Kent Minerals and Waste Local Plan

Planning for the future of minerals and waste in Kent

Evidence Base for the Draft Minerals and Waste Plan

Interchangeability of Construction Aggregates

September 2013

Kent County Council

Front Cover Images

Top left: Storm Beach Gravel 10mm, Dungeness

Top right: Crushed Ragstone 10mm, Maidstone

Bottom left: Recycled River Gravel (Flint) 10mm

Bottom right: Fine Aggregate (Concrete/Sharp Sand), Lydd

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i Abbreviations

AAR	Alkali Aggregate Reaction
AOD (aod)	Above Ordnance Datum
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
BS	British Standard
BU	Boughton Unit
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
EN	European Standard
ESO	European Standardisation Organisations
ETSI	See CENELEC
HU	Hermitage Unit
m	metre
mm	millimetre
m^2	square metre
m^3	cubic metre
μm	micron (one millionth of a metre)
MCHW	Manual of Contract Documents for Highway Works
MMO	Marine Management Organisation
MPA	Marine Protected Area
Mtonnes/mt	Million tonnes
MWLP	Minerals and Waste Local Plan
mya	Million years ago
PD	Published Document
PFA	Pulverised Fuel Ash
SBJU	Sub Black Jack Unit

UK	United Kingdom

1 Introduction

1.1 Background

1.1.1 The diversity of rocks that occur within the County of Kent has provided a wide range of economic minerals for exploitation. These minerals have been utilised over the centuries and have contributed to the wealth and environment of the County. Within this diversity, this paper examines how these differing mineral horizons contribute to the construction aggregate needs of the County.

1.1.2 This report is part of the evidence base for the preparation of the Kent Minerals and Waste Local Plan (MWLP). It updates an earlier report published in March 2006 on the interchangeability of all widely available construction aggregates in Kent. The earlier report concentrated solely on ragstone but this report looks at interchangeability issues for all construction aggregates available in Kent.

1.1.3 This report will consider indigenous aggregates such as building sand, sand and gravel, ragstone, locally recycled aggregates, imported aggregates (crushed rock, marine dredged sand and gravel) and industrial by-products (slag, power station ash, colliery waste, cement-stabilised minestone).

1.2 Material selection

1.2.1 Construction aggregates comprise a wide range of materials of differing mineralogy. The diversity of chemical composition, the hardness of the different types of raw material, the reactivity/stability of the materials in use and the consistency of the resource are all pertinent issues when analysing and deciding what makes a good aggregate. Construction aggregates must provide a consistent quality that enables the end user to be confident that the product being chosen will do the job it is being chosen to do. To this end, a wide range of testing standards have been devised to assist the construction industry in deciding which are the best aggregates to undertake a particular function.

1.2.2 In the United Kingdom British Standards (BS) have been devised to test aggregates to ascertain their suitability to do the function for which they are being chosen. A European Standard (EN) is a standard that has been adopted by one of the three recognised European Standardisation Organisations (ESO): European Committee for Standardisation (CEN), European Committee for Electrotechnical Standardisation (CENELEC) or European Telecommunications Standards Institute (ETSI). It is produced by all interested parties through a transparent, open and consensus based process. These standards are numbered according to the European Code but the standards are produced by national bodies. Hence the British Standards Institute produces codes for the United Kingdom that are compatible with similar national bodies within the European Union. These standards normally begin with the letters BS EN followed by a unique number and title, for example: *BS EN 933-1: Tests for geometrical properties of aggregates: Part 1: Determination of particle size distribution - Sieving method*. This system enables all materials to be tested against a standard test to identify those materials best suited to that end use. A list of some of the British Standard tests used for testing aggregates may be seen in Appendix 1. These tests are relevant to the properties required for making concrete. Other tests exist for the preparation of coated materials used in the construction of roads.

1.3 Comparative properties of aggregate

1.3.1 The comparative properties of rocks include physical properties, mechanical properties and chemical properties. These properties have been chosen to enable the rocks and minerals best suited to be used as construction aggregates. A list of these properties and their purpose is described in Appendix 2.

2 Construction aggregates

2.1 Introduction and definitions

2.1.1 Construction aggregate is a broad category of coarse particulate matter used in construction. Coarse particulate matter was originally defined in the Wentworth Scale of particle size and is generally regarded as being greater than 0.062 mm and described as sand, gravel, pebbles, cobbles and boulders in increasing magnitude[(1)]. Fine particulate matter is everything smaller than 0.062mm and is referred to as silt or clay and should not be confused with the term fine aggregate, which refers to the finer elements of construction aggregates (i.e. sand sized particles). Table 1 below provides some examples of typical construction aggregates.

Table 1 - Examples of typical construction aggregates

	Coarse Aggregate 20mm single size Source: Storm Gravel Beach Deposits

1 See Appendix 4: Classification of particle size including the Wentworth Scale

Coarse Aggregate 10mm single size Source: Crushed Rock, Ragstone Hythe Beds	
	Fine Aggregate Concreting Sand Source: Storm Gravel Beach Deposits
Fine Aggregate Building Sand Source: Folkestone Beds	

	Blended Aggregate Ballast/20mm All In Source: Storm Gravel Beach Deposits
Rock/Building Stone Armour Stone Source: Ragstone Hythe Beds	
	Recycled Aggregate MOT Type 1 Source: Road Planings

Note: A 50 pence coin is approximately 27 mm across its widest point.

2.1.2 Construction aggregate is obtained from a variety of sources and a considerable range of materials. It is generally broken into two elements:- coarse aggregate and fine aggregate.

2.1.3 Coarse Aggregate

Coarse aggregate is generally greater than 4 mm in size and is subdivided and categorised further on size. The most common sizes of aggregate used in construction are, in decreasing size, 40mm, 20mm and 10mm.

2.1.4 Fine Aggregate

Fine aggregate tends to be finer than 4 mm but coarser than 0.062 mm and is often referred to as 'sand'. Fine aggregate is also restricted on the amount of silt and clay size particles that may be present, i.e. passing a 0.063 mm sieve (63 micron (µm)); this is a change from the old British Standards, which defined fines as material passing a 75 µm sieve.

Considerable research has gone into the effect of fines passing the 63µm sieve on the strength of concrete. The content of this -63µm fraction can be further subdivided into silt and clay fractions. It is the mineralogy of these two fractions that may be critical to the final strength of the concrete. Chemical analyses of the silt element of this fraction has shown that its mineralogy can reflect the mineralogy of the coarse and the fine aggregate and therefore would not necessarily be detrimental to the strength of the concrete or mortar. In some circumstances it may even be advantageous to the strength or appearance of the final product.

Natural sands and gravels may be prone to the presence of clay particles and this can be detrimental to the strength of concrete for several reasons, so current standards aim to eliminate this -63µm fraction from the product by minimising the amount of clay mineral present in the sand. However the sand manufactured from crushing rock is less likely to contain detrimental clay minerals and research has shown that fine aggregates produced by crushing rock may contain a greater quantity of the -63µm fraction and still be fit for purpose.

The content of silt in mortar sands, for example, is specified as follows[(2)]:

The European Standard prescribes different limits for fines content; the quantity that is permitted to pass the 0.063 mm 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 0.063 mm sieve are:

2 CEMEX Experts in Mortar Educational Guide to Aggregates

- 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 standards 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.

2.1.5 Primary Aggregate

Primary aggregates are those obtained from naturally occurring rocks. These aggregates may be obtained from all three of the major rock classifications:

- Igneous
- Sedimentary
- Metamorphic

Igneous rocks commonly quarried for aggregate are granite, basalt and diorite, sedimentary rocks include limestone, sandstone and sand and gravel whilst metamorphic rocks include gneiss and quartzite.

2.1.6 Secondary Aggregate

Secondary aggregates are derived from processes that produce a by-product that has the properties that make it suitable for use as a construction aggregate. Examples of secondary aggregate are rocks produced as a by-product of a mining operation such as colliery shale from coal mining and china clay sand from the production of kaolin, or as a ‘waste’ from metal refining such as slag and the ash residue from burning coal for power generation.

2.1.7 Recycled Aggregate

Recycled aggregates are primary, secondary or recycled aggregates that have been previously used as an aggregate and have subsequently been reclaimed during the redevelopment of land. Recycled aggregates arise from construction and demolition (concrete, bricks, tiles), highway maintenance (asphalt planings), excavation and utility operations.

The sole criterion for the use of all aggregate is that it is or may be made fit for purpose.

2.2 Local resources

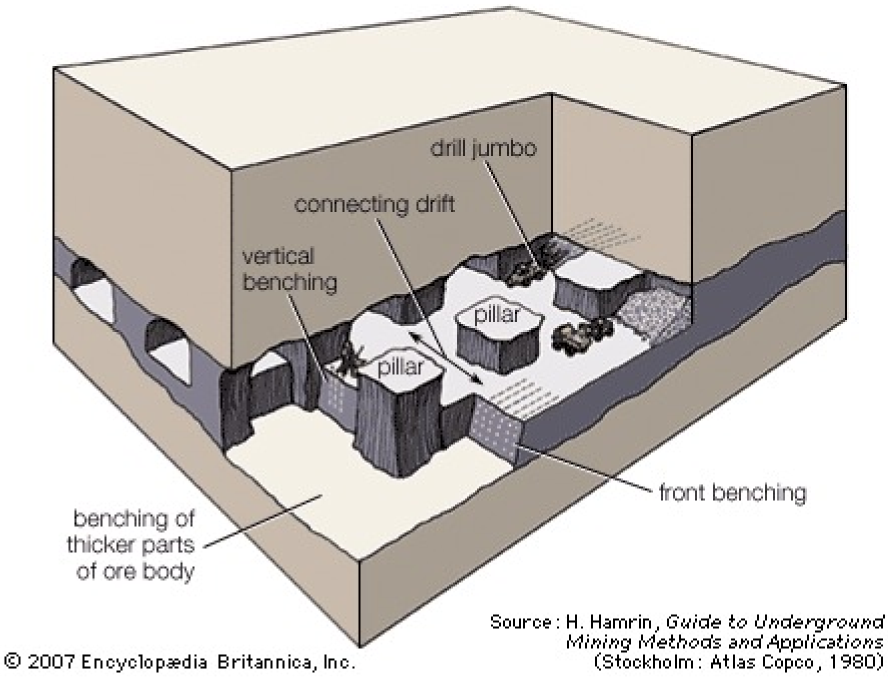
2.2.1 In Kent, construction aggregates are obtained from the Storm Gravel Beach Deposits in the Dungeness/Romney Marsh area, river terrace gravels in the Stour, Darenth and Medway valleys. Building sand is supplied principally from the Folkestone Beds but with supplementation from the Thanet and Oldhaven & Woolwich Beds and crushed rock from the ragstone layers in the Hythe Beds, principally from the Maidstone area.

2.2.2 In the future, there is the potential for deep mined Carboniferous limestone and Pennant sandstone in East Kent.

2.2.3 In considering the sustainable use of the local construction aggregate resources, maximising the use of recycled, secondary and substitute aggregates reduces the need to extract primary aggregates and therefore extends the life of these resources for future generations.

2.2.4 Another factor that may aid sustainability is the quantity of primary aggregate that may be obtained from a given surface area of land. For example, in Kent, the quantity of ragstone, which may be won from a hectare of land may be 500,000 tonnes, storm gravel beach deposits between 80,000 and 180,000 tonnes/hectare whilst a typical river terrace gravel may yield 30,000 tonnes/hectare. If a Carboniferous limestone mine were to be developed yields of 1 million. tonnes/hectare plus could be extracted even with only 40% of the limestone being mined utilising a bord and pillar technique of extraction (Figure 1).

