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DUBAI MUNICIPALITY

ADVISORY NOTES
ON
BUILDING MATERIAL
SPECIFICATIONS

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JANUARY 1991

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ADVISORY NOTE

NUMBER : 001 JUNE, 1990

CONCRETE AGGREGATES

FOREWORD

These Advisory Notes have been prepared and compiled by the Quality Control and Research Section in liaison with others from various sections and departments of the Municipality; to all of them, we gratefully acknowledge their contribution and effort.

The primary aim of these Notes is to set a comprehensive directory and awareness trend towards selection of basic construction materials, their quality assurance and control and to act as specification guides. They represent a distillation of the knowledge and experience of many people from within the Municipality and outside and much enthusiastic effort has gone into their production. Work is in progress to compile Advisory Notes on other materials not included in this collection. We are also examining the possibility of extending this project to include building services and design.

These Notes are not Local Order or Standards yet much in them could be used in this way. They are the first comprehensive documents on construction materials produced locally; because of this they are bound to be somewhat controversial. Dubai Municipality would welcome comments based on the practical application of these Notes so that eventually they may be updated.

DIRECTOR

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ON
CONCRETE AGGREGATES

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1. INTRODUCTION

Aggregates are granular materials obtained by processing natural mineral sources. Since aggregates make up about 60% to 75% of the concrete volume, their selection is important. Aggregates should consist of particles of adequate strength and resistance to exposure conditions and should not contain materials that will cause deterioration of concrete. The commonly held view that aggregate is completely inert filler in concrete is not true, its physical characteristics and in some cases its mineral and chemical composition affect to a varying degree the properties of concrete both in its plastic and hardened states.

Aggregates are generally divided into two groups : fine and coarse. Fine aggregates consist of natural or manufactured sand with particle sizes upto 5mm. Coarse aggregates are those with particles larger than 5mm. The maximum admissible grain size of the coarse aggregate in concrete depends upon the design of structural parts of the concrete construction. The maximum grain size of aggregate for reinforced concrete mostly ranges from 20mm to 40mm.

Aggregates are classified in terms of their density as heavy weight : greater than 3000 kg/m3; normal weight : between 2000 to 3000 kg/m3 and light weight : less than 2000 kg/m3. This ADVISORY NOTE applies only to normal weight aggregates and is intended to highlight on the compliance requirements for use in concrete works.

The aggregates used for concrete works in the Emirate are of normal weight and comprise :
Fine aggregate : beach sand, wadi sand, screened / crushed or blend of these;
Coarse aggregate : crushed stone or crushed wadi gravel.

2. AGGREGATE SOURCES

There are two important reports relating to aggregate resources. First, the "Mineral Survey of Northern Emirates" by Hunting Geology and Geophysics Limited (1975), describes the geological outlines of the Emirates.
Second, "General Survey of Aggregate Resources in UAE" by C.E.B.T.P. (France) (1977) examines the mineralogical, physio-chemical characteristics of aggregates being used then and proposes new sources for suitable aggregates, namely wadi plains and some mountains.

The sources of concrete aggregates which are being worked are :-

[a] Stone quarries of limestone and gabbro.

[b] Gravel pits in wadi beds and terraces.

[c] Sand pits near beaches.

2.1 Limestone Quarries

These are predominantly in Ras-Al-Khaimah area and at Jabel Roudah. At R.A.K., residual penetration in the cracks and fissures in the rock mass sometimes contaminates the quarried product. It is difficult to detect visually in the processed material but breaks down on wetting. In some quarries of R.A.K. area, a dark shelly bed occurs which when crushed is difficult to distinguish visually from sound aggregates. The presence of significant amounts of either material would be revealed by high aggregate crushing values and sulphate soundness losses. In Jebel Roudha quarries, there are some accumulations of residual soil. These are however quite easy to detect.

