitumen.

So, the big question is – how can we find out if a particular rock type is suitable for its intended end-use? What properties of the rock can be measured and how? The main aggregate tests are illustrated and explained below.

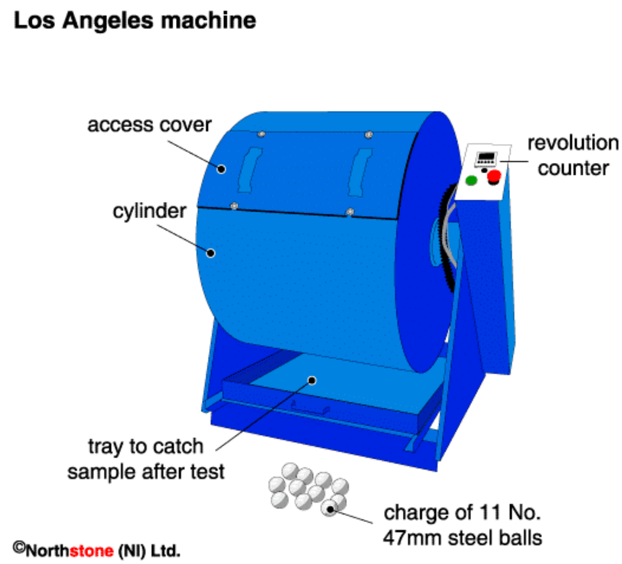
Note: since 2004, the range of tests carried out on aggregates for construction purposes has been harmonised throughout the European Union. Some familiar aggregate tests previously used in the UK and Ireland, such as Aggregate Crushing Value, Ten Percent Fines Value, Aggregate Impact Value, and Wet Attrition Value, have been withdrawn from use, and do not now have the status of a national standard. Flakiness Index is now measured using round bar sieves, rather than slotted trays. Sieve sizes have also been changed. The remaining tests, such as Polished Stone Value, Aggregate Abrasion Value, and Magnesium Sulphate Soundness, have been retained virtually intact. Aggregate strength is now assessed using the Los Angeles test, which has replaced the Ten Percent Fines Value. Other European tests, such as Methylene Blue (level of harmful fines), Shape Index (particle length to width ratio), Impact Value (NOT former BS test, but based on a DIN method), Micro Deval (wear), Freeze Thaw, Resistance to Thermal Shock, and "Sonnenbrand" of basalt, are not in general recommended for use in the UK. For detailed information on European aggregate size designations and UK guidance on tests.

Strength

Los Angeles Test (*LA*)

The complete test is detailed in BS EN 1097-2, under the title *"Methods for the determination of resistance to fragmentation".* The Los Angeles machine consists of a large cylinder made of 12mm thick steel, 508mm long by 711mm diameter (internal dimensions). Its axis of rotation is mounted horizontally within a strong support frame. An internal shelf, 90mm in depth and 25mm thick, is welded across the inside of the cylinder. The whole machine is very robust and heavy.

A sample of aggregate (a specially graded mix of 10 and 14mm size fractions), weighing 5kg, is introduced into the cylinder through a hatch. A charge of eleven steel balls, each between 45-49mm in diameter, weighing in total between 4690-4860g is also added. The hatch lid is then bolted in place and the cylinder rotated for 500 revolutions at a rate of 31-33 RPM. As can be imagined, the noise from the machine is terrific, so the machine has to be operated in a soundproofed cabinet. A built-in counter stops the machine after 500 revolutions. The hatch is opened and the contents of the cylinder - the surviving aggregate particles, crushed debris and the steel balls, are emptied into a tray set underneath the opening. The balls are removed and the aggregate is then washed and sieved through a 1.6mm sieve. The fraction retained on the sieve is dried to constant mass and weighed. The result, the Los Angeles Coefficient, is calculated as:



$$\boldsymbol{LA} = \frac{5{,}000 - \text{retained mass}}{50}$$

Aggregate with a LA value of less than 30 ($\boldsymbol{LA_{30}}$) is considered strong enough for use in coating and road surface treatments (i.e., surface dressing).

