The manufacture of concrete paving blocks

CONCRETE SOCIETY OF SOUTHERN AFRICA

1. Introduction

Concrete block paving is versatile, aesthetically attractive, functional, cost-effective and requires little or no maintenance if correctly manufactured and laid. Most concrete block paving constructed in South Africa has performed satisfactorily but there are two main areas of concern: occasional failure due to excessive surface wear, and variability in the strength of blocks.

This technical note covers basic principles and aims to assist manufacturers, particularly new manufacturers, to produce a durable and consistent product.

It discusses: requirements for blocks; selection of materials; materials for manufacture; manufacturing equipment; proportioning of ingredients; manufacture; and quality control.

Scope is limited to blocks with a relatively small top surface area, i.e. about 50 blocks per square metre of paving. Flagstones are therefore not discussed.

2. Requirements for concrete paving blocks

2.1 Properties

- Blocks should meet structural requirements for paving (specified in terms of tensile splitting strength).
- Blocks should be durable: they should be able to withstand abrasion, impact and chemical attack. (specified in terms of abrasion resistance testing and water absorption testing)
- Blocks should be of uniform dimensions to facilitate correct and easy placing and ensure good rideability.
- In some applications concrete blocks are required to be aesthetically attractive.

2.2 Specification requirements

The current specification giving the requirements for concrete paving blocks is SANS 1058:2012 *Concrete paving blocks.* The specification requires that the pavers comply with certain tolerances, meet certain abrasion resistance and absorption criteria and have an average tensile splitting strength of 2,0 MPa and 2,6 MPa for class 30/2.0 and 40/2.6 blocks respectively. Table 1 tabulates these requirements.

Tests have shown that 25 MPa blocks are usually structurally adequate and that the tensile splitting test gives a better indication of structural performance than compressive strength. However to increase the durability of blocks in certain environments consideration should be given to increasing the strength of the blocks.
Blocks are manufactured in various thicknesses of 50, 60, 80, 100 and 120 mm. It is rarely economical to manufacture the last two sizes.

Table 1: Performance requirement for tests specified in SANS 1058 Concrete paving blocks

Class	Tensile splitting strength (MPa)		Abrasion resistance		Water absorption	
	Average	Individual (Minimum)	Average	Individual (Minimum)	Average	Individual (Minimum)
30/2.0	2.0	1.5	15g	20g	6.50%	8%
40/2.6	2.6	2.0				

3. Selection of materials

3.1 Cement

All cement sold in South Africa must meet the requirements of SANS 50197 for Common cement or SANS 50413 for Masonry cement and the National Regulator for Compulsory Standards (NRCS) requirements as detailed in NRCS VC9085. Bags should be clearly marked with the strength grade, notation indicating composition and a Letter of Authority (LOA) number issued by the NRCS. An LOA is issued for each cement type from each source. To verify valid LOA numbers contact the NRCS on 012 428 5199 or www.nrcs.org.za.

Note that Masonry cements complying with SANS 50413 are not permitted to be used in concrete.

The strength class should be 42,5 or higher because blocks are required to develop good strength relatively quickly to permit early handling without excessive breakages. (A 32,5 strength class cement may be used if the blocks are to be subjected to elevated temperatures and/or good curing, e.g. steam curing.)

3.2 Aggregates

General

Paving blocks manufactured in accordance with SANS 1058 are required to use natural aggregates that meet the requirements for aggregates for concrete given in SANS 1083:2014 *Aggregates from natural sources – Aggregates for concrete.* Slag aggregates may also be used if they can be shown to be physically and chemically sound. Waste materials, or materials not in demand, are often sought after as these are generally relatively cheap. But the use of such materials could be at the expense of quality or result in increased costs due to the need to use higher cement contents to maintain quality. These materials might also create compaction difficulties which could adversely affect productivity and durability.

The performance of aggregates at the moulding stage and in the hardened block depends on the combined effects of particle size, grading, particle shape, and hardness. Each of these properties is discussed below.

Size

The recommended maximum nominal size of aggregate is 13,2 mm. However, the maximum size generally used is 9,5 mm.