2.2 Gabbro Quarries

They are predominantly occurring in the mountain areas of Hatta, Dhaid, Filli, Khadra and Siji. The wadi gravels are extremely variable both in rock type and grading. In the mountains, the gravels may consist predominantly of one rock type. When wadis emerge from the mountain alluvial fans are formed. The rock types in these are varied as they emanate from different sources in the parent rock. In general, grading becomes finer with distance from mountains. Sands are also obtained by crushing coarser material. These materials are predominantly serpentine sometimes chert and volcanic low graded sediments increase in content.

2.3 Calcareous Sands

These are the beach sands which are low in silica and iron on the west coast, Dubai and Northern Emirates but higher silica and iron on the east coast (Kalba). The beach sands are composed of debris from skeletons of marine organisms, the grains are therefore platy in shape and tend to be single sized. The main constituents are shells (calcium carbonate) upto 90% has been reported and such high percentages reduce, to some extent, workability of concrete mixes, strength and impermeability of hardened concrete.

Beach sands also contain inadmissible amounts of salt contaminants. The beach sand is probably the greatest single source of excessive chlorides in concrete mixes and has been responsible for expansive corrosion of steel reinforcement and the rapid structural deterioration that follows. Beach sands can also be contaminated by sulphates which cause expansion and spalling of concrete.

3. PETROGRAPHIC EXAMINATION

Petrographic examination of concrete aggregate is visual examination and analysis in terms of both lithology and properties of the individual particles. It is included as an adjunct to geologic investigations for acceptance or rejection of the source deposits. It contributes to several ways to the investigation. Probable performance of concrete aggregates in two general ways is estimated by petrographic examination. First, the examination reveals the composition and physical and chemical characteristics of the constituents. From this information, probable response of aggregates to such phenomena as attack by cement alkalis, wetting - drying and heating and cooling, usually can be estimated. Second, the examination establishes the fundamental nature of aggregates so that aggregates from unfamiliar sources can be compared with aggregates upon which information is available.

It should be emphasized that petrographical group classification of the constituents of the aggregate does not imply their suitability for concrete making; unsuitable material can be found in any type of rock so that tests on aggregates alone are of help in assessing the required properties.

4. SHAPE AND SURFACE TEXTURE

The important external characteristics of aggregates include their shape and surface texture. The shape classification is described in BS 812 as rounded, irregular, angular, flaky, elongated. Test for obtaining quantitative assessment of particle shape are also given. As regards surface texture, the characteristics are grouped, based on visual examination, into six headings viz. glassy, smooth, granular, rough, crystalline and honey-combed.

The equidimensionality and angularity of coarse and fine aggregate particles, the degree of relief of their surfaces, are all characteristics that significantly affect the properties of both fresh and hardened concrete. Differences in particle shape and surface texture, will affect the bulk void contents and frictional properties of the aggregates and in turn, affect the volume of cement paste that must be used to fill the voids in the aggregate and then provide extra volume of cement paste to "float" the aggregate and provide the mass with enough plasticity to achieve thorough mixing and dispersion of the ingredients. In the hardened concrete, the compressive and flexural strengths, the elasticity and the distribution of stresses within the concrete are influenced by particle orientation, the shape and surface texture.

Maximum degree of packing resulting in minimum void space can be achieved by aggregates of good cubic shape. Elongated and flaky particles must therefore be minimised. Good quarrying and crushing practices must be exercised to produce high quality aggregates. The shape of the aggregate produced is governed by the type of secondary crusher and its relation to the primary as well as the rock types. A low reduction ratio - the maximum intake size compared to the maximum output size - at each stage, favours the production of near cubical aggregates. A reduction ratio of approximately 4 : 1 should give good results.

4.1 **Flakiness Index**

Aggregate particles are classified as flaky when they have a thickness (smallest dimension) of less than of 0.6 of their nominal size. The index of an aggregate sample is found by separating the flaky particles and expressing of their mass as a percentage of the mass of the sample tested. This test is not applicable to material passing a 6.30mm BS test sieve or retained on a 63.00mm BS test sieve. When the flakiness index has been determined for individual size fractions, the overall flakiness index is calculated as the weighted average of the individual size fractions.

Flakiness index when determined in accordance with BS 812 Section 105.1 : 1985, the maximum limits for combined coarse aggregates are 50 for uncrushed gravel and 40 for crushed rock or crushed gravel. However, lower limits are recommended in Table 2.

