Learning text part 03

MPA Mortar

Aggregates

Contents

Health and safety

All mortar mixtures, both wet and dry, are abrasive and alkaline. When working with wet mortar, waterproof or other suitable protective clothing should be worn. Guidance on the use of these materials can be found in MPA Mortar data sheet No. 20.

Introduction

This learning text covers the formation, specification and properties of the aggregates used in mortar. A glossary of terminology used and a bibliography are included while the final section contains self-assessment questions and answers. Sand - sometimes referred to as 'fine aggregate' - is the main constituent of masonry mortars and renders. Some screeds incorporate a coarse aggregate (normally 10mm maximum size) but generally sand is their major constituent.

Sand quality is affected by a number of factors:

- mean particle size
- grading
- presence of impurities
- shape
- texture.

As the main constituent of masonry mortars, renders and screeds, sand has a significant effect upon the properties of the product in both its fresh and hardened state. Selection of suitable aggregates, capable of producing a product with the optimum properties, is most important. Design of mortar mixes is based on the concept that the voids in the sand, which are generally in the range 25-40%, will be filled with binder. Where voids are not completely filled, there is an increasing risk that the mortar will not be durable. A later learning text in this series, part 6, Properties of masonry mortars, explains the importance of desirable properties of masonry mortar, which are influenced by the grading and consequent voids within the mix.

Rock formation

The earth is composed of rocks that have been formed over hundreds of millions of years. Its centre is a core of solid material, believed to be made up of nickel and iron. A number of layers, some composed of liquid material called magma, make up the structure of the earth with the outermost layer being called the crust. The earth's crust varies a great deal in thickness ranging from about 65km under mountains, to as little as 5km under some oceans. The crust is the source of rocks used by mankind.

Geologists divide rocks into three categories:

- Igneous rocks - derived from molten material, which originates from the layers below the earth's crust and is ejected by volcanoes. Some molten material solidifies before it reaches the earth's surface and that is the reason a range of igneous rocks exist, their properties being dependent on the rate of cooling as well as the chemical composition of the liquid magma. Igneous rocks include granite, diorite and basalt.
- Sedimentary rocks - the majority of these originate as accumulations of material, formed as a result of the transportation of solid particles eroded from preexisting rocks to the place where they are deposited as sediments. Other sedimentary rocks are formed from the accumulation of animal or vegetable remains. A third group is formed from the precipitation of materials carried in solution. Sedimentary rocks include limestone, sandstone and gritstone.
- Metamorphic rocks - metamorphism is the term used to describe the transformation of rocks into new structures and mineral compositions, as a result of the energy put into them by heat and/or pressure. When fine grained limestone is metamorphosed then the whole mass is recrystallised into marble, coloured bands in the material arising form the varying chemical compositions of the original limestone.
Metamorphic rocks also include slates and gneisses.

Aggregate processing

Sand and gravel

Sands and gravels are obtained by either a wet or dry extraction process.

In the wet process, the main types of equipment used are suction dredgers, floating cranes, floating grab dredgers and draglines. In the dry process the first step is removal of the topsoil or overburden, then a front-end loader or excavator digs out the material which is conveyed to the processing plant. Extracted material is washed in a scrubber at the processing plant to remove clay and silt particles and then screened into its constituent sizes. The fine material passes to a series of classifiers where a process of differential settlement allows various grades of sand to be produced. Material then passes to a dewatering system to allow the excess processing water to be removed.

An alternative to the washing and classification system is to dry screen the extracted material, leaving a product which will have a higher proportion of fine material which may be beneficial in the production of mortar.

Sands and gravels are normally rounded or irregular in shape. Increasingly some gravels are crushed to produce smaller particles with an angular shape similar to crushed rock.

Crushed rock

Crushed rocks are obtained from a quarry by drilling and blasting the bedrock. The rock is then transported to the processing plant where, after removal of the fine material, it is crushed and screened a number of times before arriving at its selected sizes. Due to the processing requirements, crushed stone is more expensive to produce than sands and gravels.