Figure 1 - Bord and pillar extraction technique



2.2.5 Therefore, where deposits are thicker, the yield per hectare increases. This means that less land is required to maintain supplies of aggregate and thereby the size of new areas of land required for quarrying is reduced.

2.2.6 These indigenous deposits are supplemented by marine dredged sand and gravel from the North Sea and English Channel and imported crushed rock, such as granite, gritstone and limestone, transported into the County by rail and sea. In addition there are also supplies of local slag and ash and colliery minestone as well as imported slag and ash.

2.3 Sand and gravel deposits

2.3.1 Sand and gravel deposits are sedimentary in nature and are referred to as coarse, rudaceous deposits that are either loose or indurated. Indurated deposits are also referred to as conglomerates or breccias[(3)]. The difference between conglomerates and breccias is the former tend to be formed of rounded fragments whilst the latter contain angular to sub-angular fragments.

2.3.2 In Kent the sand and gravel deposits are of the loose variety that have been deposited either as river gravels along ancient river valley floors or as a result of wave action along the coast of the County.

2.3.3 There are three different forms that have been exploited in Kent:

- Storm Beach Gravels
- Flint Gravels
- Sandstone gravels

2.3.4 The storm beach gravels make up the Dungeness peninsula. These deposits are some of the youngest sedimentary deposits in the County having been laid down in the last 5,000 years. It has been established that the Dungeness Foreland itself formed within the last 1,000 to 500 years. The erosional and depositional forces that have created the Dungeness Foreland are still active today and will continue to formulate the shape of the coast into the future.

2.3.5 The Storm Beach Gravels of Dungeness contain a high gravel to sand content with 95% of the gravel being flint, derived from the eroded chalk cliffs to the south west and north east of the area.

2.3.6 River terrace gravels have been a much extracted source of aggregate. They are one of the most widely used local aggregate types in south-east England to the major markets. In Kent two forms of river gravel have been extracted, flint gravel and sandstone gravel.

3 See Appendix 3: Glossary

2.3.7 The flint gravels occur in the areas where the rivers have developed valleys through the chalk escarpment and beyond whilst the sandstone gravels occur in the Weald vale and have been derived from the erosion of the Wealden sandstones.

2.3.8 Flint is a very hard and relatively inert mineral, which makes it an ideal medium for use as an aggregate and particularly in concrete.

2.3.9 The sandstone gravels, as the name suggests, are the degraded fragments of the Wealden sandstones, the coarse aggregate is not as durable as flint gravel and the aggregate has a tendency to degrade into the discrete sand particles that make up the gravel particles, consequently there are limitations in its use as an aggregate.

2.3.10 The sand associated with the gravel is generally coarse in nature and is often referred to as sharp sand unlike building sand (see below). This sand may also be referred to as concreting sand.

2.4 Marine dredged aggregates

2.4.1 Marine dredged aggregates are derived from the seas around the United Kingdom. These deposits within the coastal waters of the United Kingdom are owned by the Crown Estates and licences are granted by the Marine Management Organisation (MMO) to extract these minerals.

2.4.2 Marine dredged aggregate is a form of sedimentary rock that is derived from the erosion of other rocks. Therefore the type of aggregate will vary according to the original source material of the deposit. These source rocks may be igneous, sedimentary or metamorphic in nature or a mixture of two or all three types

2.4.3 Kent receives its supply of dredged materials from the southern North Sea off East Anglia, Thames Estuary and from areas off the south coast in the English Channel. In the main these deposits tend to be flint gravels and sand but the quantities of sand and coarse aggregate may vary from licence to licence. The wharves are often supplied from different locations to maintain a balanced supply of fine and coarse aggregate.

2.4.4 Figures 2 to 5 taken from the Crown Estates website[(4)] identify the licenced areas from which Kent receives its marine dredged material.

4 See http://www.thecrownestate.co.uk/media/215377/aggs_ten_year_review.pdf

Figure 2 - East Coast Region

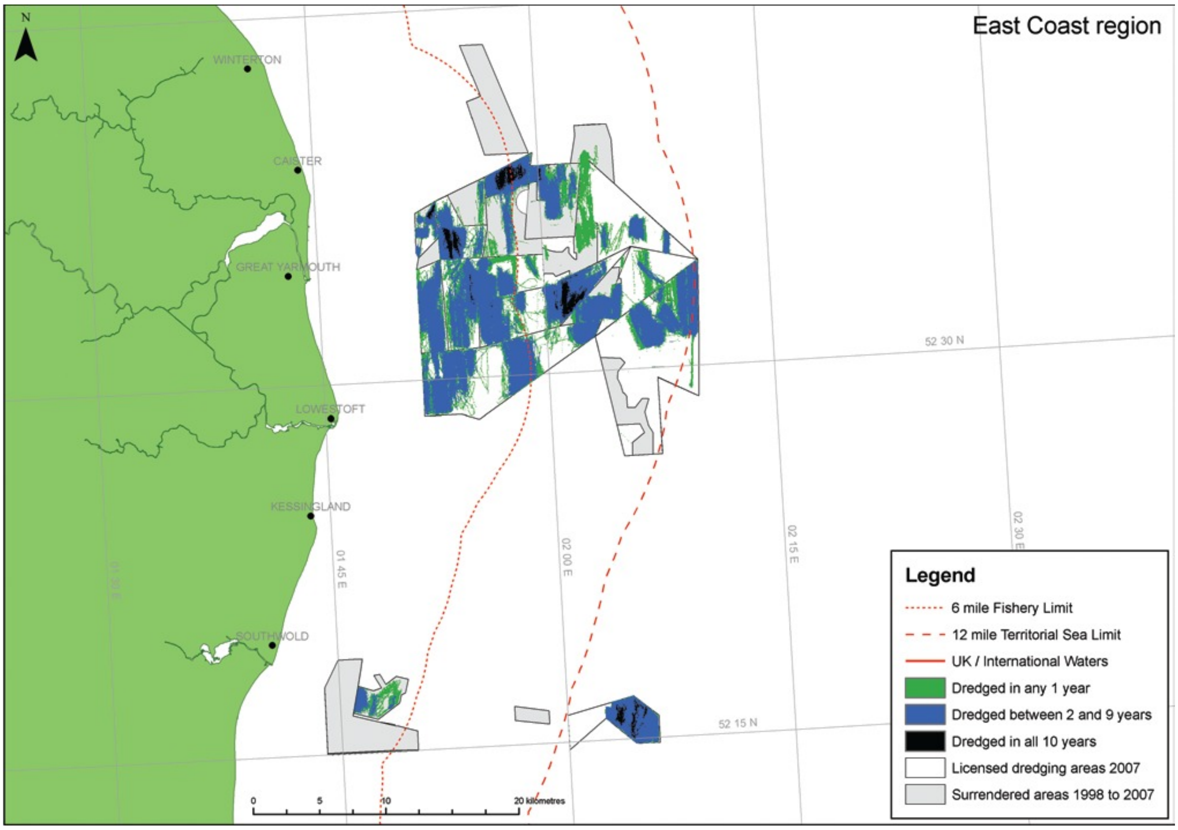


Figure 3 - Thames Estuary Region

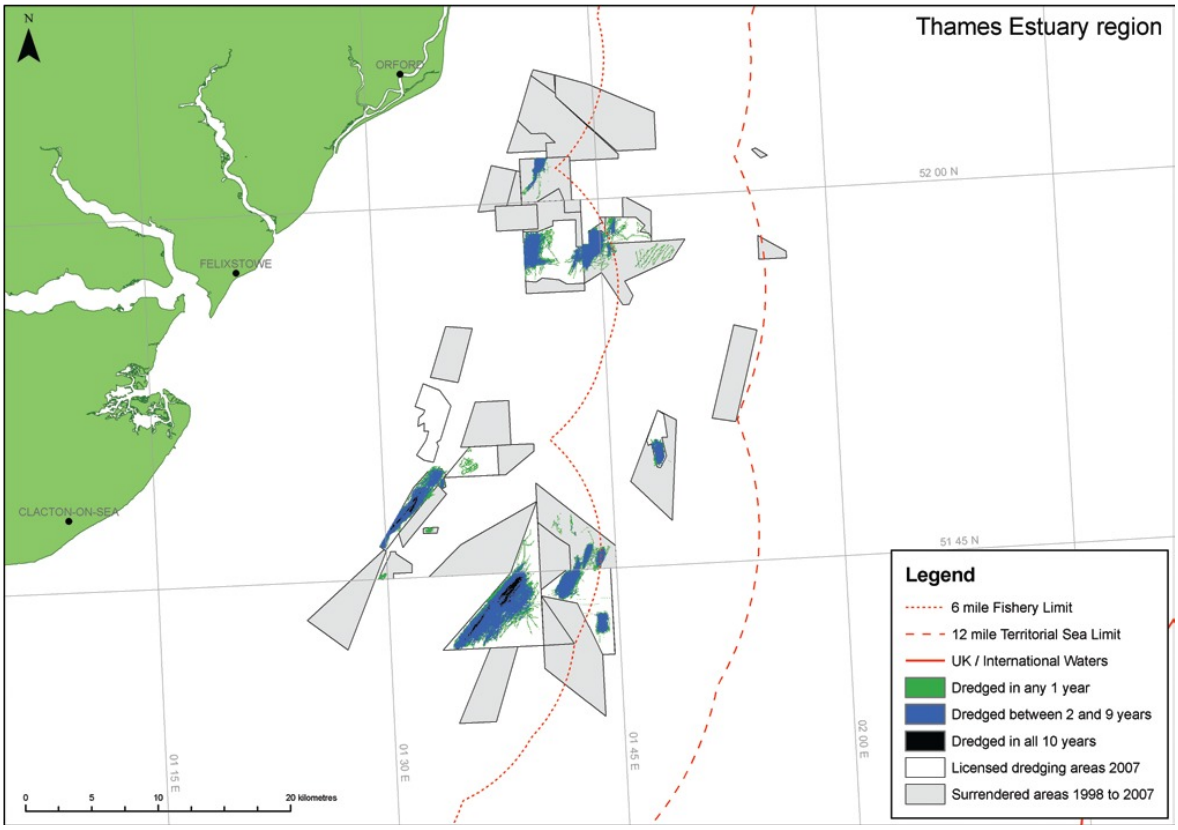


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Figure 4 - East English Channel Region