Railway Ballast: The test is modified to test railway ballast, in that 5kg of 32/40, together with 5kg of 40/50, is placed in the cylinder with 12 steel balls and rotated for 1000 revolutions. For railway ballast:

$$\boldsymbol{LA} = \frac{10{,}000 - \text{retained mass}}{100}$$

Abrasion resistance (toughness)

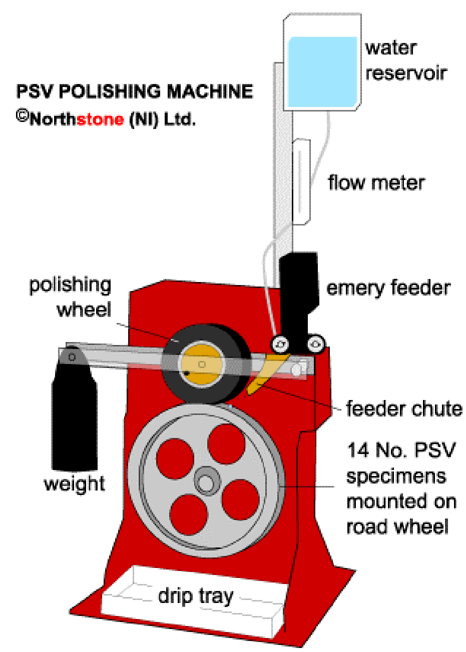
Aggregate abrasion value (AAV) – This test sorts out aggregates which might be strong but are not resistant to the abrasive action of vehicle tyres if used in the surface course of roads, i.e., though suitable in every other respect, they wear-out too quickly in use. In this test, 14 mm chippings are placed face-down in a rectangular mould. Fine sand is placed in the mould to half the depth of the chippings. The mould is then filled with resin and allowed to set. Duplicate (two) test specimens are cast for each test. The weighed specimens are then mounted in diagonally opposing clamps, face down against a large circular steel lapping wheel. A weight, which bears down on the back of the specimen, is also mounted into each clamp. The machine is then started and coarse abrasive sand is feed from a feeder hopper mounted in front of each clamp. The machine is run for 500 revolutions. The abrasive sand wears away the specimens. After the test, the specimens are removed from the machine, cleaned and re-weighed. The results is expressed as a percentage of the weight lost against the original weight of the sample. The lower the value, the more abrasion resistant the aggregate is.

Resistance to chemical degradation

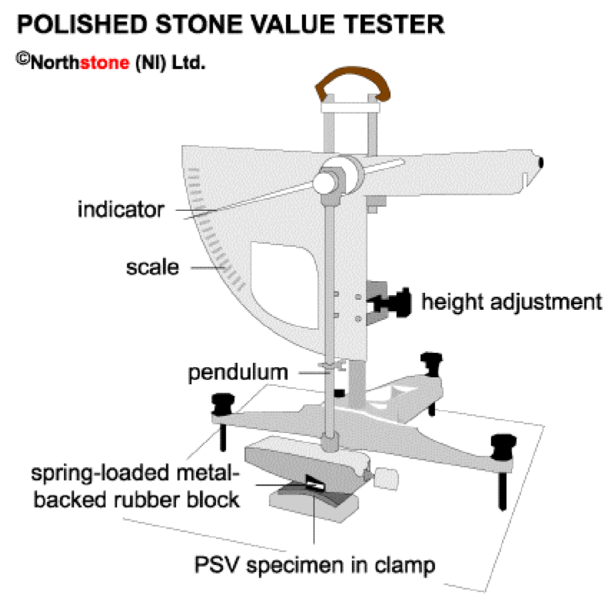
Magnesium sulphate soundness test (*MS*) – This test measures how resistant an aggregate is to chemical weathering and can be carried out on different aggregate sizes. For the test, a weighed sample of aggregate is placed in a wire mesh basket. The basket is suspended in a saturated magnesium sulphate solution for a period of time. The basket is then removed and dried in an oven. This is one cycle. Ten soaking and drying cycles are carried out. In the soaking cycles, the magnesium sulphate solution penetrates into the surface of the aggregate particles through any pores that exist. During the drying cycles, the magnesium sulphate crystallises in the aggregate pores, and as it crystallises it exerts tremendous pressure on the surrounding rock matrix. If weak, the aggregate matrix will disintegrate and fall through the mesh of the enclosing wire basket. When all the soaking/drying cycles have been carried out, the remaining aggregate is washed, dried and re-weighed. The result is expressed as a percentage of the weight of aggregate lost against the original weight. Very weak rocks will disintegrate completely in a small number of test cycles. Results tend to be worse for smaller aggregate sizes. Aggregates with a test result less than $\boldsymbol{MS_{25}}$ (less than 25% loss) are considered suitable for general purpose use.