Marine dredged

Extraction of marine aggregates is a similar process to the wet process of sand and gravel extraction, except that the suction pump or dredger is located on a ship with a hold capacity of up to 5,000 tonnes. Marine aggregates are extracted from a number of locations around the UK coast. Material is off loaded at wharves and then processed, particular care being taken with washing and draining to reduce the chlorides that are present from seawater. Use of marine aggregates has increased as fewer reserves of land-based materials are available and planning permission for extraction becomes more difficult to obtain. Thus is particularly noticeable in areas such as London where there is good river access.

Grading of aggregates

Sands, gravels and crushed stone come in a variety of shapes and sizes and classification of these materials into approximate size fractions is called grading. Traditional terminology was to classify aggregates as belonging to one of three categories; all in aggregate; coarse aggregate and sand. These are defined below but it should be noted that the first two categories are not used in mortar production.

• All in aggregate: this is material composed of a mixture of coarse material and sand.

• Coarse aggregate: over 4mm material. This classification can be further divided into graded and single-size aggregates. A graded aggregate consists of particles of different sizes from the maximum down to the minimum.

• Sand: The European Standard uses the term fine aggregate in place of sand for material less than or equal to 4mm in size but the terms are interchangeable and the word 'sand' more commonly used.

The European Standard BS EN 13139 lists the preferred sizes of aggregates for mortar, these are: 0/1mm, 0/2mm, 0/4mm, 2/4mm and 2/8mm. (Where the first figure in each set represents d and the second D). A table within the standard prescribes for most of the preferred aggregate sizes; limits for percentages passing sieves with an aperture of:

2D referred to as oversize
1.4D referred to as oversize
D referred to as oversize
d. referred to as undersize (not specified for the 2/4 and the 2/8 sizes)
0.5d referred to as undersize (not specified for the 2/4 and the 2/8 sizes)

Aggregate producers have data on typical gradings and the tolerances that normally occur.

Sieve sizes in European standardisation have been divided into three sets - Basic, Set 1 and Set 2. Individual countries will adopt the basic set plus either set 1 or set 2. The UK has adopted the basic set and set 2 and therefore its sieve sizes are as shown in Table 1:

PD 6682-3 lists the sieves that are applicable to aggregates for use in mortars and screeds and these are shown in Table 2 opposite.

Sand particle shape can be important with excessive amounts of flaky or elongated particles sometimes proving problematic for the site operative. Resultant mortar may feel harsh and difficult to work on the trowel

0 0.063
1 0.125
2 0.250
4 0.500
6.3 (6) 1.00
8 2.00
10 2.8
12.5 (12) 6.3
14 8.0
16 10.0
20 14.0
31.5 (32) 16.00
40
63

Table 1: ***Basic set plus set 2***

0.063
0.125
0.250
0.500
1.00
2.00
2.8
6.3
8.0
10.0
14.0
16.00

Table 2: ***Sieve sizes applicable for aggregates for use in mortar and screed***

and joints may prove more difficult to finish. Similarly crushed material is more angular than naturally rounded material and again can be more difficult to work.

Lightweight aggregate

The European Standard for lightweight aggregate (BS EN 13055-1) specifies the properties and technical requirements for lightweight aggregates for mortar and concrete. The term 'lightweight aggregate' covers a wide range of materials, some of which are naturally occurring, others are by-products of industrial processes or processed natural materials. Testing of lightweight aggregate is similar to that undertaken for natural aggregates - chloride and sulfate content, loss on ignition and organic material. Sieve analysis determines particle size distribution and a table within the standard prescribes minimum test frequencies.

Impurities

European Standard BS EN 13139, Aggregates for mortar, incorporates a useful annex - Guidance on the effects of some chemical constituents of aggregates on the mortar in which they are incorporated. Small quantities of some impurities can have a significant effect on the properties of the mortar, render or screed and therefore their presence must be avoided if possible.