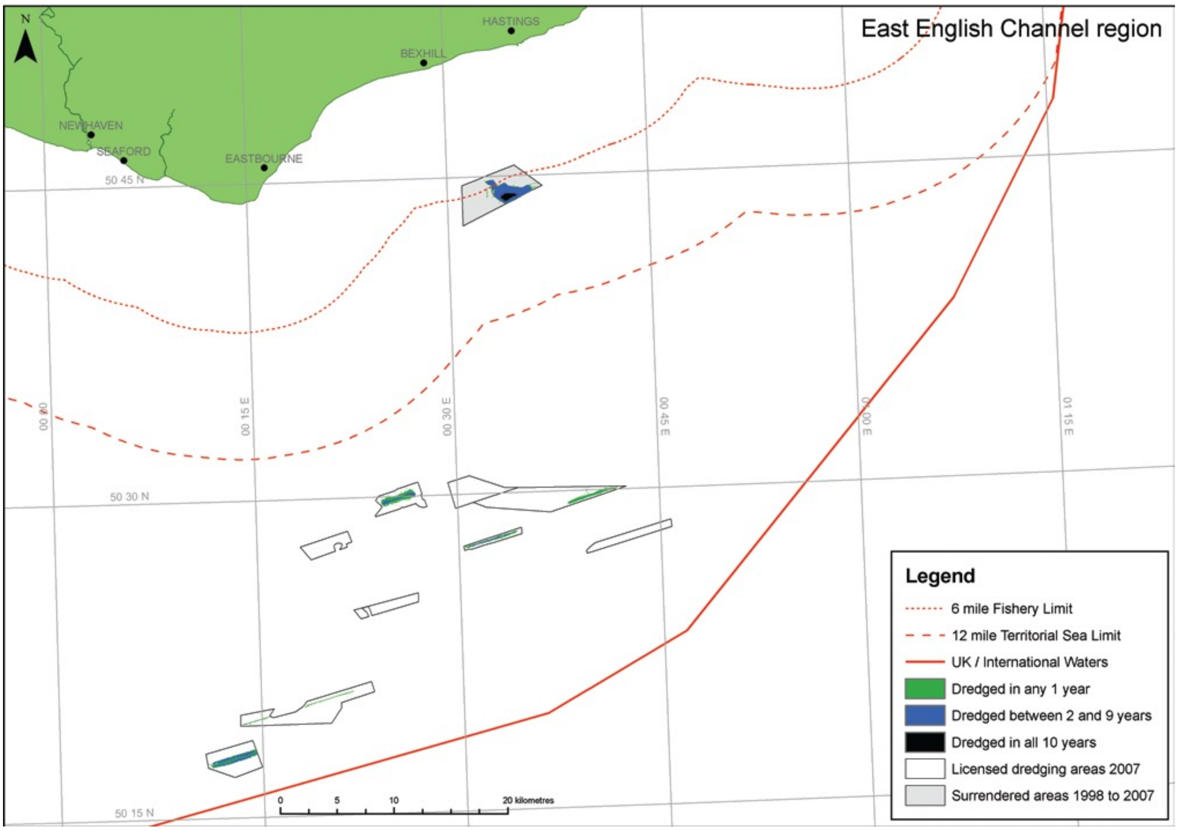


Figure 5 - South Coast Region

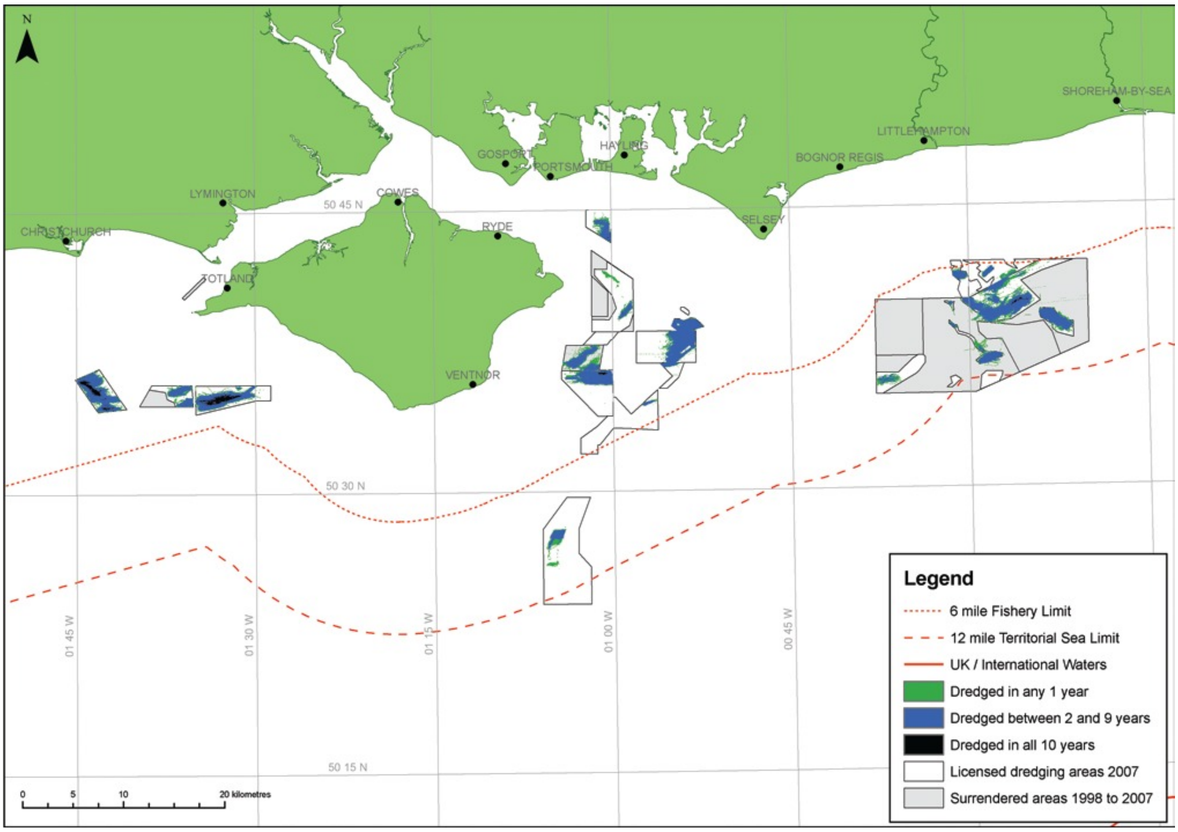


Figure 6 - Discharging marine dredged sand and gravel from a dredger

2.4.5 The sand and gravel is collected from the seabed by specially designed ships with powerful suction pumps that draw the sand and gravel up pipes mixed with seawater. Once in the ship's hold the seawater is separated off and returned to the sea. The dredgers that operate in and out of Kent Wharves vary in size between 4,000 and 10,200 tonnes capacity. This variation in dredger size reflects the variation in the depth of water, tides and size of the wharves around the coast of Kent.

2.4.6 Once landed, the sand and gravel is processed in a similar way to land won sand and gravel.

2.4.7 The preparation of inshore and offshore marine plans is being developed by the Marine Management Organisation[5], an independent body tasked by Government to deliver statutory marine plans in the areas that make up English inshore and offshore areas. This is a new concept to manage the inshore and offshore marine environment. It will balance the development of the marine environment with the marine protected areas. Marine protected areas include heritage sites and marine habitats. Other designations include marine conservation zones, which are a new type of Marine Protected Area (MPA) brought in under the UK Marine Act[6]. Marine Conservation Zones will form a key part of the UK MPA network.

5 Decision on first marine plan areas October 2010, Marine Management Organisation
6 UK Marine and Coastal Access Act 2009

2.5 Crushed rock

2.5.1 Crushed rock is derived from geological horizons where the source rock generally has to be blasted from the ground. Typical geological horizons for aggregate production are granite, diorite, and basalt though most crystalline igneous rocks can produce an acceptable aggregate. Common sedimentary rocks used for aggregate are limestone, gritstone and sandstone whilst metamorphic rocks such as marble, hornfels, quartzite, gneiss and granulite are exploited for the purpose.

2.5.2 Crushed rock quarries are more likely to be developed in deposits with extensive reserves. The largest reserves tend to be associated with large igneous intrusions, for example, the Glensanda Quarry owned by Aggregate Industries on the shores of Loch Linnhe in Scotland is quoted in company literature as having reserves in excess of 800 million tonnes of aggregate. This site is one of the quarries that supply the Isle of Grain importation wharf in Medway Authority. The ships that deliver to this wharf may carry up to 97,000 tonnes of aggregate at a time and self discharge at rates of 6,000 tonnes per hour. This particular wharf operates as a hub redistributing the aggregate in smaller ships to other ports and river wharfs in London and Kent, by rail into London and Kent and locally by road. Other sources of crushed rock imported by sea come from Ireland and Norway.

2.5.3 Crushed rock aggregate also imported to the south east are Carboniferous limestone from the Mendip Hills in Somerset and igneous deposits located in Leicestershire. These materials are imported by train to strategically located rail depots in Kent.

2.5.4 In Kent the only indigenous source of crushed rock currently extracted is ragstone from the Hythe Formation. It was originally worked as a building stone that supplied large areas of south east England including London and Essex. It has been used in some of the iconic buildings of London and Kent including the Tower of London, Canterbury and Rochester Cathedrals, Rochester Castle and the Archbishops' Palace in Maidstone.

2.5.5 Its durability was recognised in the 20th Century by industry as a good local supply for the crushed stone aggregate market.

2.5.6 Ragstone was one of the materials that figured in the development of mechanical testing of aggregates by Lovegrove *et al*. Edwin J Lovegrove was a pioneer in the testing of aggregates in the early part of the 20th Century and his test results on ragstone are referred to in the Geological Survey Memoir for the Maidstone Area (1963)[7].

2.6 Secondary aggregates

2.6.1 Secondary aggregates are generally the by-products of other industrial activities (Figure 7 overleaf). Types of secondary aggregates used in Kent are colliery shale/minestone, slag and power station ash (PFA).

7 Geological Survey of Great Britain Geology of the Country around Maidstone (1963), B.C. Worssham

Figure 7 - Specification for Highway Works (MCHW 1) Application of Secondary and Recycled Aggregates

Application and Series ► / Material ▼	Pipe Bedding	Embankment and Fill	Capping	Unbound Mixtures for Sub-base	Hydraulically Bound Mixtures for Sub-base and base	Bitumen bound Layers	Pavement Quality Concrete
Blast furnace slag	☑	☑	☑	☑	☑	☑	☑
Burnt Colliery Spoil	X	☑	☑	☑	☑	X	X
China Clay Sand/Stent	☑	☑	☑	☑	☑	☑	☑
Coal Fly Ash/Pulverised Fuel Ash (CFA/PFA)	☑	☑	☑	X	☑	☑	☑
Foundry Sand	☑	☑	☑	☑	☑	☑	☑
Furnace Bottom Ash (FBA)	☑	☑	☑	X	☑	X	X
Incinerator Bottom Ash Aggregate (IBAA)	☑	☑	☑	☑	☑	☑	☑
Phosphatic Slag	☑	☑	☑	☑	☑	☑	☑
Recycled Aggregate	☑	☑	☑	☑	☑	☑	☑
Recycled Asphalt	☑	☑	☑	☑	☑	☑	☑
Recycled Concrete	☑	☑	☑	☑	☑	☑	☑
Recycled Glass	☑	☑	☑	☑	☑	☑	X
Slate Aggregate	☑	☑	☑	☑	☑	☑	☑
Spent Oil Shale/Blaise	X	☑	☑	☑	☑	X	X
Steel Slag	☑	☑	☑	☑	☑	☑	X
Unburnt Colliery Shale	X	☑	X	X	☑	X	X

Key	
☑	Specific (permitted as a constituent if the material complies with the Specification (MCHW 1) or General Provision (permitted as a constituent if the material complies with the specification (MCHW 1) requirements but not named in the Specification (MCHW 1))
X	Not permitted

