CHAPTER V

CRUSHED ROCK AGGREGATES

The natural aggregates are any inorganic mineral materials used in a combination with a binding material, such as bitumen, lime or portland cement for the construction purposes ASTM, 1962). The aggregates can be classified as "coarse" or "fine" on the basis of their particles size. The coarser variety includes the particles with the size larger than 4.75 mm in diameter. Otherwise they are of the "fine" group. Of all sizes, the crushed rocks, gravel, and sand find an extensive use as the aggregate materials. The physical and chemical properties of these materials are the important characteristics of the aggregates. These properties result from the material origin as well as other natural processes, such as weathering, transportation and deposition. Thus a knowledge of the geological factors operative in their formation not only guides to a proper location of their availability, but also aids in the right choice and appropriate utilization. The main tests for the aggregates properties include grading, shape analysis, determination of the bulk density and voids, impact value, crushing value, soundness. The petrographic examination should also be performed. The properties are summarized in Table 5.1.

For aggregate materials, most tests are for the physical and mechanical and only a few for the chemical characteristics.

Table 5.1 Necessary tests of rock aggregated sample (after Talbot, 1979)

Kind of Test	Standard
I Physical Tests	
Aggregate grading	BS 882, I201:1973; BS 812:1975; ASTM Designation C-136, C-33
Aggregate shape, angularity, sphericity, roundness, surface texture	BS 812:1975
Specific gravity, density unit weight	BS 812:1975, ASTM Designation C-127, C-128
Water absorption	BS 812:1975; ASTM Designation C-127, C-128
Aggregate shrinkage	BRS Designation 35
Petrographic examination	ASTM Designation C-295
II Mechanical Tests	
Atrength :	
Aggregate impact value	BS 812 : 1975
Aggregate crushing value	BS 812 : 1975
Ten percent fines value	BS 812 : 1975
Franklin point-load test	
Schmidt rebound munber	
Durability :	
Aggregate abrassive value	BS 812 : 1975
Aggregate attrition value	
Los Angeles value	ASTM Designation: C-131
Polish stone value	BS 812 : 1975
Sulphate test	ASTM Designation: C-94
Slake durability	
III Chemical Tests	
Chlorite content	BS 812:1976; ASTM Designation: D-1411

The tests to be described are based on a combination of British Standard (BS) and American Society for Testing and Materials Standards (ASTM Standards) specifications.

5.1 Physical Tests

The determination techniques of the physical properties are described below.

5.1.1 Grading

The grading is to determine the size by means of sieving an air-dried sample. The size of both natural and crushed rock aggregates are differentiatied at every 5 mm level into coarse and fine aggregates. Various parameters have been suggested to summarise the characteristic of the grade in as few terms as possible. The fineness modulus (FM) is estimated as the sum of all the cumulative weight percent values divided by 100.

$$FM = \frac{\text{Cumulative Weight \%}}{100} \qquad \text{............(5.1)}$$

The uniformity coefficient (CU) is an index of the grain size dispersion such that:

$$CU = \frac{D_{60}}{D_{10}} \qquad \text{............(5.2)}$$

and CZ, the coefficient of curvature, such that:

$$CZ = \frac{D_{30}^2}{D_{60} \times D_{10}} \qquad \text{............(5.3)}$$

where the effective particle size D_{60} = sieve aperture size through which 60% of the material passes

D_{30} = sieve aperture size through which 30% of the material passes, and

D_{10} = sieve aperture size through which 10% of the material passes

The value of CU and CZ are used to distinguish the different sorts of grading as shown in Table 5.2.

Table 5.2 Classification of grading (after Talbot, 1982).

CU	CZ	Grading
>35	<6	well graded
>15	<6	medium graded
<15	<6	poorly graded
<15	>6	gap graded

The results of grading or size test of the crushed graywacke aggregates from Chiew Larn are tabulated in Table 5.3. The sieve size fraction of the graywacke aggregate as obtatined is in a group of poorly graded according to Table 5.1.

Table 5.3 Results of grading tests.

No. of tests	Rock type	Fineness modulus (FM)	Uniformity coefficient (CU)	Curvature coefficient (CZ)
1	Gwke	2.86	6.00	1.50
2	Gwke	2.90	66.07	1.55
3	Gwke	4.39	3.54	1.31
4	Gwke	3.15	1.39	1.01
5	Gwke	6.27	3.05	2.22

5.1.2 Shape

The shape of the aggregates depends on the mineral composition, fabric, and other natural properties as well as the manner of crushing for the crushed aggregates. It can be expressed in term of the "roundness" and "sphericity". The roundness is defined as the ratio of the average radius of curvature of the corners and edges of the particle to the radius of the maximum inscribed circle. The roundness can be roughly classified using the criteria expressed in Table 5.4.