5. GRADING

The grading of aggregate has a pronounced effect on the strength of concrete. The grading of fine aggregate has a much greater effect on workability of concrete than does the gradings of the coarse aggregate. Experience has demonstrated that either very fine or very coarse sand, or coarse aggregate having a large deficiency or excess of any size fraction is usually undesirable. The grading of the aggregate is governed by the screening operation. The most common causes of badly graded aggregates are overloading screens and attempting to screen damp material. Screens should be regularly checked for clogging and wear.

Graded aggregates for concrete should contain particles ranging in size from largest to the smallest. Gradings of aggregate, coarse, fine and all-in, falling within the limits of either BS 882 : 1983 or ASTM : C33-86 could be followed.

5.1 Coarse Aggregate

It is advisable that coarse aggregate should be obtained in separate single sizes rather than as one graded material. The component sizes can then be combined in the concrete mixes within the limits permitted in the specification.

5.2 **All-in Aggregate**

All-in aggregate which is composed of both fine and coarse aggregate, is seldom used for structural re-inforced concrete work because grading may vary considerably. To ensure that proper amount of fine aggregate is present, the separate delivery of and batching of coarse and fine aggregate is preferable. Supply of all-in aggregate is not a practice being followed in the Emirate.

5.3 Fine Aggregate

A wide range of gradings of fine aggregate is acceptable for concrete. It is however to be noted that the use of very coarse sand in concrete mixtures results in harshness, bleeding and segregation; and the fine sand requires a comparatively a large amount of water to produce the necessary fluidity and also tends to cause segregation. The BS 882 gives overall limits for grading and also additional limits for grading types designated as C, M and F. For standard mixes of concrete, grading type F may not be recommended (refer clause 6.1.3.4 of BS 8110 : Part 1 : 1985, Structural Use of Concrete) and is governed by the coarseness of the coarse aggregate.

Beach sands and crushed / uncrushed wadi gravel sands are the two sources of fine aggregates available. Both of them are being used in concrete works either individually or in combination.

5.3.1 **Beach Sand**

Beach sands are often single - sized which can make mix design difficult. The grading is usually be of type F and finer and sometimes coarser. The coarser material would then be comprising predominantly broken shells and large shell fragments. Any theoritical improvement by the use of such 'coarser' sand is likely to be nullified by the shape of shell fragments. No sooner such coarse shell fragments are discarded, the grading of remaining portion would be of type F.

As is well known, beach sand is contaminated with salts - chloride can be removed by washing but not sulphate. Normally material finer than 75 micron would be within acceptable limits. Also effective washing may be very expensive and not feasible. Another problem with washed beach sand is the dispersion and movement of chlorides within the stockpile mass which may be difficult to control.

5.3.2 Wadi Sand

Material of sand size can occur either on its own or in association with coarser gravel sizes. The sand tend to be rounded and darkish in colour and consist of a variety of rock types. Sands are also produced by crushing the larger sizes.

Natural sands are the products of weathering and often contain a high proportion of absorbent, silt and clay size material. Even crushed gravel sands, the finer fractions will tend to contain a high proportion of weathered material. The problem with wadi sand is the presence of high and the variable dust content very much in excess of allowable limits, inevitably leading to variable water demand. It is observed that the material finer than 75 micron is generally very much higher than the specified limit of 3%. It is possible to achieve this figure by selective winning and screening methods and the use of dust extraction equipment (washing / blowing).

It is very important that while washing, fine material passing 300 micron sieve is not excessively removed, otherwise the resulting concrete mix will be lacking in cohesion and in particular may be unsuitable for a mix which is to be placed by pump. From this point of view, fractions finer than 300 micron size should be of the order of 30%.

It is to be noted that wadi sands are normally free from salt contaminants, a point in its favour.

5.3.3 Recommendation

Beach sand is too fine, need to be washed carefully and it's salt content checked frequently both on-site and in the laboratory. Exercising control over salt contents has been proven to be difficult. Even if the chlorides were to be within permissible limits, the grading may be unsuitable for structural concrete works. Hence, use of beach sand in re-inforced concrete works is advised to be avoided.