Smaller sizes (≤ 4,75 mm) may be used to suit circumstances or may be specifically selected to obtain a particular surface texture. Generally, the use of coarse particles results in savings in binder provided the mix is properly proportioned. If coarse aggregate particles are too big, or if too much coarse aggregate is used in the mix, it may be difficult to achieve good compaction and acceptable surface texture.

Grading

Continuous grading will facilitate compaction. Guidelines for grading are given in Table 2. If a material is unsatisfactorily graded for use on its own, good grading may be achieved by blending two or more materials. This is particularly true of crusher sands.

Table 2: Recommended aggregate grading for making paving blocks

Sieve size mm	Cumulative percentage passing
13,2	100
9,5	90-100
4,75	70-85
2,36	50-65
0,30	10-25
0,15	5-15
0,075	2-10
Fineness modulus 3,2-4,2	

Particle shape

Because paving blocks are manufactured from semi-dry mixes, chunky particle shape will facilitate compaction. This property is more likely to be found with natural sands. On the other hand, good 'plastic' stiffness is required as the units are extruded and handled straight after compaction in the mould. Here crusher sand is suitable because its elongated particle shape prevents sagging of the product. It may therefore be beneficial to use a blend of natural sand (for easy compaction) and crusher sand (for 'plastic' stiffness).

Hardness

For concrete subject to abrasion, SANS 1083 specifies that coarse aggregate should have a minimum 10% fines aggregate crushing test (FACT) value of 110 kN. Fine aggregate, i.e. crusher sand, derived from such rock will be satisfactory. However, there is no specification requirement in SANS 1083 for fine aggregate. Sands containing large amounts of unsound weathered material should be avoided. Natural sands with a high silica content are suitable.

Sand and stone chip particles derived from rock types available commercially can differ considerably in hardness, e.g. The 10% FACT of limestone is about 100kN; that of andesite lava could exceed 450 kN. Abrasion resistance depends on many factors but the single most important factor is the degree of cementing of particles at the surface. Factors like surface texture, shape, cement content, compaction and curing are therefore important.

All aggregates complying with SANS 1083 should give satisfactory wear performance. But, assuming that aggregate particles are well cemented at the surface of the block, for most modes of wear the service life of block paving can be extended by using the harder aggregate types. To enhance wear resistance, selected aggregates should be used in a richer topping layer about 15 mm thick moulded simultaneously with the base concrete.

3.3 Pigments

Quality pigments are commercially available to add colour to paving blocks. Dosage, which will depend on the colour selected and the natural colour of the aggregate and cement being used, is generally 5%, but not more than 10%, by mass of the cement. Experimentation may be required to determine the correct dosage because the colour of the finished product in a dry state is influenced by density, curing and surface texture.

3.4 Chemical admixtures

Concrete paving blocks are manufactured from semi-dry mixtures which possess poor flow properties even under vibration. Using water-reducing, plasticizing or compaction aiding admixtures to improve compactibility may be cost-effective.

4. Manufacturing equipment

4.1 Batching equipment

To ensure that a uniform product is obtained, weigh-batching is recommended. For smaller projects, whole bags of cement should be used if the sizes of batch and mixer are compatible.

4.2 Mixer

Because a semi-dry mixture is used to mould concrete paving blocks, effective mixing can be done with pan and trough mixers. Drum-type mixers are unsuitable.

The size of the pan mixer must be related to production so that batches are used up within a reasonable time, i.e. before workability is reduced by moisture loss or hydration of the cement.

4.3 Moulding machine

Unlike bricks and blocks used for masonry, paving blocks must be dense (fullest possible compaction to be achieved). Equipment must be capable of a high degree of compaction and satisfactory output. A combination of vibration and pressure is the most effective way of achieving compaction. Moulding pressure should be 10 MPa or more. Stationary plants using the pallet system are almost exclusively used as they are capable of providing the necessary high levels of vibration and pressure. Hand machines and "egg-layers" are unlikely to produce a satisfactory product unless more cement is used.

4.4 Curing chamber

Newly moulded blocks should be subjected to some form of curing. The form of curing ranges from the prevention of moisture loss to the use of elevated temperature and high humidity, e.g. steam curing. Further details are discussed in section 6.5.