Table 5.4 Classification of particle shape (after BS 812, 1967).

Classification	Description	Examples
Rounded	Fully water-worn or completely shaped by attrition	River or sea-shore gravel; desert, sea-shore and wind blown sand
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Other gravels; land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; crushed slag
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions	-
Flaky and Elongated	Material having the length considerably larger than the width, and the width considerably larger than the thickness	-

A British Test (BS 812, 1975) was proposed to measure the angularity as the angularity number (AN) which was defined thus

$$AN = \frac{67 - 100W}{c.Ga} \qquad \text{...............(5.4)}$$

where W = weight of a standard volume,

c = standard volume by the cylinder, and

Ga = apparent specific gravity of the material.

The AN value for the practical aggregates lies between 0 and 11.

The sphericity (S) has been defined as the cube root of the ratio of volume of the particle to the volume of the circumscribing shere (BS 812 : Part 1, 1975). The calculation for the sphericity is as below.

$$S = (bc/a^2)^{1/3} \qquad \text{...............(5.5)}$$

where a, b, c = longest, intermediate and shortest dimensions.

For the sphericity of concrete aggregates, commonly two indices are used, namely, the "flakiness index" and "elongation index". The flakiness index (FI), is the weight percentage to the particles whose thickness is less than 0.6 times of the mean dimension to the total mass, calculated from the expression

$$FI = \frac{w_1 + w_2 + w_3 + \ldots.}{W_1 + W_2 + W_3 + \ldots.} x100 = \frac{\Sigma w}{\Sigma W} \times 100 \qquad \text{.....(5.6)}$$

where W = weight of the individual size fraction, and w = weight of the respective amounts passing through the metal gauge.

The elongation index (EI) is the weight percentage of the particles whose length is greater than 1.8 times of the mean dimension, to the total mess, estimated as

$$EL = \frac{\Sigma A}{\Sigma W} \times 100 \qquad ....(5.7)$$

where A = weight of each of the size fractions retained on the metal gauge, and

W = weight of each the size fraction passing through the gauge.

A few values of the shape test result are presented in Table 5.6.

5.1.3 Gross Apparent Specific Gravity

Instead of an absolute specific gravity, the measurement of which would involve an establishment of the volume of entirely unbound pores and would require the grinding of each particle, the gross apparent specific gravity is the ratio of the weight of a saturated-dry sample of the aggregate to the weight of water occupying a volume equals to that of it. This is the gross apparent specific gravity

$$S.G. = C/(B + A - C) \qquad ....(5.8)$$

where S.G. = specific gravity,

A = weight of the vessel containing the sample and topped up with water,

B = weight of vessel full of water, and

C = weight of surface dry sample.

The average value of specific gravity from variation determination condition is summarized in Table 5.6.

5.1.4 Bulk Density and Voids

The bulk density (ρ_b) is the unit weight of the aggregate material. The value provides a basis for classifying the aggregates into the light-weight, normal-weight and heavy-weight types. A relationship between the gross apparent specific gravity for the saturated and bulk density allows the calculation of the void ratio (v):

$$v = \frac{S.G. - \rho}{S.G.} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (5.9)$$

The values of density and void ratio obtained in this study are reported in Table 5.6.

5.1.5 Petrographic Examination

The petrographic studies are required to describe and classify the constituents of the sample, to determine the physical and chemical character of each constituent, and to describe the proportion of the constituents. The results obtained from the microscopic study are displayed in Table 4.2.

5.2 Mechanical Tests

5.2.1 Aggregate Crushing Value

The aggregate crushing strength value (ACV) is expressed as the ratio, in percentage, of the size fraction passing through a 2.36-mm sieve to the initial sample weight. The value indicates the relative measure of its resistance to crushing under a gradually applied compressive load. To find ACV, an approximately 2-kg sample is subjected to a continuous load through a piston which builds the load up to 40.64 tons in ten minutes. The fraction of aggregate material passing through a 12.5-mm sieve and being retained on a 10.0-mm sieve is chosen for the test. The cylinder assembly with the aggregate and plunger of 150 mm diameter in position was placed in a compression testing machine and the load was applied up to 400 kN at a rate of 67 kN/s, each time compacting the material with a tamping rod for 25 times.

The average crushing value of the aggregate from the tests performed in this study is 20.61%.

5.2.2 Los Angeles Abrasion Value

The method to determine the durability know as the Los Angeles abrasion value had already been explained in details in Chapter 4. The test results of the pebbly graywacke is summarized in Table 4.21.