Use of wadi sand alone in concrete mixes, usually be harsh calling for assistance of suitable admixtures. Since fine fractions below 300 micron size present in the sand has an important bearing on cohesiveness of the concrete mix, perhaps an addition of a certain percentage of beach sand could be considered to overcome such a deficiency. Blending of the two sands is to be controlled such that salt contaminants are within permissible limits and at the same time arrive at a blend to improve the workability of the mixes. However, if chlorides are not controlled to the required degree, then possibility of exceeding the limits in the blended sand can be disastrous. Since difference in chloride levels from batch to batch may induce corrosion due to potential difference even if chlorides are within limits.

6. SHELL CONTENT

Some aggregates, particularly those from marine sources, may contain hollow and / or flat shells which if present in sufficient quantities affect the properties of fresh and hardened concrete. BS 882 specifies limits of shell contents in coarse aggregates and "no requirement" in fine aggregates.

The coarse aggregates used in concrete works can easily comply with the specified limits as they normally do not contain shells. The beach sand are the one that contains large amounts of shells and since no requirement on shell content limits are specified, they too comply. However, there should be some restrictions on their use, as some beach sands comprise large size shell fragments. These tend to affect the workability of concrete but are not themselves harmful in the reinforced concrete though limit may be set on the content. Coarse screenings retained on 2.36mm sieve could be rejected if they contain predominantly shells. There is no requirement of shell content in beach sands passing 2.36mm size sieve.

7. MECHANICAL PROPERTIES

Aggregates must posses a reasonably high degree of inherent strength and stability to resist, without detrimental degradation, the stresses, impacts and wear actions to which it may be exposed both in concrete production, operations and ultimately in concrete in service. The roughest treatment to which an aggregate may be subjected in terms of mechanical forces and attrition is in the concrete production process. In pavements and hydraulic structures subject to eroding forces may expose aggregate near or at the surface to a variety of impact and abrasive stresses which will be of overriding importance in aggregate evaluation and selection.

British standards assess the mechanical strength of aggregates by 10% fines test and as an alternative an impact test while the ASTM specification by abrasion test. The kind of determination of mechanical property of the coarse aggregate should be stated. The property should be proved by fulfilling any one of the limiting values corresponding to the test method used.

8. SOUNDNESS

Certain aggregates which are apparently suitable for use, when tested by the normal test procedures, may fail in service in certain circumstances. Such aggregates are said to be unsound. The sulphate soundness (ASTM test for soundness of aggregates by use of sodium sulphate and magnesium sulphate C-88) is mostly used for determining the overall quality of aggregate. The British Standards has recently formulated the test method for determination of soundness, BS 812 : Part 121 : 1989 by use of magnesium sulphate. The method is applicable to aggregate passing a 14.0mm test sieve but is retained on a 10.0mm test sieve.

Although individual particles behave differently in concrete, it is desirable to have general criteria for the acceptance of an aggregate. The tests determine aggregate resistance to disintegration by saturated solution of sulphates. It furnishes information helpful in judging the soundness of aggregates subject to weathering action, particularly when adequate information is not available of the new and unfamiliar sources. The test does indicate weaknesses in aggregates. If the specification limits are used carefully together with sound engineering judgment, the test is certainly useful because of the relatively short time needed to perform it.

According to C.E.B.T.P. report, certain types of serpentine minerals are deleterous. They are highly sensible to water in the long run resulting in numerous disorders. In so far as risks do exist, a severe control of the materials specially those coming from the serpentine belt. The report recommends Soundness Test may be adopted considering that degradation of aggregates by saturated solutions of sulphates.

It should be noted that reproducibility of test results are poor. Further the lack of correlation between the sulphate loss and the performance of aggregates in field concrete militates against setting inflexible acceptance limits for the sulphate loss and disregarding judgment in interpreting the results. The limits specified in ASTM C-33 are 15% in fine aggregates and 18% in coarse aggregates when magnesium sulphate is used in both cases. But a more stringent figures are recommended.