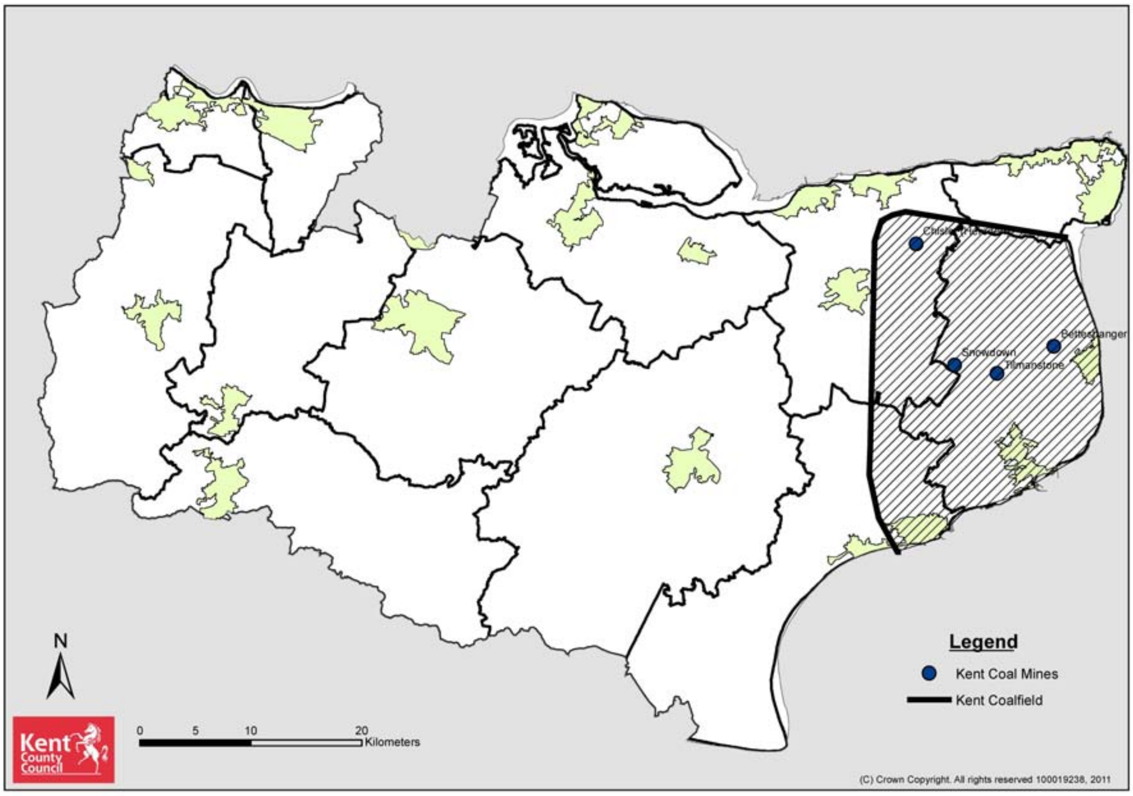
Source: Design Manual for Roads and Bridges Volume 7 Pavement Design and Maintenance

2.6.2 Colliery Shale/Minestone

In the mining industry whether opencast or underground stone is produced that is not the main mineral sought in the process. For example, when mining for coal, large quantities of colliery shale are produced that are necessarily tipped in areas adjacent to the mine. In some cases these tips have been landscaped and provide a new feature in the landscape. In Kent the four main coal mines all had associated shale tips. In the case of Betteshangar the tip has been landscaped into a country park. However, three other shale tips have been worked to some degree or other at Hersden, Snowdown and Tilmanstone. The tips at Hersden and Snowdown have been used wholly or in part as a source of aggregate fill. The Hersden site has now been redeveloped as an industrial estate but Snowdown still has potential resources available if a suitable means of access could be established. Tilmanstone tip has been partially reworked as a source of shale for brickmaking. However, the brickworks have closed and there are no current plans to either reopen it or make use of the shale for other purposes.

Colliery shale comes in two forms: burnt and unburnt. This distinction has a major impact on the use of the mineral highlighted in Figure 7 above. The location of the four collieries in East Kent are shown in the following map of the Kent Coalfield (Figure 8).

Figure 8 - East Kent Coalfield and location of coal mines



2.6.3 Slag

Slag is the by-product of metal smelting. Slag is the stony waste matter separated from metals during the smelting or refining of ore. It may be used in structural concrete as a ground powder, in coated macadam or as a sub-base material in road construction. It may even be used as a fertiliser.

Slag produced at the Sheerness steelworks on the Isle of Sheppey has been used in Kent as a secondary aggregate.

BS EN 15167-1:2006 Ground granulated blast furnace slag for use in concrete, mortar and grout. *Definitions, specifications and conformity criteria* is the British standard used to control its use.

2.6.4 Power Station Ash or Pulverised Fuel Ash (PFA)

When coal is burnt in coal fired power stations, the ash produced as a residue may be used as an engineering fill or as a component in concrete. It may also be used as a lightweight aggregate to make concrete blocks.

Kingsnorth Power Station in Medway was the only operational coal fired power station (ceased generation March 2013) that locally supplies pulverised fuel ash, stockpiles are currently being exploited. A new source of secondary aggregate, the bottom ash from the Allington waste to energy plant, is now used in the manufacture of breeze blocks.

BS 6610:1996 Specification for Pozzolanic pulverized-fuel ash cement and *BS 3892-1:1993. Pulverized-fuel ash. Specification for pulverized-fuel ash for use with Portland cement* are two standards that specify composition, production and properties of processed ash. Describes supporting tests and gives procedure for equivalence of mixer combinations to blended cements.

2.7 Recycled aggregates

2.7.1 Recycled aggregates are increasing in importance year on year as confidence grows in the products produced and the techniques and management of aggregate recycling improve. At least two companies in Kent now employ aggregate washing plants in the production process.

2.7.2 2003 was the first year in which the Aggregate Monitoring Report for the South East England Regional Assembly first quantified the contribution recycled aggregates made to the construction aggregate regional supply. This contribution is now an integral part of the construction aggregate supply chain.

2.7.3 Once used as a general fill, improvements in controlling and reducing contaminants has resulted in these aggregates being used in concrete and coated macadam. In 2010, 90% of secondary and recycled materials were used as aggregates. As mentioned in the building sand section below, the British Standard

(*BS EN 12620: 2002 Aggregates for concrete*) also specifies the properties that recycled aggregates need to meet to be acceptable for making concrete. FM Conway is one Company in Kent that uses recycled aggregates in concrete[(8)].

2.8 Building sand

2.8.1 Building sand is fine aggregate that is less than 5mm in size. It has a wide range of uses that include mortar sand, plastering sand and asphalt sand. It can be found naturally in geological horizons such as the Folkestone Beds or it can be manufactured from crushed rock. It can be prepared for use simply by dry screening or it may be washed and graded using sophisticated washing and grading plants. Building sand is sometimes referred to as soft sand.

2.8.2 Building sand differs from concreting sand being generally finer and softer in texture. The two distinct sands are processed to meet different British Standards for example, *BS EN 13139:2002 Aggregate for mortar* deals with mortar sands whilst *BS EN 12620:2002 Aggregates for concrete* specifies the properties of aggregates and filler aggregates obtained by processing natural, manufactured or recycled materials and mixtures of these aggregates for use in concrete.

3 Case history: the effect of geology on a Kent construction aggregate

Geology of the Hythe Formation (Ragstone and Hassock)

3.0.1 This geological horizon has a long history of supplying material to the construction industry. This section deals with how its exploitation has changed over the centuries and how modern quarrying techniques have improved its sustainable use.

3.0.2 In the south of England the Cretaceous rocks have been exposed by the Wealden anticline an eroded elongated dome that extends in England from the Dover Straits in the east to the west of Petersfield in Hampshire. The Lower Cretaceous horizons are framed by the arched Upper Cretaceous escarpment of the Chalk.

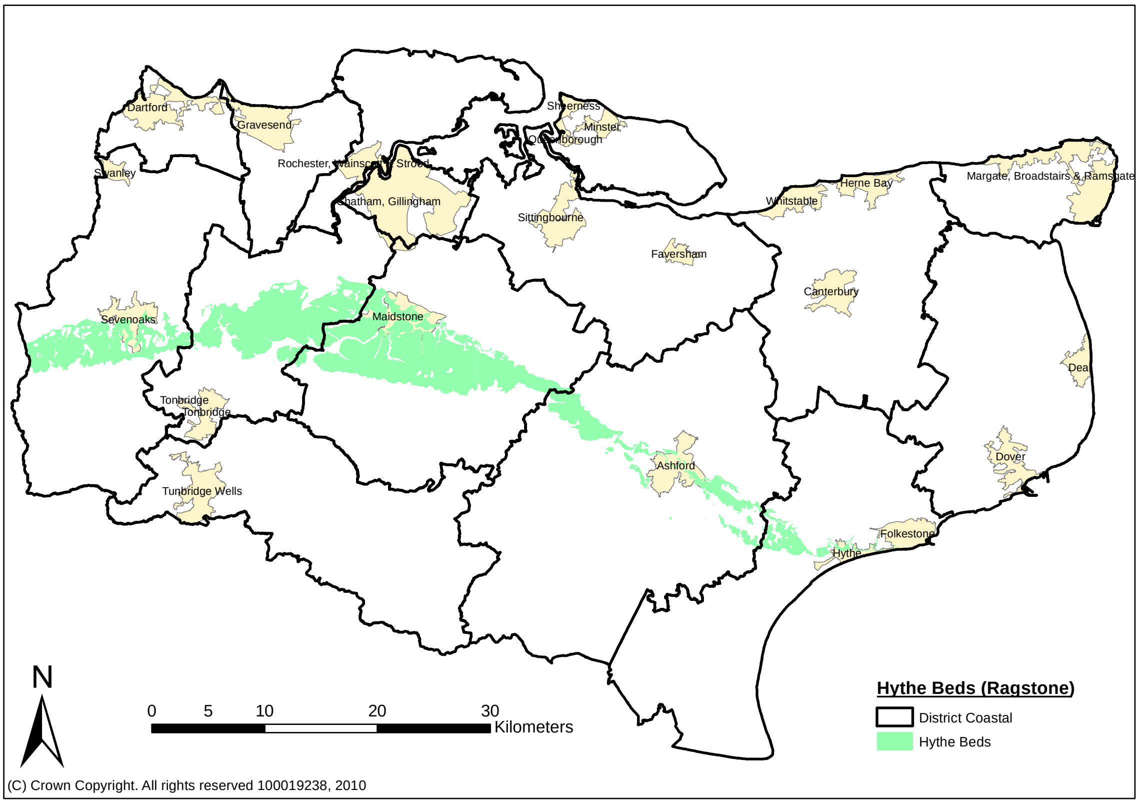
3.0.3 The Hythe Formation lies within the Lower Cretaceous forming a continuous horizon and distinctive escarpment feature overlooking the flat Weald Clay valley from Hythe on the Kent coast along the northern section to Leith Hill Surrey, the highest point at 294 m AOD around its westernmost extremity at Petersfield Hampshire returning to the coast between Eastbourne and Pevensey in Sussex.

3.0.4 The Hythe Beds vary in thickness from 18 to 90 metres. The lithology[(9)] of the beds also varies significantly consisting of hard sandy limestone interbedded with loosely cemented calcareous, argillaceous sandstone in Kent and Sussex (east of the River Arun). Whilst west of the Arun and in Surrey and Hampshire, the beds are sandstones with lenticular beds of chert.

8 See http://www.fmconway.co.uk/services/AsphaltAndAggregateProducts.aspx
9 See Appendix 3: Glossary

3.0.5 In Kent itself the beds form an east west outcrop from Hythe to Westerham (Figure 9). The outcrop is most extensive from Ulcombe east of Maidstone to Ightham near Borough Green. It is this area that has seen the most intensive quarrying of the horizon. Old quarries at Boughton, Spot Lane, Tovil, East Farleigh, Fant, Allington, Ditton, Offham and Borough Green illustrate the extensive exploitation of the ragstone rock in and around Maidstone.

Figure 9 - Hythe Beds in Kent



3.0.6 In Kent, the ‘ragstone’ beds or ‘lanes’ (sandy limestone) typically vary in thickness between 50mm and 600mm, though one bed at Hermitage Quarry has been measured at 1100 mm (Figure 10). Interbedded with the ragstone are ‘hassock’ layers, a calcareous sand or argillaceous sandstone. The hassock beds vary in thickness from 50 mm to 1000 mm. In this area the Hythe (Beds) Formation is estimated to be between 21 and 37 metres in thickness. Good correlation has been established between the current quarries and the former quarries in the Maidstone area using certain distinctive beds.