5. Proportioning of ingredients

Proportioning involves finding the best aggregate grading, aggregate:cement ratio and water content, for the specific blockmaking equipment and the way in which it is operated. Each of these aspects is discussed in the following sections.

5.1 Establishing a suitable grading

In general, the aggregate should be graded to permit full compaction of the mix with the least effort. If full compaction is not achieved, voids have a disproportionate effect on strength: 1% voidage reduces strength by about 6%.

Good compaction will be facilitated by using aggregates which are continuously graded (and have good particle shape).

A grading envelope for aggregates which has been found suitable in South Africa is given in section 3.2. The envelope should be used for guidance only as it does not take particle shape into account; materials having a grading outside the suggested envelope may give satisfactory results. Generally, the poorer the shape the greater the voidage and, usually, the greater the amount of aggregate fines, fillers or cement that is required to reduce or eliminate voidage. Typical overall gradings of all solid particles are given in Appendix 1.

Small stone is often incorporated into the mix, resulting in a coarser grading and lower cement content. The stone content is usually between 10 and 25%. However, stone in the mix may change the surface texture and could interfere with compaction of the mortar between stone particles, particularly at acute angles in the block profile. Compressive strength could be reduced even though density may be increased. Finer graded mixes are generally preferred for coloured blocks.

The above information should provide a reasonable starting point for production. Examination and testing of the product should indicate what further adjustments are required to achieve the desired density and surface texture. (Density and the degree of cementing of particles may be assessed by cutting the block through at right angles to the plane of compaction with a diamond saw.)

5.2 Cement content

The cement content to achieve the required strength level will depend on the following factors:

- Type of cement
- Required rate of strength gain
- Degree of compaction and resultant voidage
- Ambient temperature
- Type and duration of curing

It is not practicable to obtain information on some of these parameters by simulating site practice in a laboratory. The only accurate method of establishing the optimum cement content is through a series of trials, using the machine intended for production, in which cement content is varied and the physical properties monitored.

5.3 Water content

The optimum moisture content (OMC) for moulding depends on the materials being used, quality of vibration, and moulding equipment. Generally, the coarser the particles are graded and the greater the compactive effort, the lower will be the OMC. Using a moisture content below OMC will hamper good compaction and may necessitate longer periods of vibration which in turn will reduce output. Lack of compaction will reduce durability. Using too much water will result in a reduction of density and may cause units to stick in the mould and thus make extrusion difficult, or cause deformation of the units after extrusion.

5.4 Trial mixes

The optimum mix proportions can only be obtained through extensive trials. Due to the performance requirements of paving block batching by mass is recommended. Table 3 gives examples of typical cement to aggregate proportions for trial mixes that can be used to do initial testing. These trial mixes can then be adapted to alter the performance of the paving blocks. It is important to measure and calculate the total water content for each trial mix for future testing and production. The trial blocks should be tested in accordance with SANS 1058:2012 to check they meet all performance requirements.

Table 3: Trial mixes per 50kg bag of cement

Mix No	Cement	Aggregate
1	50 kg	100 kg
2	50 kg	120 kg
3	50 kg	140 kg

6. Manufacture

6.1 Batching

The different aggregate types should be stored separately and in such a way that they are well drained. They should be protected from rain so as to remain reasonably dry before being mixed with the cement, thus ensuring that the OMC is not exceeded.

The cement, except when batched by whole bags, should be weighed to an accuracy of 1%. Aggregates should be weighed to an accuracy of 2%.

It is essential to make allowance for moisture contained in the aggregates by adjusting the weight of aggregate batched.

6.2 Mixing

After batching, the aggregates and binder are discharged separately or simultaneously, together with pigment if required, into the mixer and thoroughly mixed before any additional water is added. Mixes having high fines contents may require longer mixing.

Based on measurement of the variable moisture content of the aggregates or visual assessment by experienced personnel, water is added to the mixture to bring it to OMC. Uniformity is important because differences in water content from batch to batch will result in differences in quality.

It must be noted that certain pigments, because of their particle shape, can have a significant effect on OMC.