9. DELETERIOUS SUBSTANCES

The deleterious or harmful substances can be classified in four groups according to their composition or physical properties.

[1] "Clay and Silt" refers to incoherent finely disseminated materials finer than 75 microns. This includes the fine material that occur in lenses and layers in gravel deposits and the fracture fines produced by crushing gravel and rocks. Fracture fines consisting of grains smaller than 75 microns and crusher dust which before washing, usually adheres to the surfaces of the crushed particles. Large amounts of dust are produced when aggrillaceous limestones and gravels are crushed as has been the case in the local resources.

[2] The term "Clay Lumps" means lumps of clay in the aggregate which remain cohesive during processing and are not disseminated throughout the aggregate. The lumps contain silt or very fine sand and often held together by clay as has been observed to occur in R.A.K. aggregates.

[3] "Friable and Soft" particles are usually distinctly or deeply weathered rocks or mineral agglomeration.

[4] "Organic Impurities" may consist of plant roots, twigs and other vegetable materials. These may occur as contaminants in particles or as particle coating.

9.1 Effect of Deleterious Substances on Concrete

Large amounts of fines, materials finer than 75 microns, in an aggregate increase the water requirement resulting in excessive drying, shrinkage and low strength of hardened concrete. The adverse effect is greater when the fines contain clay minerals, particularly those of the swelling group such as montmorillonite as they are likely to occur in serpentanite. These minerals increase the amount of volume change in the hardened concrete and cause the formation of micro-cracks.

When clay lumps survive mixing and placing, and occur at the surface of hardened concrete, they may wear and cause unsightly pits and pop-outs.

Large quantities of friable and soft particles cause a reduction in strength. Smaller quantities significantly lower the abrasion resistance of concrete surfaces exposed to severe attrition and impact.

Organic impurities consisting of principally of tannins retard the hardening and reduce concrete strength, particularly at early ages.

9.2 Limits for Deleterious Substances

BS 882 : 1983 gives limits for material finer than # 200 (75 micron) sieve both for fine and coarse aggregate types, while ASTM C 33 - 86 gives tests requirement for organic impurities besides the limits for material finer than 75 micron size.

10. ALKALI AGGREGATE REACTION IN CONCRETE

Concrete can deteriorate as a result of an interaction between alkaline fluids, principally originating from the portland cement; and reactive minerals in certain types of aggregates. The mechanism of deterioration is known as alkali aggregate reaction (AAR). It can occur in a number of forms, the most common being alkali silica reaction (ASR).

Silicon aggregates are the most common type susceptible to alkali attack. Of the different minerals in silica group, opal which has a very disordered structure is the most reactive form of silica; while quartz which has a well ordered structure is normally unreactive. The conditions necessary for the reaction to occur are :-

(i) Sufficiently alkaline solution in the pore structure of the concrete.

(ii) An aggregate combination susceptible to attack by this alkaline solution.

(iii) A sufficient supply of water.

These three conditions have to be met simultaneously if ASR were to occur. The ASTM C33-86 therefore stipulates that aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere or contact with moist ground should not contain any materials that are deleterously reactive with the alkalis in cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, the aggregates may be used with a cement containing less than 0.6% alkalis calculated as Na2O.

If the amount of potentially reactive material in the aggregate exceeds 0.5% by weight of total aggregate, the alkali available from the cement should not be allowed to exceed 3 kg/m3 of concrete.

ASTM specification gives two test methods for potential reactivity of aggregates and cement aggregate combination C 289 and C 227 respectively.

The British Research Establishment Digest 330, lists aggregates composed of the rock or artificial material types that are unlikely to be susceptible to damaging attack by cement alkalis. According to this list, the gabbro and limestone which are the main sources for aggregates in UAE are not susceptible.

Alkali aggregate reaction has not been identified as a significant cause of deterioration of concrete in U.A.E. Nevertheless, contract specifications always specify use of cements containing low alkali cements equivalent Na2O of 0.6% or less. It is advisable to test the aggregates of and on for their reactive characteristics.