Figure 10 - Rag and Hassock Beds, Hermitage Quarry

Note: Ragstone beds are lighter in colour than the hassock beds

3.0.7 Geological evidence submitted with recent planning applications has proposed four distinctive zones or three distinctive units within the Hythe Beds. Oaken Wood is an area proposed as an extension to Hermitage Quarry near Barming to the west of Maidstone, whilst Blaise Farm Quarry is another ragstone quarry to the south of West Malling. These zones and units were identified at three locations as follows (Table 2):

Table 2 Geological zones identified at Oaken Wood, Hermitage and Blaise

Oaken Wood	**Hermitage Lane**	**Blaise Farm Quarry**
Chert Ragstone Zone	Hermitage Unit (HU)	Hermitage Unit (HU) (Part)
Grey Ragstone Zone		
White Ragstone Zone	Boughton Unit (BU)	Boughton Unit (BU)
Dark Blue-grey Ragstone Zone	Sub Black Jack Unit (SBJU)	Sub Black Jack Unit (SBJU)

3.0.8 The zones are typified by a relative increase of ragstone to hassock from the lower Sub Black Jack Unit (32%), Boughton Unit (42%) to the higher Hermitage Unit (55%). The absence of the upper part of the Hermitage Unit at Blaise Farm

Quarry explains the higher hassock to ragstone percentages identified in the geological information supplied with its planning application. The Hermitage Unit of Hermitage Quarry contains the two uppermost zones identified in the geological report on the Oaken Wood prospect. Reviewing the geological memoir for Maidstone it is possible to identify the appearance of the different marker horizons and therefore develop a picture of the extent of the Hermitage, Boughton and Sub Black Jack sequences across the Maidstone area.

3.0.9 Until Gallagher Aggregates introduced the washing of hassock at Hermitage Quarry, this material had limited uses. Where the hassock had minimal silt content when mixed with crushed ragstone it could make a fair crusher run[10] but most of the time it failed the MOT Type 1 Sub-base specification; consequently its main use during the '80s and '90s was as a low value general fill material. Their advanced crushing, screening and washing plant (installed between the late '90s and 2004) has enabled Gallagher Aggregates to improve the range of uses of both the ragstone and the hassock beds, thereby raising the value of the hassock and making it more marketable.

3.0.10 At Blaise Farm Quarry, the increased hassock content, reduced ragstone content and the minimal production plant reduces the quarry's ability to meet the higher specification markets particularly as a concrete aggregate.

4 Interchangeability of aggregates

IInterchangeability of construction aggregates

4.0.1 Figure 11 overleaf is taken from the Kent Minerals Local Plan Report of Studies September 1990. It illustrates the range of materials used in Kent for construction aggregate at that time.

10 See Appendix 3: Glossary

TRM5: Interchangeability of Construction Aggregates

Figure 11 - The Interchangeability of Construction Aggregates 1990

THE PRINCIPAL REQUIREMENTS

1. Structural concrete a. Coarse aggregate	b. Fine aggregate	2. Buried concrete	3. Bulk fill	4. Granular bases	5. Coated roadstone a. Base Course	b. Surfacing	6. Hot asphalt a. Coarse aggregate	b. Fine aggregate	7. Highway surface dressing	8. Building sands	9. Industrial Sand	***AVAILABLE MATERIALS***
(I)	LOCAL RESOURCES											
*	(*)	*										1. Beach gravels
*	*	*	*	*								2. River gravels a. flint dominant
		*	*	*								b. sandstone dominant
		*	*									3. Ragstone
	*		*				*			*	*	4. Soft sands a. Folkestone Beds
			*									b. Thanet Beds
			*							*		c. Oldhaven & Woolwich
*	*	*	*	*	*		*					5. Potential deep-mined limestone
(II)	IMPORTS											
*	*	*	*	*								6. Marine dredged sand and gravel
*	*	*	*	*	*	*	*	(*)	*			7. Granite and gritstone
*	*	*	*	*	*		*					8. Somerset and Avon limestone
(III)	SUBSTITUTE MATERIALS											
			*	*	*	*	*		*			9. Slag
			*									10. Power station ash (PFA)
			*									11. Colliery waste
			*	*								12. Cement-stabilised minestone

(*) WHEN BLENDED WITH NATURALLY OCCURRING SANDS

4.0.2 Figure 11 did not include recycled aggregates at the time this report was written. This figure illustrates the uses applied to the various aggregate sources available at that time. This report will update that figure as now applies some 20 years later.

4.0.3 On the basis of the technology and investment applied to the winning and working of ragstone at Hermitage Quarry and the growth in the use of recycled aggregates it is possible to update Figure 11 above. The revised figure is set out opposite (Figure 12).

Figure 12 - The Interchangeability of Construction Aggregates 2012

THE PRINCIPAL REQUIREMENTS

1. Structural concrete		2. Buried concrete	3. Bulk fill	4. Granular bases	5. Coated roadstone		6. Hot asphalt		7. Highway surface dressing	8. Building sands	*AVAILABLE MATERIALS*
a. Coarse aggregate	b. Fine aggregate				a. Base Course	b. Surfacing	a. Coarse aggregate	b. Fine aggregate			
(I)	**LOCAL RESOURCES**										
*	(*)	*									1. Beach gravels
*	*	*	*	*							2. River gravels a. flint dominant
		*	*	*							b. sandstone dominant
*	*	*	*	*	*		*			*	3. Ragstone
	*		*				*			*	4. Soft sands a. Folkestone Beds
			*								b. Thanet Beds
			*							*	c. Oldhaven & Woolwich
*	*	*	*	*	*		*				5. Potential deep-mined limestone
(II)	**IMPORTS**										
*	*	*	*	*							6. Marine dredged sand and gravel
*	*	*	*	*	*	*	*	(*)	*		7. Granite and gritstone
*	*	*	*	*	*		*				8. Somerset and Avon limestone
(III)	**SUBSTITUTE MATERIALS**										
			*	*	*	*	*		*		9. Slag
			*								10. Power station ash (PFA)
			*								11. Colliery waste
			*	*							12. Cement-stabilised minestone
		*	*	*	*	*	*	*			13. Recycled Aggregates†

(*) WHEN BLENDED WITH NATURALLY OCCURRING SANDS
(†) DEPENDENT ON THE QUALITY OF THE RECYCLING
* CHANGES IN FIGURE 12 FROM FIGURE 11

4.0.4 With improved processing particularly the washing of the aggregate, ragstone and recycled aggregates have shown that better use of local resources can make a bigger and more sustainable contribution to the construction aggregate market in Kent. By selective processing a proportion of recycled coated materials may be blended with primary aggregates in the production of coated roadstone, asphalt and granular bases. Crushed concrete aggregates may be used in buried concrete mixes and most recycled aggregates can meet bulk fill needs.

5 Conclusions

5.0.1 Construction aggregates are sourced from a diverse collection of materials. They range from those that are naturally occurring to those that have been purposely manufactured, recycled or exist as by-products/waste from other industrial activities.

5.0.2 The varied nature of construction aggregates and their uses is based and controlled by a system of standards designed to ensure the aggregates are fit for purpose for particular applications.

5.0.3 Different construction aggregates meet differing needs and uses, therefore care has to be taken to ensure the application will be sustainable and will endure for the planned life of the structure.

5.0.4 Not all construction aggregates can be substituted directly for each other. Flint aggregate, for example, though extremely durable should not be used in road surfacing due to its low anti-skid polished stone value (PSV) unlike a sandstone with a high PSV value even though chemically they may be very similar their physical characteristics are different, to the degree that they are not interchangeable in this particular application.

5.0.5 Similarly soft sand is required in mortar mixes (it cannot be substituted by sharp sand or recycled aggregate) in the construction industry where it is generally applied.

5.0.6 Though interchangeability does happen, a variety of different types of aggregate including land won sand and gravel, marine dredged aggregates, crushed rock and recycled aggregates can now be used in concrete and concrete products, this exemplifies that there is flexibility in application that helps to ensure an efficient and sustainable management of aggregate resources.

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Appendix 1: European/British Standards

European Standards

(as specified by the British Standards Institute)

BS EN STANDARD	TITLE	GUIDANCE DOCUMENT
BS EN 12620	Aggregates for concrete	PD 6682-1
BS EN 13043	Aggregates for bituminous and surface treatments for roads, airfields and other trafficked areas	PD 6682-2
BS EN 13139	Aggregates for mortar	PD 6682-3
BS EN 932 series	Tests for general properties	
BS EN 933 series	Tests for geometrical properties	
BS EN 1097 series	Tests for mechanical and physical properties	
BS EN 1367 series	Tests for thermal and weathering properties	
BS EN 1744 series	Tests for chemical properties	
BS EN 13179 series	Tests for filler aggregates	
BS EN 13285	Unbound mixtures specification	

Appendix 2: Properties of rocks used for construction purposes

Introduction

"*Construction materials engineering and testing is a critical component in the process of taking a structure off the blueprint and making it a reality*" [11].

Minerals and rocks used for construction need to have properties that make them suitable for purpose. The properties of different rocks and minerals have been evaluated over time through their success or failure to do the task required. It has become clear that certain rocks are more suitable than others to meet the different criteria required to fulfil the building need.

As a result of construction becoming ever more demanding and the cost of failure ever greater, the need to ensure that the materials used for construction will meet the demands being put upon them has become paramount. As a consequence of this a range of tests have been devised and developed to assess the building materials for physical, chemical and mechanical properties.

A physical property is any measurable property the value of which describes a physical state, examples of physical properties are density, strength, volume, length, mass, permeability, absorption and flexibility.

A chemical property is any of a material's properties that becomes evident during a chemical reaction; that is, any quality that can be established only by changing a substance's chemical identity, examples of chemical properties are chemical composition, reactivity, toxicity, flammability and chemical stability.

Mechanical properties of a material are those properties associated with its reaction to various applied forces, examples of which are strength, ductility, ultimate tensile strength, hardness, bendability, impact strength and compression

The current most versatile building material today is concrete. In 2004 world total annual production of hydraulic cement was about 2 billion tonnes (Gt), and production was very unevenly spread among more than 150 countries. This quantity of cement is sufficient for about 14–18 Gt/year of concrete (including mortars), and makes concrete the most abundant of all manufactured solid materials. The yearly output of hydraulic cement is sufficient to make about 2.5 metric tons per year of concrete for every person on the planet[12]. The production of concrete relies on all properties of the constituent materials being comprehensively tested for the above properties.

11 Quote from HSA website

12 Background Facts and Issues Concerning Cement and Cement Data
By Hendrik G. van Oss USGS 2005

Testing of aggregates

To understand the properties of rocks when used for construction purposes a system of testing has been established. This testing has been refined and revised over time to introduce confidence in the testing procedure and establish a system that will reproduce consistency in the results obtained for each source of aggregate To this end a standard has been established that ensures that tests undertaken on different materials will produce results consistent with the material concerned and allow those results to be compared with alternative materials thereby ensuring that aggregate properties may be assessed with confidence and allow for fair comparison.

The following European Standards cover the properties of aggregates; each is divided into a number of Parts as indicated.