Silt, clay and fines

Fines (as opposed to fine aggregate) are defined in the European standard as material passing a 0.063mm sieve. It also prescribes different limits for fines content; the quantity that is permitted to pass the 0.063mm sieve depends on the aggregate size and the proposed end-use of the mortar. End-use applications are divided into four categories:

- Category 1: Floor screeds, sprayed repair mortar and grouts (all aggregates)
- Category 2: Rendering and plastering mortars (all aggregates)
- Category 3: Masonry mortars (all aggregates except crushed rock)
- Category 4: Masonry mortars (crushed rock)

The limits permitted to pass the 0.063mm sieve are:

- Category 1 - 3%
- Category 2 - 5%
- Category 3 - 8%
- Category 4 - 30% (except the 0/8 and the 2/8 aggregate sizes where the limit is 11%)

The standard states that where the fines limit exceeds 3%, but a history of satisfactory use exists, no further testing may be necessary. A greater proportion of fines are permitted for crushed rock, as the fine material resulting from the mechanical crushing of rock is not as likely to contain harmful materials such as clay.

There is a fifth category (category five), which is applicable only to the 0/1mm aggregate size. The producer is required to declare the percentage passing the 0.063mm sieve. In some instances, eg, marine dredged material, where there are no inherent fines, it may be beneficial to add filler aggregate (passing 0,063mm) to improve the workability and consistency.

Organic matter

Decaying vegetation may result in aggregates being contaminated with organic matter. This may have a retarding effect on the setting of cementitious material and may result in lower strengths of the hardened material at all ages. The presence of most harmful organic compounds can be detected by a simple test based on the use of sodium hydroxide. BS EN 1744-1 describes the test in Clause 15.1.

Chlorides

Chlorides present in aggregates may dissolve in the mixing water and promote corrosion of any embedded metal. They may also cause efflorescence, which is a white deposit that may form on the surface of brickwork. The rate at which mortar, render or screeds gain strength may also be affected. Annex D of BS EN 13139 recommends that the water-soluble chloride content of the aggregate does not exceed 0.15% for plain mortar and 0.06% for mortar with embedded metals, eg, wall ties or lathing support. The chloride content is determined in accordance with the method given in clause 7 of BS EN 1744-1.

Sulfates

Presence of sulfates can lead to the expansion of the mortar and the formation of unsightly deposits on the mortar surface. Their presence may be determined by the method given in clause 12 of BS EN 1744-1.

Iron pyrite

A form of ferrous sulfide may be present in some aggregates. This can react and oxidise to form iron hydroxide, which is brown in colour. Iron pyrites can cause staining and lead to pop-outs at the surface, a more visually apparent problem with screeds and rendering and plastering mortars.

Lignite and coal

Lignite and coal particles may cause brown stains and/or pop-outs to appear at the surface of the hardened material. Lignite particles can be a very serious problem if they are present in some screeds. They have a lower density than the mortar matrix and float to the surface and may pop out.

Shell content

Shell content is normally unimportant for sand, although site operative regional preferences may play a part in deciding the suitability of the material. Where screed mixes are to be produced using an aggregate size larger than 4 mm, the shell content may need to be determined. BS EN 12620 Aggregates for concrete including those for use in pavement, recommends a maximum limit of 10% for coarse aggregate.

Mica

Mica occurs as a by-product of china clay production. It has higher water demand for a given level of consistence and therefore may have an adverse affect on strength. However, mica sparkles and is welcomed by some construction professionals. Micaceous sands are mainly confined to the South West of England where it is widely used for mortar production.

Testing

Testing is the means by which the properties of a material are routinely evaluated and compared with the appropriate specification. The type of material in which the aggregate is going to be used may well lead to different specification requirements. Test results also provide a historic record of how the properties of a material vary with time.

The introduction of European standards has resulted in the revision of a number of traditional test methods and the introduction of some unfamiliar ones.