After mixing, the mixture (and topping mix if required) is stored in hoppers ready for dispensing into the moulds.

6.3 Filling of moulds

Most production machines operate on one of two basic principles. In the first and more widely used system, an amount of mixture is progressively compacted under vibration until a predetermined height has been reached. In the second system, a gauged quantity of mixture is compacted for a set period. In both cases, variations in density will result if the gauged quantities are not consistent or the mixture is not uniformly distributed within the mould. These variations are over and above those due to variations in moisture content. Filling is usually facilitated by a period of pre-vibration after which the moulds are "topped up" with a second filling of mixture.

Where topping layers are used the "topping up" is done using a special topping mix. For very cohesive mixes some difficulty may be experienced when filling the moulds.

6.4 Compaction

The optimum period of vibration must be determined experimentally in the plant but is usually 3 to 12 seconds. Good compaction is more difficult to achieve in thicker blocks and those that have acute angles. For this reason concrete pavers with a thickness greater than 80 mm are seldom manufactured. Frequency and amplitude of vibration should be optimised for the specific materials being used and the number of blocks being moulded per cycle.

6.5 Curing

As with all concrete products, the quality of concrete pavers is improved by water curing. However, it is not practicable to apply significant amounts of water onto newly moulded pavers or subsequently to subject them to water sprays or immersion in water.

The phenomenon of efflorescence further complicates curing in practice. After moulding and on drying, soluble calcium hydroxide may migrate to the surface of the block, particularly if it is porous. Here the calcium hydroxide combines with carbon dioxide from the atmosphere to form less soluble calcium carbonate which is white in colour. Known as lime bloom, it is particularly noticeable on coloured pavers. Other than for aesthetic reasons, lime bloom is not a problem and will disappear with time by normal weathering and the action of rainwater which is mildly acidic. It can also be removed by chemical treatment. Unfortunately, the severity of lime bloom increases with effectiveness of wet curing.

In practice, curing can be effected in one of three ways: moisture retention, steam curing and thermal insulation. These methods are discussed in the following paragraphs.

Moisture retention

This is the least sophisticated method; it is especially effective for blocks that are less dense and thus tend to lose moisture rapidly. Loss of moisture from newly made blocks is prevented by wrapping them in plastic sheeting. However, if blocks are stored under moist conditions whereby condensation can occur (e.g. overnight when pavers are stored under plastic sheeting), lime bloom and staining (colour changes) can still occur.

Steam curing

Although steam curing adds to production costs it is particularly good for early strength development, provision of adequate wear resistance and prevention of lime bloom and staining. This system is unaffected by seasonal changes. (Cement extenders respond well to elevated temperatures.)

Thermal curing

Newly moulded paving blocks are placed in an insulated chamber for a period of 24 hours. Temperature is increased by the heat of hydration of the cement and no additional heat is provided. The method is therefore inexpensive. A constant temperature of 35°C or more can be maintained with this system. A high humidity is provided from moisture within the units and good curing can be achieved.

After initial curing by one of the methods described above, the pavers are sufficiently hard for stacking, packaging, etc. Shrink-wrapping helps retain moisture for extended hydration but might promote lime bloom.

7. Quality control

Control measures should be implemented to:

(a) Monitor changes in materials so that timely changes can be implemented in manufacture.
(b) Routinely monitor the quality of the product for compliance with the specification.

Measures under category **(a)** include:

- Regularly monitor changes in grading and moisture content of aggregates.
- Monitor mix consistence.
- Measure wet density of blocks (by weighing). Causes for a change in density must be investigated.

The more routine quality/compliance tests under category **(b)** include to be done in accordance with SANS 1058:

- Check on dimensions of blocks.
- Tensile splitting strength tests.
- Carry out abrasion tests at an appropriate age.
- Check on water absorption.

Appendix 1

Typical gradings for aggregate and cement combined

Sieve size mm	Cumulative percentage passing
9,5	100
6,7	85-100
4,75	75-100
2,36	60-80
1,18	48-65
0,60	38-55
0,30	30-45
0,15	27-40
0,075	23-35

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