BS EN 932, Tests for general properties of aggregates

1. Methods of sampling
2. Methods of reducing laboratory samples
3. Procedure and terminology for simplified petrographic description
4. Not issued
5. Common equipment and calibration
6. Definitions of repeatability and reproducibility

BS EN 933, Tests for geometrical properties of aggregates

1. Determination of particle size distribution. Sieving method
2. Determination of particle size distribution. Test sieves, nominal size of apertures
3. Determination of particle shape. Flakiness index
4. Determination of particle shape. Shape index
5. Determination of percentage of crushed and broken surfaces in coarse aggregate particles
6. Assessment of surface characteristics. Flow coefficient of aggregates
7. Determination of shell content. Percentage of shells in coarse aggregates
8. Assessment of fines. Methylene blue test
9. Assessment of fines. Sand equivalent test

10. Assessment of fines. Grading of fillers (air-jet sieving)

11. Classification test for the constituents of coarse recycled aggregate

BS EN 1097, Tests for mechanical and physical properties of aggregates

1. Resistance to wear (micro-Deval)

2. Resistance to fragmentation

3. Loose bulk density and voids

4. Voids of dry compacted filler

5. Water content (drying in ventilated oven)

6. Particle density and water absorption

7. Particle density of filler (Pyknometer method)

8. Polished stone value

9. Resistance to wear by abrasion from studded tyres (Nordic test)

10. Water suction height

BS EN 1367, Tests for thermal and weathering properties of aggregates

1. Determination of resistance to freezing and thawing

2. Magnesium sulfate test

3. Boiling test for Sonnenbrand basalt

4. Determination of drying shrinkage

5. Determination of resistance to thermal shock

6. Determination of resistance to freezing and thawing in the presence of salt (NaCl)

BS EN 1744, Tests for chemical properties of aggregates

1. Chemical analysis

2. Not issued

3. Preparation of eluates by leaching of aggregates

5. Determination of acid soluble chloride salts

6. Determination of the influence of recycled aggregate extract on the initial setting time of cement

BS EN 932 - 1 1997 Tests for general properties of aggregates. Methods for sampling[13] is the current European Standard that specifies methods for obtaining samples of aggregates from deliveries, preparation and processing plants including stocks (It also has additional Parts 2, 3, 5 and 6 that deal with reduction of sample size, petrographic description, equipment and definitions respectively (currently there is no Part 4 issued))..

The aim of sampling is to obtain a bulk sample that is representative of the average properties of the batch. The methods specified in this standard are also suitable for obtaining sampling increments which may be tested separately.

The methods specified in this European Standard are based on manual procedures. Mechanical or automatic sampling and sample reduction may also be used.

Criteria for the design and the assessment of such equipment are given in an annex of this standard.

The methods specified in this European Standard are limited to civil engineering purposes.

Physical Properties

Measurements that can be taken without changing an aggregate or mineral are known as “physical properties”:

Density

The density or mass density of a material is defined as its mass per unit volume. As defined and calculated according to "BS EN 1097- 6:2000 Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption".

Strength

Strength of a material is its ability to withstand an applied stress without failure

Strength may be measured in three ways:

1. Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. Concrete can be made to have high compressive strength,

13 http://www.bsigroup.com/

e.g. many concrete structures have compressive strengths in excess of 50 MPa, whereas a material such as soft sandstone may have a compressive strength as low as 5 or 10 MPa[(14)].

2. Tensile strength (TS), ultimate strength or ultimate tensile strength is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract. Tensile strength is the opposite of compressive strength and the values can be quite different.

3. Shear strength in engineering is a term used to describe the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. When a paper is cut with scissors, the paper fails in shear.

<u>Volume</u>

Volume is how much three-dimensional space a substance (solid, liquid, gas, or plasma) or shape occupies or contains, quantified numerically using the SI derived unit, the cubic metre.

<u>Length</u>

Length most commonly refers to the longest dimension of an object. (Length is a measure of one dimension, whereas area is a measure of two dimensions (length squared) and volume is a measure of three dimensions (length cubed). In most systems of measurement, the unit of length is a fundamental unit, from which other units are defined.

<u>Mass</u>

Mass in simplistic terms is its weight. Mass is measured in grams, kilograms and tonnes (the term mass becomes very complicated when gravity and relativity are considered).

<u>Permeability</u>

Permeability is a measure of the ability of a material to transmit fluids. This could be through the mineral or rock itself or through joints and fractures within the rock mass.

<u>Absorption</u>

Commonly applied to water, absorption is the ability of a material to absorb water and hold it in itself.

14 MPa = megapascal where 1MPa = 1000000 Pa (Pascal = SI derived unit of pressure)

Tests for Physical Properties

2.1 There are a number of tests that test stone for its resistance to wear or fragmentation. They include the micro-Deval abrasion test, Los Angeles abrasion test, aggregate abrasion value (AAV), polished stone value (PSV), ten percent fines (TFV), aggregate impact value (AIV) and aggregate crushing value (ACV). The initial four tests are particularly important for materials to be used in the construction of road surfaces whereas the latter tests are strength orientated and are equally important in concrete aggregates.

Micro-Deval Abrasion Test

BS EN 1097-1:2011 Tests for mechanical and physical properties of aggregates. Determination of the resistance to wear (micro-Deval).

The Micro-Deval is used to test the resistance of fine/coarse aggregates to degradation by abrasion. This testing of fine/coarse aggregates determines their abrasion loss in the presence of water and an abrasive charge. Test results are helpful in judging the suitability of fine/coarse aggregates subject to weathering and abrasive action when adequate information is not available.

A pre-soaked aggregate sample is placed in the jar with a fixed volume of water and a fixed quantity of 9.5mm stainless steel balls. The unit is then put into rotation for a known period of time. The period of time depends on the initial grade of the sample. At the end of the cycle, the sample is removed and the aggregate quality is determined by the percentage of loss by gradation.

LOW RESULT BEST

Los Angeles Abrasion Test

This test is an indication of coarse aggregate resistance to abrasion and mechanical degradation during handling, construction, and use. The test is undertaken in a rotating drum containing a specified number of steel balls and a given number of rotations of the drum. The result is expressed as % changes in original weight of the sample.

BS EN 1097-2:1998 Tests for mechanical and physical properties of aggregates. Methods for the determination of resistance to fragmentation specifies procedures for the determination of the resistance of coarse aggregate to fragmentation. Two methods are defined:

a. the Los Angeles test (reference method)

b. the impact test (alternative method)

The impact test can be used as an alternative to the Los Angeles test but a correlation with the Los Angeles test should first be established to avoid double testing and ensure mutual recognition of results. The Los Angeles test (reference method) should be used in cases of dispute.

This European Standard applies to natural or artificial aggregates used in building and civil engineering.

LOW RESULT BEST

Aggregate Impact Value, (AIV)

Similar results to Aggregate Crushing Value except for brittle rocks, e.g. Quartzite and hard grit stones, which can be up to 3 points higher. Basically the AIV is the percentage of fines produced from the aggregate sample after subjecting it to a standard amount of impact.

The standard amount of impact is produced by a known weight, i.e. a steel cylinder, falling a set height, a prescribed number of times, onto an amount of aggregate of standard size and weight retained in a mould.

BS EN 1097-2:1998 Tests for mechanical and physical properties of aggregates. Methods for the determination of resistance to fragmentation.

See Los Angeles Test above.

LOW RESULT BEST

Aggregate Abrasion Value, (AAV)[15]

With the test a known mass of aggregate chippings are set in resin in a small flat test panel and subject to abrasion on a grinding apparatus that is fed with a known type of silica sand. The loss in weight of the aggregate after a specified time as a percentage of the original weight is the AAV.

Specimens of chippings passing 14mm and retained on the 20mm-14mm flake-sorting sieve, are held in resin and subjected to wear on a standard flat circular metal surface fed with high silica sand. Percentage loss in weight is the A.A.V. Results range from 1 (some flints) to 15 (normally regarded as too soft for use in wearing course). This test is now an optional part of BS EN 1097-8:2009 Polished Stone Value.

LOW RESULT BEST

Aggregate Crushing Value, (ACV)

15 Found on http://www.encyclo.co.uk/visitor-contributions.php

In brief, in *BS 812: Part 110*[16], a sample of 14 mm size chippings of the aggregate to be tested is placed in a steel mould and a steel plunger inserted into the mould on top of the chippings. The chippings are subject to a force rising to 400 kn over a period of 10 minutes, usually by placing in a concrete crushing apparatus.

The fine material (passing a 2.36 mm sieve) produced, expressed as a percentage of the original mass is the aggregate crushing value, (ACV).

LOW RESULT BEST

<u>Ten Percent Fines Value, (TFV)</u>

Chippings and apparatus as ACV. Value is the load in kN (kilonewtons) required to produce 10% fines.

BS 812-111:1990 Testing aggregates. Methods for determination of ten per cent fines value was a test that gave a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. This test has been withdrawn from British Standards though some companies continue to use it as a guide to the aggregate quality.

It has been superseded by a part of the *BS 812 series*, which describes methods for the determination of the 10% fines value (TFV) of aggregates which give a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

In this British Standard two procedures are described, one in which the aggregate is tested in a dry condition and the other in which it is tested in a soaked condition.

The methods in this standard are applicable to both weak and strong aggregates passing a 14.0 mm test sieve and retained on a 10.0 mm test sieve.

HIGH RESULTS BEST

<u>Polished Stone Value, (PSV)</u>

This is a measure of an aggregate's resistance to the polishing action of vehicle tyres. (Values for typical aggregates are Limestone - 40/45, Granite - 50/65, Gritstone - 55/70+).

BS EN 1097-8:2000 Tests for mechanical and physical properties of aggregates. Determination of the polished stone value is the critical test.

HIGH RESULT BEST

<u>Magnesium Sulphate Soundness Value, (MSSV)</u>

16 BS 812 consists of a number of parts which is gradually being replaced by European Standard BS EN 933 in all its parts

Magnesium sulphate soundness value (MSSV) is the soundness of an aggregate as measured by the magnesium sulphate soundness test. This is a test to simulate weathering characteristics of an aggregate, or more precisely its ability to resist weathering. The particular aggregate being tested is subject to a number of immersions in an aggressive solution of magnesium sulphate to hasten the degrading process the environment has on an aggregate. After the aggregate has been subject to the testing regime the remaining weight of the aggregate is expressed as a percentage of the original weight.

It is a general requirement that the aggregate shall have a MSSV above 75. In the BS 812 test (% retained), higher values indicate increased soundness. In the ASTMSee Appendix 3 Glossary C88 test (% loss), smaller values indicate increased soundness (this test is sometimes called the Sodium Sulphate Soundness Test where sodium sulphate is used instead of magnesium sulphate).

Magnesium Soundness Test, (MS)

See MSSV above.

BS EN 1367-2 : 2009 - Tests for thermal and weathering properties of aggregates. Magnesium sulfate test

Aggregate Size

The size of an aggregate is not quite what it seems. The size of a particular aggregate will depend on what sieve sizes determine the grading of an individual material, or in the case of a quarry what screen sizes are used to separate out the raw aggregate.

If you have a production plant where the normal sieve/screen sizes are, 37.5mm, 28 mm 20mm, 14mm, 10 mm 6.3 mm etc., a 28 mm aggregate will be that aggregate which passes the 28 mm sieve and is retained on the 20 mm sieve. So, in the case of a 28 mm aggregate the size could be 27.9mm or 20.1 mm, and still be regarded as a "28 mm aggregate".

This variance in true size can be a particular problem with surface dressing chippings, which are single size. It leads to such expressions as a "bold" 10 mm chipping, or a "small" 10 mm chipping, meaning the bulk of the chippings are quite near the 10 mm size or the 6.3 mm size. In the case of coated stone used in road construction, chippings being "bold" or "small" can necessitate a change in binder spread rates to ensure retention of the chipping, or to prevent "fatting up" of binder.

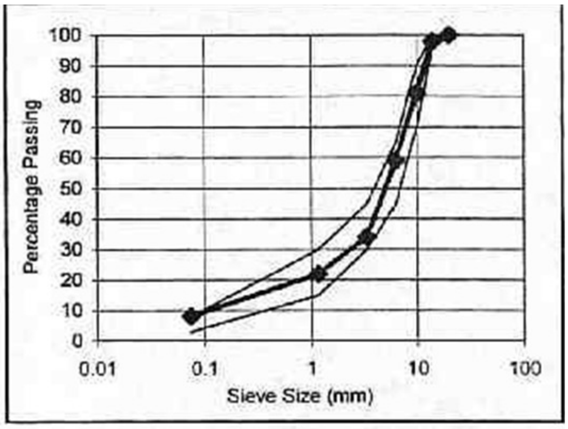
BS EN 933-1 Tests for geometrical properties of aggregatesDetermination of particle size distribution. Sieving method

Aggregate Grading

Aggregate grading is the term given to the percentages of the different size fractions, after sieving, that go to make up the aggregated bulk of the material (Figure 13).