BS EN 932: Tests for general properties of aggregates

• BS EN 932- Part 1: Methods for sampling
The objective is to obtain a bulk sample that is representative of the average properties of the batch. Bulk samples can be reduced to portions suitable for testing by two principal methods - using a riffle box or by coning and quartering.
- Riffle box: There are several sizes of riffle box to suit different sizes of aggregate, one of which is illustrated in Figure 1. The box consists of an even number of chutes discharging in alternate directions. The material is passed through the riffle box, which divides it into two portions, one of which is discarded. The other portion is passed through again and the process repeated until the sample has been reduced to the required size. A riffle box can only be used on dry material.
- Coning and quartering: this method of sample reduction involves shoveling the bulk sample to form a cone, which is then turned over three times and flattened. The sample is then divided into four quarters and two of the diagonally opposite quarters discarded. The process of coning and quartering is repeated until the sample is reduced to the appropriate size for testing.

Figure 1: **A riffle box**

• BS EN 932- *Part 5: Common equipment and calibration.*

This part gives details of the common equipment required for aggregate testing and the required precision of the various items of equipment.

BS EN 933: Tests for geometrical properties of aggregates

BS EN 933 - *Part 1: Determination of particle size distribution - Sieving method*
Sieving is a method of dividing up a material into size fractions by passing it through sieves with decreasing apertures. The quantity of material on each sieve is measured making it possible to calculate a particle size distribution (grading) for the sample. Results of a sieve analysis are frequently plotted on a log scale to produce a particle size distribution chart (or computer printout). The range of gradings that are acceptable for a particular application are referred to as a grading envelope. Figure 2 shows a selection of sieves.

The term particle size distribution is sometimes used instead of grading

Figure 2: ***Grading sieves***

Two tests prescribed in the test method series BS EN 933, those for sand equivalence and methylene blue absorption, have not been fully accepted in the UK. PD 6682-3 states "these tests are not considered sufficiently precise for determining harmful fines content in sand for mortar in the United Kingdom". Nevertheless, these two tests are outlined in the following sections.

• BS EN 933- *Part 8: Assessment of fines - Sand equivalent test*

This is a rapid test to determine the proportion of clay or plastic fines in the 0/2mm fraction of a sand. A small quantity of flocculating solution and a measured volume of oven-dried sand are poured into a measuring cylinder. Agitation loosens the clay-like coatings from the coarser particles, then irrigation with additional flocculating agent forces the clay-like material into suspension above the sand. The sample is allowed to settle for a twenty-minute period and the heights of the columns of clay and sand measured. The sand equivalent is reported as the ratio of the height of the sediment expressed as a percentage of the total height. This test is very similar to the field settling test used for concrete aggregates, the difference between the two tests being the composition of the flocculating agent.

• BS EN 933 - *Part 9: Assessment of fines – Methylene blue test*

This test is used to assess the quantity of potentially harmful fines in sands and is undertaken by adding methylene blue dye to a sample in suspension and measuring the quantity of dye absorbed. The principle of the test is that clay minerals adsorb basic dyes from aqueous solutions, therefore the greater the quantity of dye absorbed, the greater the quantity of potentially harmful fines present.

• BS EN 1097-6 *Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption.*

This part of the standard describes two methods for determining particle density and water absorption. For coarse aggregates a method that requires the use of a wire basket is specified and for sand a method that uses a pyknometer - a glass jar with a tightly fitting stopper. The water absorption of a sample is the increase in mass of an oven-dry sample when it is immersed in water. The greater the volume of voids in the sample, the easier it is for water to penetrate it and hence the higher the water absorption. The particle density of a sample is determined by calculating its mass and dividing this by the volume the sample occupies.