11. SALT CONTAMINATIONS

Aggregates in particular beach sands, contain excessive amounts of chloride and sulphate salt contaminations.

Whenever there is chloride in concrete, there is an increased risk of corrosion of embedded metal. The higher the chloride content, the higher the rate of hydration reaction, or if subsequently exposed to warm moist conditions, the greater the risk of corrosion. Chlorides may also adversely affect the sulphate resistance of concrete.

Sulphates are present in most cements and also in aggregates; excessive amounts of water soluble sulphate from these or other mix constituents can cause expansion and disruption of concrete. As no fully satisfactory test method is currently available for the determination of the water - soluble sulphate content of a mix, the acid - soluble content is taken to be equivalent to the total water soluble content.

BS 882 : 1983 and BS 8110 : Part 1 : 1985 gives guidance for limits of chlorides and sulphates in aggregates and concrete. However, considering the high temperature and humidity conditions prevailing in the Emirate, rather more stringent limits are being specified by Dubai Municipality.

11.1 Site Testing of Sands for Chloride Salt Contaminant

For exercising control over chloride salt in sands, it is strongly recommended that rapid test methods be used regularly on site as preliminary checks before resorting to the more sophisticated analytical methods.

BS 812 : Part 117, Appendix 'B' describes a qualitative field test for determination of chlorides ions referred to as 'Quantab Test'.

Another field oriented method is by the use of 'Test Kit' developed by Dubai Municipality.

If these field tests indicate border line cases, then full chemical determinations of chloride should be carried out to verify the rapid readings and also to fully ensure that the chloride content is within the limit.

12. SPECIFIC GRAVITY AND ABSORPTION

Specific gravities give us the means to convert weights to absolute volumes required in the mix design exercise for proportioning. Specific gravities can also be used for identification or acceptance purposes. Three specific gravities are determined :-

(i) Bulk specific gravity.

(ii) Bulk specific gravity (saturated surface dry basis, SSD).

(iii) Apparent specific gravity.

Absorbed water is the unbound water contained in the permeable pores of the aggregate particles that may be driven of by oven drying at 100 to 110 degree celsius.

The water carried by an aggregate that is not contained in the pores is surface water or free water. The difference in the two waters is that absorption is a property of the aggregate, while the free water is variable and a property of the aggregate only in that the capacity to carry free water is related to surface area. Absorption is expressed as a percentage of the oven dry weight. Because of the surface area per unit volume of material, for similar minerals, absorption is generally higher for fine aggregates than for coarse aggregates.

In batching concrete, most aggregates are to be in SSD plus condition. If this is not the case, aggregates can absorb mixing water and affect the workability of the mixture. Surface water is part of the mixing water in concrete mixes. For coarse aggregate, it will range from 1 or 2 percent. Fine aggregate free moisture range from 3 to 8 percent with 4 to 6 percent being about normal.

Knowledge of and adjustment for surface moisture is the key to successful consistency control in concrete batching and mixing operations. The aggregate stockpiles will have moisture gradients from top to bottom so that systematic removal of material from a stockpile will allow moisture contents to change gradually. Bins left filled overnight will have a concentration of moisture at the discharge gate making it necessary to treat the first few batches for moisture adjustments on individual basis.

13. **DRYING SHRINKAGE**

Some aggregates change volume considerably from the wet to dry stage and identified as "Shrinkable Aggregates" and this may affect the concrete in which they are incorporated. No limit is quoted in the specification. Typical values for local aggregates (serpentinite) are likely to be about 0.05%. The significance of this property is that the shrinkage of the aggregate can be a major component of shrinkage in concrete. Values greater than above 0.05% should be treated with even more caution as shrinkage cracking has tended to be a major deficiency in local concretes.

The increased shrinkage of concrete may cause problems in structures whose design is based on the properties of "normal" aggregate concrete. This can result in deterioration of exposed concrete and excessive deflections of reinforced concrete unless special measures are taken.

The BS 812 : Part 120 : 1989 describes the method for determining the shrinkage and on the basis of this, aggregates with drying shrinkage upto 0.075% is classified as category A, and aggregates exceeding 0.075% as category B. Category A, aggregates are suitable for all concrete purposes. Category B, aggregates are recommended for use in positions where complete drying out never occurs i.e. members not exposed to weather.