Figure 13 - Tabular and Graphical Representation of Particle Size Distribution

Aggregate Grading (crushed rock)		
Sieve Size	% Passing	Specification
20mm	100 ✓	100
14mm	98 ✓	95 - 100
10mm	81 ✓	70 - 90
6.3mm	59 ✓	45 - 65
3.35mm	34 ✓	30 - 45
1.18mm	22 ✓	15 -30
75µm found	8 ✓	3 - 8
Binder Content (125 pen grade)		
found	5.2 ✓	4.6 - 5.6



To obtain the different size fractions for weighing, the sample of aggregate is sieved on the appropriate sieve sizes for the particular material, and the retained aggregate amounts weighed. This process is known as "grading", or, more scientifically put, you are determining the particle size distribution of the material. The necessary sieve sizes for a particular material will be found in the appropriate specification to which the material is supplied.

The test for particle distribution of a "dry stone" aggregate is fully described in BS EN 933-1:2012. Tests for geometrical properties of aggregates. Determination of particle size distribution. Sieving method

The reverse process to performing a grading on a material is a supplier blending appropriate amounts of single size aggregates to create the correct blend of aggregate to satisfy the "mix" specified.

The Client/Engineer will in due course perform a grading on supplied material to ensure it meets the specification.

<u>Flakiness</u>

Flakey is the term applied to aggregate or chippings that are flat and thin with respect to their length or width.

Aggregate particles are said to be flakey when their thickness is less than 0.6 of their mean size.

The flakiness index is found by expressing the weight of the flakey aggregate as a percentage of the aggregate tested. This is done by grading the size fractions, obtained from a normal grading aggregate, in special sieves for testing flakiness. These sieves have elongated rather than square apertures and will allow aggregate particles to pass that have a dimension less than the normal specified size, i.e. 0.6 of the normal size. This grading process is normally performed by hand because flakey chippings tend to 'lie' on the sieve surface rather than fall through the aperture.

There are a number of material and aggregate specifications that have a maximum amount of flakey material allowed, e.g. surface dressing chippings.

Flakey aggregate has less strength than cubical aggregate, and does not create the dense matrix that well graded cubicle aggregate is able to do, and it will provide less texture when used in surface dressing for roads – e.g. granular sub-base with a high proportion of flakey aggregate tends to segregate and be difficult to compact, although performing a normal aggregate grading test will show it conforms to specification. Flakey chippings do not create the surface texture that a cubicle or angular chipping is able to produce.

BS EN 933 - 3 Tests for geometrical properties of aggregatesDetermination of particle shape. Flakiness index

Grading Zone

A grading zone is more easily explained when set down on logarithmic graph paper, (see diagram above).

To explain it in words, it is the area contained between a line drawn through the maximum amounts permissible to pass any particular specified sieve, and a line drawn through the minimum amounts permissible to pass the same specified sieves. The area contained between these two lines is known as the "grading zone".

When plotting an actual grading result, providing the ‘‘plot’’ remains within the zone/envelope the aggregate tested is within specification. If the line of the ‘‘plot’’ leaves the grading zone the aggregate sample is out of specification. Recording the results of tested materials on a graphical basis makes it far easier to assess the quality of a material than looking at a string of numbers, you are able to tell at a glance whether a material is well graded or gap graded, a fine material or a coarse material. However, results presented graphically are not easy to store on databases.

Well Graded

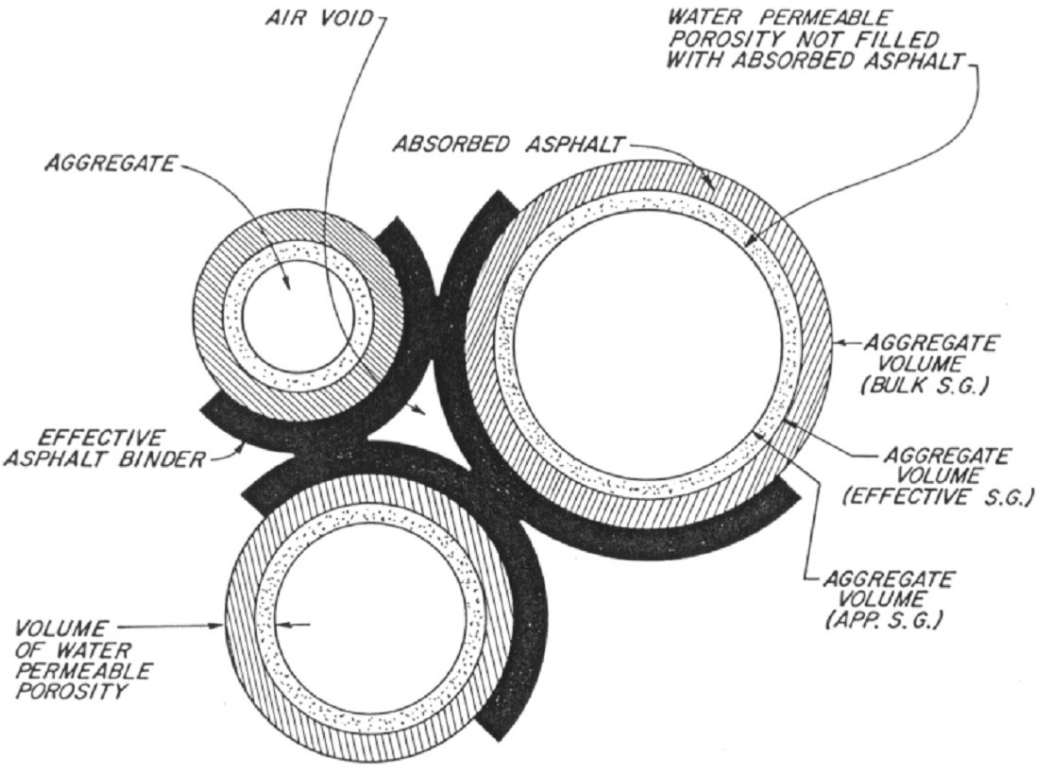
Well graded means that within a material that is well graded there is a good distribution of all the aggregate sizes from largest to smallest, coarse aggregate to ‘‘dust’’. With a well graded material all the different size aggregate particles will position themselves within the total matrix in such a way to produce a tightly knit layer of maximum possible density, when compacted correctly.

A well graded material is better able to carry and spread load imposed on it than a poorly graded material. It will also possess good stability, with good distribution of load/stress spreading out uniformly through the material to the road pavement layer below.

There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of the aggregate materials.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the design of hot mix asphalt or Portland cement concrete. The following diagram illustrates the interaction of voids, particles and the binding agents either cement or bitumen (Figure 14).

Figure 14 - Aggregate Specific Gravities



Poorly Graded

A poorly graded material is one where the size/particle distribution of the supplied material is out of balance with the intended specification/design of the received product. There may be too high a percentage of fines or coarse within the material, and maximum density by proper compaction will not be achievable.

Segregation, i.e. separation of particular aggregate sizes, usually the larger sizes, is much more likely to occur in a poorly graded material.

Segregation leaves laid areas with too many fines, or areas that are "open" due to patches of coarse material. Both conditions making the particular structure in question less able to perform its load spreading function.

Gap Graded

The term gap graded refers to a material when one or more of the aggregate sizes in a normal downward distribution of aggregate particle sizes are missing, hence producing a "gap" in the grading where there is little or no aggregate of a particular size to be found.

This can be quite detrimental to the strength of macadam which relies on mechanical interlock of aggregate particles for its strength.

Moisture Content - Water Absorption - Frost Susceptibility

The amount of water that an aggregate can absorb tends to be an excellent indicator as to the strength of the aggregate, or alternatively its weakness.

Strong aggregates will have a very low absorption figure, i.e. below 1%.

Above 4% absorption you need to perform further tests on the aggregate to determine its acceptability, it may be frost susceptible. A test for water/moisture absorption is described in *BS EN 1097-6: 2000: Tests for mechanical and physical properties of aggregates: Part 6: Determination of particle density and water absorption*.

Chemical Properties

Statistics that are provided by a reaction are referred to as “chemical properties. A substance’s molecular structure must be affected to observe chemical properties, the traits which cannot be determined by touching or viewing the substance

Chemical composition

An aggregate may be a rock that is an aggregate of minerals and/or mineraloids and therefore does not have a specific chemical composition. An aggregate may also be a mineral that is a naturally occurring solid chemical substance that is formed through geological processes and that has a characteristic chemical composition, a highly ordered atomic structure, and specific physical properties. Minerals range in composition from pure elements and simple salts to very complex silicates with thousands of known forms.

BS EN 1744-1 Tests for chemical properties of aggregates. Chemical analysis

Reactivity

Reactivity is the rate at which a chemical substance tends to undergo a chemical reaction.

Toxicity

The toxicity of aggregates in building materials is important when considering the use for which the material is being considered. Toxicity may be a problem if an aggregate contains a chemical that is for example prone to breaking down into harmful toxins such as carbon monoxide. In some areas of Great Britain igneous rocks contain radioactive minerals that break down into radon gas. According to the United States Environmental Protection Agency, radon is the second most frequent cause of lung cancer, after cigarette smoking, causing 21,000 lung cancer deaths per year in the United States.

Asbestos is a naturally occurring mineral that was used for many years as a building material because of its heat resisting properties. When the detrimental health effects were discovered during the last century its use has been banned and a program of removal from buildings undertaken to remove the hazard. Its presence in rocks used as aggregate could be a problem.

It is therefore important to understand the full mineralogy of any aggregate.

<u>Flammability</u>

Flammability as the term suggests refers to the ability of a material to burn or ignite. This is not a common property of aggregates or building stone, but some rocks do contain small percentages of coal or lignite. Other rocks such as bituminous limestone may contain small quantities of oil or carbonaceous material that could ignite in certain circumstances.

Again it is important to understand the full mineralogy of any aggregate.

<u>Chemical stability</u>

Aggregates which have chemical stability will neither react chemically with the binding agents such as cement or bitumen in a harmful manner nor be affected chemically by other external influences. Most common aggregates have a service record which provides the best information on their suitability for their selection as nonreactive aggregates. If new areas of extraction are being explored for future aggregate supply then laboratory tests should be used to confirm the chemical soundness of the material.

One well known form of chemical reaction involving aggregates is the alkali silica reaction. Alkali-Silica Reaction (ASR) or alkali aggregate reaction (AAR) is a term mainly referring to a reaction which occurs over time in concrete between the highly alkaline cement paste and non-crystalline silica (silicon dioxide), which is found in many common aggregates. Opal is one form of cryptocrystalline[17] silica known to participate in this reaction. This reaction can cause expansion of the altered aggregate, leading to spalling and loss of strength of the concrete. *ASTM [18] C289 - 07 Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)* is one chemical test used to test the suitability of an aggregate to be used in concrete with portland cement.