BS EN 1744-1 *Tests for chemical properties of aggregates – Part 1: Chemical analysis.*

• Water soluble chloride: three methods are given for the determination of water soluble chloride. The reference method is titration with silver nitrate solution (Volhard method).
• Acid soluble sulfate: this involves dissolving a crushed sample in hydrochloric acid and precipitating the sulfate as barium sulfate. The precipitate is then filtered and ignited in a muffle furnace and the remaining mass weighed.
• Organic compounds: a 3% solution of sodium hydroxide is poured into a glass bottle to a height of 80mm. A sample of the material being tested, which all passes a 4 mm sieve, is poured in until the height of the solution is 120mm. The stopper is placed in the bottle and it is vigorously shaken and then allowed to stand for twenty-four hours. The solution's colour is then compared to a standard colour solution. A rule of thumb is that if the test solution is clear, no harmful organic materials are present. If it is the colour of a beer shandy, small quantities are present. Where the solution is the colour of a bitter beer the material is heavily contaminated. Where coloration of the test sample occurs more precise tests have to be undertaken.
• Loss on ignition: a sample, which has been dried at approximately 100˚C, is weighed into a tared crucible and placed into an electric muffle furnace at a temperature of 975oC for a minimum period of an hour. The sample is then removed and allowed to cool, then reweighed. The loss in mass is expressed as a percentage of the original mass and reported as the loss on ignition.

A table within Annex E of BS EN 13139 prescribes minimum test frequencies for the various properties and the appropriate test method.

The following two tests are for concrete and screed applications only but are included for completeness.

Figure 3: ***Sieves used for the determination of flakiness index***

• BS EN 933 - *Part 3: Determination of particle shape - Flakiness index*

Flakiness index is not applicable to particle sizes less than 4mm. To determine a sample's flakiness index, it is first reduced into a number of size fractions, for example passing 10mm retained on 8mm or passing 6.3mm retained on 5mm. The individual size fractions are then sieved on special sieves, (see Figure 3) the aperture of these is the larger of the two size fractions (D) divided by two (eg, for the 8-10mm size the aperture of the flakiness sieves would be 5.0mm). Flakiness is therefore a measure of particles, which are approximately half the nominal size in thickness.

The flakiness index is arrived at by calculating the percentage in mass of the total sample, which pass the appropriate sieve flakiness sieves.

• BS EN 933-7 *Part 7: Determination of shell content - Percentage of shells in coarse aggregate*
This test involves sorting by hand the number of particles of shell in a given sample and expressing the mass as a percentage of the total sample.

Handling and storage

Where aggregates are not stored in overhead bins, they should be stored on clean hard bases that permit free drainage. Care must be taken that cross contamination between different sized materials does not take place. It is good practice not to store sand which is to be used in mortar production next to coarse aggregate.

Attention should be given to potential contamination from overhanging trees, especially when the material is stored for extended periods. During cold weather it is advisable to cover sand stockpiles to prevent the material from freezing, especially if it is intended to use is in the early hours of the morning when any ice particles will not have melted.

European standards

Historically, the specification for aggregates for use in mortars, screeds and renders was covered by a number of British Standards. These have been superseded by the European standard BS EN 13139. British Standards Institution has also published

PD 6682-3, *Aggregates Part 3: Aggregates for mortar- Guidance on the use of BS EN 13139.*

This published document (PD) provides amplification on the standard requirements and a comparison of the grading requirements and other properties against the superseded British Standard.

Glossary of Terms

The definitions in this learning text are based on those given in BS EN 13139 and BS EN 13055-1. If taken from a different source this is indicated.

Aggregate
Granular material used in construction. Aggregate may be natural, manufactured or recycled.

Aggregate size
Description of aggregate in terms of lower (d) and upper (D) sieve sizes (see text).

Coarse aggregate
Designation given to the larger aggregate sizes with D greater or equal to 4mm and d greater than or equal to 2mm.

Fine aggregate
Designation given to the smaller aggregate sizes with D less than or equal to 4mm.
Filler aggregate Aggregate, most of which passes a 0.063mm sieve, which can be added to construction materials to provide certain properties.

Fines
Particle size fraction of an aggregate which passes the 0.063mm sieve.

Grading
Particle sized distribution expressed as the percentage by mass passing a specified set of sieves.

Lightweight aggregates
An aggregate of mineral origin having a particle density not exceeding 2,00 Mg/m^3 (2000 kg/m^3) or a loose bulk density not exceeding 1,20 Mg/m^3 (1200 kg/m^3).