14. **QUALITY APPROVAL**

14.1 Storage

Storage arrangement should be made so that aggregates are kept clean and different sizes are kept apart. Aggregates from the lower part of the stockpile should be avoided since the silt size material tends to accumulate. Stockpile should be built up in horizontal or gently sloping layers not by end dumping.

Materials can be easily be contaminated by the salts in the ground. This can happen if the capillary rise zone extends into the stockpile. To combat this, stockpile should be situated on hard surfaces or concrete apron slabs which drain away from the stored material.

The wadi sand often becomes quite dusty and contamination of dust occurs due to wind. The stockpile should be dozed regularly to minimize undue segregation and dust accumulation.

14.2 Sampling

The aim of sampling is to obtain a sample representative of the average quality. Sampling of aggregates should be done in accordance with BS 812 : Parts 101 & 102 and / or ASTM D-75. All stages of sampling leading to the production of proper test portions require skill and care. The sample should be taken by a responsible and experienced person who understand sampling standards.

Aggregate often segregate by size, fines tends to accumulate, wind would separate dry fines. Chloride salt contaminants in beach sands may go into solution due to high humidity / dew and / or water. The solution trickles / migrate into the mass of the stockpile and salts re-crystalize because of evaporation. The salt concentration then increase with depth from the surface of the heap.

Aggregates that are badly segregated present problems of varying complexity and in many cases it is better to wait until they are moved. Sampling near the ground should be done with care to avoid contamination with, for example, residue of previous material.

The procedure for sampling aggregates consists of taking sufficient number of increments (i.e. scoop fulls) from different parts of the batch such a way to represent average quality and to provide the required quantity of aggregate for the test to be subsequently to be made.

When sampling from heaps of aggregate, the increments should be taken from the positions evenly distributed over the whole area of the heap, not from the surface as such but from at least 150mm in from the surface.

When sampling for test portions required for determination of chloride salt contents in beach sand stockpile, keeping in view the likely redistribution of the salt concentration, the sample increments should be taken both from the surface as well as below the surface of the heap at least 150mm and 300mm from the surface.

The standard gives guidance for sampling materials in motion i.e, from a falling stream, from conveyor belts, etc.

The aggregation of the sampling increments yields the bulk sample, the size of which should at least be four times the quantity of aggregate required for each of the standard test to be carried out. Test portions complying with requirements of the designated tests are obtained by sample reduction operation of the bulk sample.

14.3 Standards

The standards for specific tests are shown in Table 1.

14.4 Acceptance Tests

Approval of aggregates that will be used in the concrete and their sources is the first step. Prior to delivery to the site acceptance tests nos 1 to 12 listed in Table 1 should be carried out on representative samples. Further, tests for potential reactivity and drying shrinkage are required. In case the suppliers were to produce test certificates which are carried out at the approved laboratories for the materials to be supplied, the tests need not be carried out and the results thereof is considered.

14.5 Routine Testing

It is essential that the aggregate properties are strictly controlled within specified limits so that variations are kept to a minimum. The best method of ensuring that this is so, is by means of regular routine testing. Frequency of testing should be high at the start of the production until the required degree of quality control is well established. Also the frequency depends on the amount of concrete being produced, the manner of production (e.g. readymix supply, central batch plants, etc.) and the stage of the job.

The routine tests that are to be carried out within the periods stated are shown in Table 1. This applies to a medium sized job.

14.6 Specification Limits

The limits for physical, chemical and mechanical properties are listed in Table 2.