17 See Appendix 3 Glossary
18 See Appendix 3 Glossary

Appendix 3: Glossary

Glossary of terms

A	
Arenaceous	Resembling, derived from, or containing sand.
Argillaceous	Containing, made of, or resembling clay; clayey. The term argillaceous refers to minerals which are predominantly clay or clay-like and are normally very small in size i.e. less than 2 μm (micron/micrometer). Clays and shales are thus predominantly argillaceous. The adjective "argillaceous" is used to define rocks in which clay minerals are a minor but significant component. For example, argillaceous limestones are limestones consisting predominantly of calcium carbonate, but including 10-40% of clay minerals: such limestones, when soft, are often called marls. Similarly, argillaceous sandstones are sandstones consisting primarily of quartz grains, with the interstitial spaces filled with clay minerals.
ASTM	ASTM International, formerly known as the American Society for Testing and Materials (ASTM), is a globally recognized leader in the development and delivery of international voluntary consensus standards.
B	
Breccia	Breccia is a rock composed of broken fragments of minerals or rock cemented together by a fine-grained matrix, that can be either similar to or different from the composition of the fragments. A breccia may have a variety of different origins, as indicated by the named types including sedimentary breccia, tectonic breccia, igneous breccia, impact breccia and hydrothermal breccia.
Brickearth	Clay or earth suitable for, or used in making, bricks.
C	
calcareous	Calcareous is an adjective meaning mostly or partly composed of calcium carbonate, in other words, containing lime or being chalky.

Carstone	A large concretion of consolidated material occurring in certain sedimentary rocks.
Chalk	A soft, white, porous sedimentary rock, a form of limestone composed of over 95% of the mineral calcite. Calcite is calcium carbonate or $CaCO_3$.
Cenozoic	Is an era that lasts from 65.5 mya to the present day.
Conglomerate	A conglomerate is a rock consisting of individual clasts within a finer-grained matrix that have become cemented together. Conglomerates are sedimentary rocks consisting of rounded fragments and are thus differentiated from breccias, which consist of angular clasts. Both conglomerates and breccias are characterized by clasts larger than sand (>2 mm).
Cretaceous	Is an geological period that lasted from 150 mya to 70 mya.
Cristobalite	A high temperature polymorph of the mineral quartz (SiO2) i.e. possessing a different atomic structure but identical chemical composition. It forms at temperatures above 1470°C.
Crusher run	Aggregate that has been passed through a crusher, but has not been sorted for particle size. It may be specified on the largest stone present for example 75mm crusher run or 40mm crusher run.
Cryptocrystalline	composed of crystals that can be distinguished individually only by the use of a polarizing microscope.
Crystal	A crystal or crystalline solid is a solid material whose constituent atoms, molecules, or ions are arranged in an orderly repeating pattern extending in all three spatial dimensions.
D	
Diamond	Is a crystal form of the element carbon (C). Its crystal form and stable nature make it the hardest mineral on Mohs scale of hardness.
Drift	In the UK the term drift is commonly used to describe any deposits of quaternary age(geology) (see term Superficial deposits).
E	
F	

Flint	Flint (or flintstone) is a hard, sedimentary cryptocrystalline form of the mineral quartz, categorized as a variety of chert. It occurs chiefly as nodules and masses in sedimentary rocks, such as chalks and limestones.
Frost susceptible aggregates	A frost susceptible aggregate is one which will retain water in its individual grains or within the whole aggregate mass that can freeze and thaw with changes in temperature. When water freezes it expands and this will, overtime, weaken and crack rocks and aggregates in situ causing in extreme cases failure of the building or road structure.
G	
Garnet	Is a silicate mineral with a number of varieties dependent upon the metal ion content, There are six main varieties almandine ($Fe_3Al_2(SiO_4)_3$), pyrope ($Mg_3Al_2(SiO4)_3$), spessartine ($Mn_3Al_2(SiO_4)_3$), andradite ($Ca_3Fe_2(SiO_4)_3$), grossular ($Ca_3Al_2(SiO_4)_3$) and uvarovite ($Ca_3Cr_2(SiO_4)_3$).
Glauconite	Glauconite is an iron potassium phyllosillicate (mica group) mineral of characteristic green color with very low weathering resistance and very friable.
H	
I	
Ilmenite	Ilmenite is a weakly magnetic titanium-iron oxide mineral (FeTiO).
J	
Jurassic	Is an geological period that lasted from 200 mya to 150 mya.
K	
L	
Limestone	Limestone is a sedimentary rock composed largely of the minerals calcite and/or aragonite which are different crystal forms of calcium carbonate ($CaCO_3$).

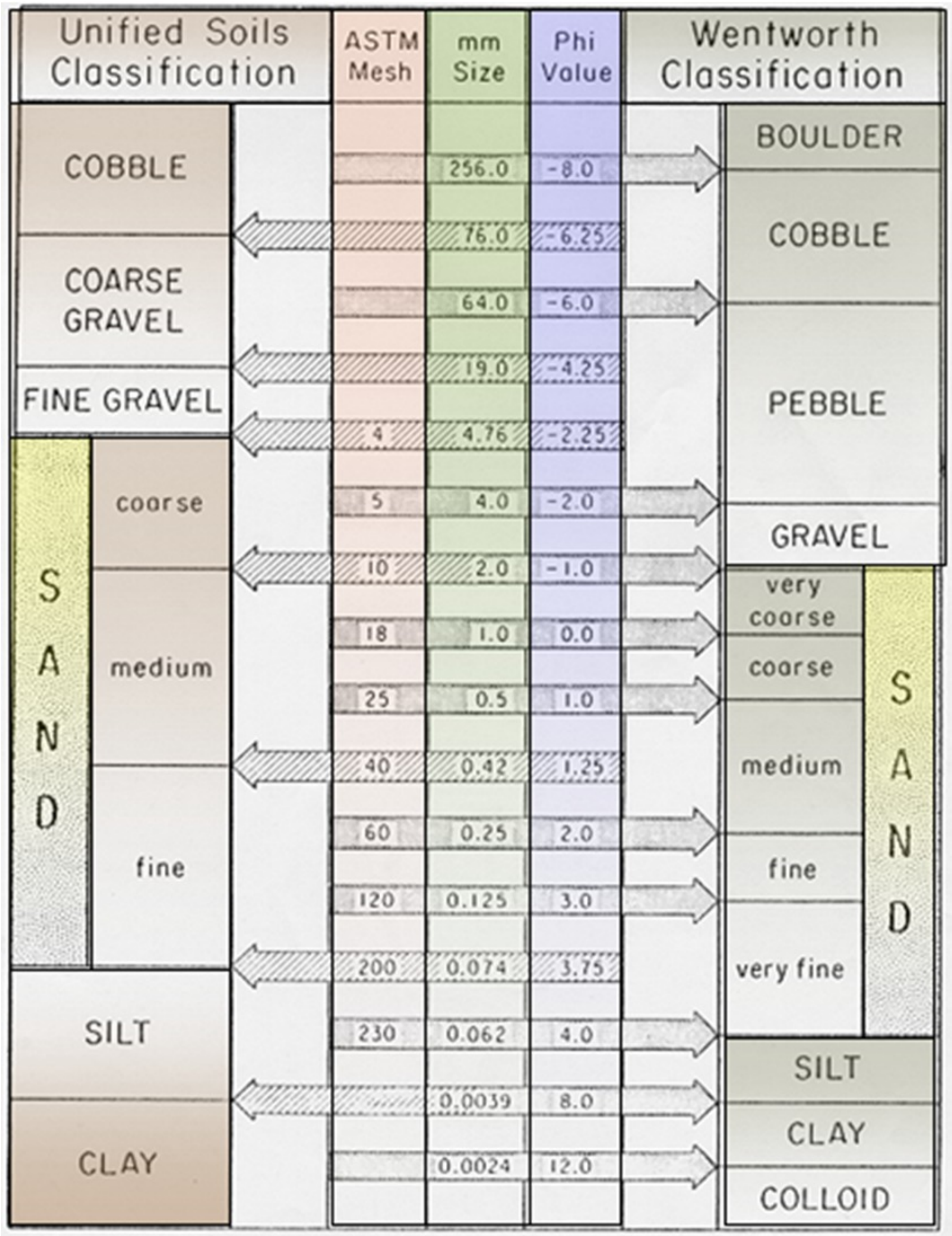
Lithology	The lithology of a rock unit is a description of its physical characteristics such as colour, texture, grain size, or composition.
M	
Mica	Mica is a general term for a group of sheet silicate minerals which have a highly perfect basal cleavage.
Mineral	A mineral is a naturally occurring solid chemical substance that is formed through geological processes and that has a characteristic chemical composition, a highly ordered atomic structure, and specific physical properties. By comparison, a rock is an aggregate of minerals and/or mineraloids and does not have a specific chemical composition. Minerals range in composition from pure elements and simple salts to very complex silicates with thousands of known forms.
Mineraloid	A mineraloid is a mineral-like substance that does not demonstrate crystallinity. Mineraloids possess chemical compositions that vary beyond the generally accepted ranges for specific minerals.
Mohs Scale	Is a relative scale of mineral hardness from 1 to 10 devised by Friedrich Mohs in 1812. 1 is talc and 10 is diamond, and in terms of absolute hardness diamond (10) is 4 times harder than corundum (9) and 6 times harder than topaz (8). The scale also uses half numbers e.g dolomite (3.5).
N	
O	
P	
Palaeocene	Palaeocene, the "early recent", is a geologic epoch that lasted from about 65.5 to 56 million years ago. It is the first epoch of the Palaeogene Period in the modern Cenozoic Era.
Periglacial	Periglacial is an adjective originally referring to places in the edges of glacial areas, but it has later been widely used in geomorphology to describe any place where geomorphic processes related to freezing of water occur. In the original meaning of *periglacial area*, an area described by the term not buried by glacial ice but was subject to intense freezing cycles and exhibits permafrost weathering and erosion characteristics.

Phi Value	Size ranges define limits of classes that are given names in the Wentworth scale. Also known as the Krumbein Phi Scale based on a formula
Q	
Quartz	Quartz is the second most abundant mineral in the Earth's continental crust, after feldspar. It is made up of a continuous framework of SiO_4 silicon-oxygen tetrahedra, with each oxygen atom being shared between two tetrahedra, giving an overall formula SiO_2.
Quaternary	The geological period of the Cenozoic Era immediately following the Tertiary. It is subdivided into the Pleistocene and the Holocene Epochs. It began about 1,640,000 years ago.
R	
Reserve	Are valuable *and* legally and economically and technically feasible to extract.
Resource	Are potentially valuable, and for which reasonable prospects exist for eventual economic extraction.
Rock (stone)	In geology, a rock or stone is a naturally occurring solid aggregate of minerals and/or mineraloids.
Ruby	Is a gemstone variety of the mineral corundum (Aluminium oxide Al_2O_3. Cr.) When Chromium is present in small quantities it adds to the redness of the ruby. Corundum is 9 on Mohs' scale of hardness.
Rutile	Rutile is a mineral composed primarily of titanium dioxide, TiO_2.
S	
Sapphire	Is a gemstone variety of the mineral corundum (Aluminium oxide Al_2O_3). It is distinguished from a ruby simply by the colour red and can be a variety of other colours such as blue, pink, yellow and green.
Sandstone	Sandstone (sometimes known as arenite) is a sedimentary rock composed mainly of sand-sized minerals or rock grains. Most sandstone is composed of quartz and/or feldspar because these are the most common minerals in the Earth's crust.

Superficial deposits	In the British Geological Survey superficial deposits refer to all geological deposits of Quaternary age. All pre-quaternary deposits are referred to as bedrock or solid geology. Superficial Deposits were previously called drift.
T	
Tectonic	Tectonics is a field of study within geology concerned generally with the structures within the lithosphere of the Earth and particularly with the forces and movements that have operated in a region to create these structures. These structures could be geological faults or volcanic activity.
Triassic	The Triassic is a geologic period that extended from about 250 to 200 mya.
U	
V	
W	
XYZ	
Zircon	Is zirconium silicate ($ZrSiO_4$) which in crystal form can range in colour from colourless through red, pink, brown, yellow, hazel, or black. The colour will depend principally on the substitution of zirconium with other elements.

Appendix 4: Classification of particle size including the Wentworth Scale

Figure 15 - Classification of Particle Size including the Wentworth Scale



4.1 **Source:**http://ross.urs-tally.com/ROSS_doc/Soil_Class_Systems.pdf