Manufactured aggregate
Aggregate of mineral origin resulting from an industrial process involving thermal or other modification.

Natural aggregate
Aggregate from mineral sources which has been subjected to nothing more than mechanical processing.

Oversize
That part of the aggregate retained on the larger of the limiting sieves used in the aggregate size description.

Popout
The expansion of a porous aggregate particle due to freezing that separates from the concrete, mortar or screed taking a portion of the surface mortar with it leaving a conical shaped hole. (Physical action)

Note: Pop-outs may also be caused by alkali silica reaction (Chemical action).

Undersize
That part of the aggregate passing the smaller of the limiting sieves used in the size aggregate description.

Bibliography

BS EN 932 - 1:1997 Tests for general properties of aggregates - Part 1: Methods for sampling.

BS EN 932 - 5: 2000 Tests for general properties of aggregates - Part 5: Common equipment and calibration.

BS EN 933 - 1: 1997 Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method.

BS EN 933 - 3: 1997 Tests for geometrical properties of aggregates - Part 3: Determination of particle shape - Flakiness index.

BS EN 933 - 7: 1998 Tests for geometrical properties of aggregates - Part 7: Determination of shell content - Percentage of shells in coarse aggregates.

BS EN 933 - 8: 1999 Tests for geometrical properties of aggregates - Part 8: Assessment of fines. Sand equivalent test.

BS EN 933 - 9: 1999 Tests for geometrical properties of aggregates - Part 9: Assessment of fines. Methylene-blue test.

BS EN 1097- 6:2000 Tests for mechanical and physical properties of aggregates Part 6: Determination of particle density and water absorption.

BS EN 1744-1:1998 Tests for chemical properties of aggregates- Part 1: Chemical analysis

BS EN 12620: 2002 Aggregates for concrete including those for use in pavements.

BS EN 13055 -1: 2002 Lightweight aggregates - Part 1: Lightweight aggregates for concrete, mortar and grout.

BS EN 13139: 2002 Aggregates for Mortar.

PD 6682 - 3: 2003 Aggregates for mortar - Guidance on the use of BS EN 13139.

BS 8204 - 1: 2003 Screeds, bases and in-situ floorings: Part: 1: Concrete bases and cement sand levelling screeds to receive floorings. Code of practice

Self-assessment questions

1 Below what sieve size is material classified as fines?

A ______

2 Which European standard is concerned with the specification of natural aggregates for use in mortars?

A ______

3 Which two impurities within an aggregate may cause staining and pop-outs?

A ______

4 What are the three categories of rock?

A ______

5 What is the recommended limit for fines in rendering and plastering mortars?

A ______

6 How is the size of an aggregate designated in the European standard?

A ______

______

7 What are the two principal effects of organic impurities in fine aggregate?

A ______

8 What does the methylene blue test measure?

A ______

9 What are the two methods for reducing bulk samples?

A ______

10 What is the typical range of voidage in a fine aggregate that has to be filled with cementitious binder to make a satisfactory mortar?

A ______

Answers to self-assessment questions

1 0.063 mm (63µm).
2 BS EN 13139 - Aggregates for Mortar.
3 Lignite, iron pyrite.
4 Igneous, sedimentary, metamorphic.
5 5%.
6 A pair of sieves designates the size of an aggregate (where the size is given in millimetres) with d as the lower limit designation and D as the upper limit designation.
7 An increase in setting time and a decrease in compressive strength.
8 The presence of clay minerals in fine aggregate.
9 A riffle box, coning and quartering.
10 25-40%.

MPA Mortar Learning Texts include:

1 Introduction to modern mortars
2 Cementitious materials
3 Aggregates
4 Admixtures, additives and water
5 Brick and block production
6 Properties of masonry mortar
7 Production, deleivery and storage of mortar
8 Mortar testing
9 Specifications
10 Quality assurance
11 Construction
12 Properties of rendering mortar
13 Best practice - potential site problems

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