5.2.3 Sulphate Soundness Test

This test is a physio-chemical deterioration to measure the resistance of rocks to disintegration after immersion in a saturated solution of sodium sulphate. The test provides a helpful information in judging the soundness of aggregates being subjected to weathering action, particularly when an adequate information is unavailable from the service records of the material exposed to actual weathering conditions. The procedure is to immerse the set amounts of various size fractions of the crushed rock in the sulfate solution and, after a given time, remove and oven-dry. Following a set number of immersion and drying cycles, the percentages mass loss from each fraction is determined by sieving and weighing. The weighted average percent losses, based on the particle size distribution of the original sample, are then calculated for each fraction. The total of these values is the sulphate soundness test value. A value of 12% (max) has been used in specification.

The mean sulphate soundness value obtained from this method tests results is 0.55%.

5.3 Relationship between Mechanical Properties of Concrete and Aggregate Properties

National Crush Stone Association (1975) revealed the relationship between aggregate characteristics and their influence on concrete as illustrated in Table 5.5. Further explanation is listed below.

(a) The gradation, shape and surface texture of rock aggregate in the concrete mixture have an important influence on the workability, finessing characteristics of fresh concrete and the strength properties of the hardened concrete. The selection of grading curves is considered from the economic factor, effective particle shape and texture of the aggregates and different types of cement.

(b) The particle shape is controlled largely by the inherent geologic composition, crystalline structure of the rock, and to some degree by the type of crusher. The flat or elongated particles are not deleterious in themselves but may decrease the concrete workability and increase the water requirement. The rock surface texture of an angular crushed-stone particles in concrete contributes significantly to the quantity of the aggregate paste bound.

(c) The hardness which depends mainly on the hardness of the constituent minerals, toughness and resistance to abrasion is provided by the Los Angeles abrasion test. The test combines the effects of impact and abrasive.

(d) Some aggregates containing sensitive clays may be susceptible to an aggregate expansion. This volume-change may create an excess pressure to the tensile strength of concrete. The cracking thus occurs.

(e) There are some undesirable chemical reactions between the aggregate surface and the cement paste. These reactions can be divided into two general groups. One is that produces the minor insolate surface defects such as surface popouts, oxidation of non-bearing minerals (staining), leaching of salts and hydration products to the surface, the efflorescence of soluable mineral (gypsum) etc., and the other is that be responsible for the excessive volume changes that will disrupt the structural integrity of the concrete which causes the volume instability and serious distress in concrete such as the silica and carbonate reactions with the alkalies in the concrete.

The test results of the pebbly graywacke aggregates done in this study are again summarized in Table 5.6. All preliminary results suggest conclusively that the quality of pebbly graywackes from the quarry areas are adequate for the rockfill, but not good enough for the rip-rap or concrete aggregate.

For the pebbly graywackes to pebbly mudstones from the diversion tunnel which had been tested for their point-load tensile strength, it was found that its strength index falls in the range of 3 to 5 MPa. When the tensile strength is converted into the uniaxial compressive strength, the value is sufficient for a concrete aggregate property. However the strong rock aggregate to be used will come from only the certain zones in this pebbly graywacke/ pebbly mudstone unit.

Table 5.6 Summary of crushed graywackes aggregates tests results.

Tests Item	Mean Value
Physical Properties	
Fineness Modulus	3.322 ± 0.720
Uniformity Coefficient	4.009 ± 2.015
Curvature Coefficient	1.519 ± 0.443
Flatness	0.533 ± 0.082
Soundness	1.777 ± 0.222
Flakiness Index	26.922
Elongation Index	66.975 ± 9.524
Sphericity	0.624 ± 0.039
Bulk Specific Gravity	2.679 ± 0.064
Saturated Specific Gravity	2.718 ± 0.063
Dry Specific Gravity	2.683 ± 0.083
Bulk Density	2.674 ± 0.064
Saturated Density	2.713 ± 0.063
Dry Density	2.678 ± 0.083
Void Ratio	1.345
Mechanical Properties	
Aggregate Crushing Value	20.606
Los Angeles Abrasion Value	28.042 ± 11.756 "A"
	44.303 + 22.688 "E"
Uniformity Factor	0.219 ± 0.119
Sulphate Soundness	0.55

Table 5.5 Relationship between aggregate characteristics and their influences on concrete (after National Crushed Association, 1975).

Characteristics of aggregate	Significance of aggregate in concrete
Size and grading	Workability of fresh concrete, economy, strength
Cleaness	Aggregate-past bond
Hardness, toughness and wear resistance	Resistance to abrasion
Soundness	Durability, resistance to weathering
Porosity, permeability, and absorbtion	Resistance to freez, and thawing, durability, mix proportioning calculation
Particle shape and surface texture	Workability of fresh concrete, strength, architectural appearance when exposed
Particle strength and elasticity	Resistance to abrasion, creep, and shrinkage
Volume stability	Drying shrinkage
Thermal properties	Durability
Specific gravity and bulk unit weight	Mix proportioning calculation and concrete density
Chemical stability	Resistance to chemical attack, strength, durability