Resistance to polishing

Polished stone value (*PSV*) – This is a most important test that an aggregate can undergo if it is to be used as a road surface course. If an aggregate polishes too much under the polishing effect of vehicle tyres, the road surface becomes very slippery, especially when wet, and the number of skidding accidents can increase. For the test, 10 mm chippings are placed face-down in a curved rectangular mould. Fine sand is then placed in the mould to half the depth of the chippings. Resin is then poured in until the mould overflows and a heavy back plate, shaped to the curve of the mould, is placed on top. When set, the specimen is freed from the mould, cleaned and inspected. Four moulded specimens are made for each sample of aggregate tested. Four specimens of a specially selected fine grained rock are also cast for use as a control. The test samples are split over two separate runs on the polishing machine.



The polishing machine consists of a large wheel which is essentially a clamping device that holds 14 cast specimens firmly in place around its rim (2 controls plus 6 pairs of samples). The wheel, complete with specimens, is mounted onto the drive shaft of the machine. A smaller rubber tyred polishing wheel, in turn mounted on a weighted pivoted arm, is brought to bear on the top surface of the large wheel. A coarse emery feeder is mounted above the road wheel. This feeds coarse emery between the two wheels during the test. Water is drip fed in at the same point as the emery abrasive. Guards are mounted in place and the wheel run at 320 rpm for 3 hours. After coarse polishing, the wheels are demounted and cleaned along with the machine and remounted together with a fine emery feeder for a second polishing run using emery flour. This is again run for three hours.



After the final polishing stage, the specimens are released from the large wheel, cleaned and then tested for skid resistance. The skid resistance tester consists of a free swinging arm mounted on an column held upright on a three-legged base. A rubber block is mounted in a spring loaded clamp in the weighted end of the arm. Each of the polished specimens are mounted in turn in a clamp held on a base plate. The specimen and rubber block are wetted, the swing or pendulum arm is raised and latched onto a rigid arm on the tester and then released. The pendulum swings down and drags the spring loaded rubber block over the convex face of the specimen and swings an indicator needle against a scale on the scale arm of the tester. The indicator needle stops and remains at the highest point of the swing. The pendulum is caught on the return downswing. The reading is then recorded. This is repeated five times for each specimen, with the last three readings being recorded and averaged.

As mentioned previously, four specimens made from each test sample, and are split into pairs and polished on two separate polishing runs. This is done in order to improve the reproducibility and repeatability of the test. The results are carefully checked for consistency and are only accepted if set test criteria are met. The higher the test result, the more polish (or skid) resistant the aggregate is. When designing a road, the road engineer specifies the minimum PSV value that the aggregate used in the surface course has to have. This minimum value required depends on the volume and type of traffic using the road. For high risk sites, such as approaches to pedestrian crossings or traffic lights, a minimum PSV of 70 is set.

The PSV values of naturally occurring rocks have been studied on a number of occasions. As a general rule, it has been found that rock types consisting of a variety of mineral grains of different hardness or size, or of harder grains in a softer cementing matrix, give higher PSV values compared to rocks composed of uniform grains of uniform hardness in a similarly hard matrix. The most polish-resistant naturally occurring rock type is greywacke, a type of sandstone. Flint limestone (excepting an occasional gritty type) and granite tend to have low PSV values and polish too quickly to be used in surface courses. Basalts and dolerites tend to fall between the low PSV rock types and the gritstones.

Traffic categories which require a minimum PSV of 70 are surfaced with calcined bauxite, an artificial aggregate formed by fusing aluminium oxides in a high temperature kiln. Calcined bauxite is similar to emery, a naturally occurring mix of corundum (Al_2O_3, second only to diamond in hardness) and magnetite (Fe_3O_4). The calcined bauxite is crushed to produce fine 2-3mm aggregate which is applied to the road as a dressing on bitumen extended epoxy resin, (Shellgrip), or on two-pack epoxy resin (Prismo Tyregrip), or, mixed with thermoplastic resins an laid as a hot screed (Prismo Zebragrip).