TABLE 1 - FREQUENCY OF ROUTINE TESTS ON AGGREGATES

(WHEN CONCRETE IS BEING PRODUCED REGULARLY)

(REFER TABLE 2 FOR PERMISSIBLE LIMITS)

Sr.No.	Kind of Requirement - Test Method	Test Frequency Rate
1.	Grading - BS 812 Part 103	Each two weeks or per 100 m3 whichever is more frequent.
2.	Mterial finer than 0.075mm - BS 812 Part 103	- do -
3.	Clay lumps and Friable particles - ASTM C 142	- do -
4.	Organic impurities - BS 1377 Test 8	Each month or per 200 m3 whichever is more frequent.
5.	Water absorption - ASTM C 128 / C 127	- do -
6.	Specific Gravity - ASTM C 128 / C 127	- do -
7.	Shell content - BS 812 Part 106	Each two months or per 100m3 whichever is more frequent.
8.	Particle shape - BS 812 Parts 105.1, 105.2	- do -
9.	Acid soluble chlorides, Cl	
	Qualitative - BS 812 Part 117 Appendices A/ B	On each delivery to site
	Quantitative - BS 812 Part 117 Appendix C	Each week if result is more than 75% of the limit and Each month if result is less than 75% of the limit.
10.	Acid soluble sulphates, SO3 - BS 812 Part 118	Each two weeks if result is more than 75% of the limit and Each two months if result is less than 75% of the limit.
11.	Soundness, MgSO4 (5 Cycles) - ASTM C 88	Each two months
12.	Mechanical strength	
	10% fines or impact value - BS 812 Parts 111, 112	Each three months
	Los Angeles abrasion - ASTM C 131 / C 535	- do-
13.	Moisture variation in sand - by Moisture Meters	Twice daily

Note : Drying Shringkage and potential reactivity of aggregates shall be determined initially at the start of the project or whenever there is a change in the source of supply.

TABLE 2 - LIMITS FOR PHYSICAL, CHEMICAL & MECHANICAL PROPERTIES OF AGGREGATES FOR CONCRETE

Sr. No.	Kind of Requirement	Test Methods		Permissible Limits	
		BS 812 :	ASTM :	Fines	Coarse
1.	Grading	Part 103		Standard	Standard
2.	Material finer than 0.075mm	Part 103			
	Natural, uncrushed / crushed			max. 3%	max. 1%
	Crushed rock			max. 7%	max. 1%
3.	Clay lumps and friable particles		C 142	max. 1%	max. 1%
4.	Light weight pieces		C 123	max. 0.5%	max. 0.5%
5.	Organic impurities, Test 8 of BS 1377			max. 0.05%	
6.	Water absorption		C 128 / C 127	max. 2.3%	max. 2%
7.	Specific gravity (apparent)		C 128 / C 127	min. 2.6	min. 2.6
8.	Shell content in aggregates	Part 106			
	Coarser than 10mm				max. 5%
	Between 5mm and 10mm				max. 15%
	Between 2.36mm & 5mm			max. 10%	
	Finer than 2.36mm			Note 1	
9.	Particle shape				
	Flakiness index	Part 105.1			max. 25%
	Elongation index	Part 105.2			max. 25%
10.	Acid soluble chlorides, Cl	Part 117, Appendix 'C'			
	For reinforced concretes made with				
	SRPC cements			max. 0.03%	max. 0.01%
	OPC and MSRPC cements			max. 0.05%	max. 0.02%
	For mass concrete made with				
	SRPC cement			max. 0.03%	max. 0.02%
	OPC and MSRPC cements			max. 0.05%	max. 0.04%
	For prestressed concrete and steam cured structural concrete			max. 0.01%	max. 0.01%
11.	Acid soluble sulphates, SO3	Part 118		max. 0.3%	max. 0.3%

NOTE 1 : There is no requirement of shell content in sands passing 2.36mm size sieve.

Continued

TABLE 2 - LIMITS FOR PHYSICAL, CHEMICAL & MECHANICAL PROPERTIES OF AGGREGATES FOR CONCRETE (Continued)

Sr. No.	Kind of Requirement	Test Methods		Permissible Limits	
		BS 812 :	ASTM :	Fines	Coarse
12.	Soundness, $MgSO_4$ (5 cycles)		C 88	max. 12%	max. 12%
13.	Mechanical strength				
	10% fines value	Part 111			min. 100 kN
	or Impact value	Part 112			max. 30%
	Los Angeles Abrasion		C 131 / C 535		max. 30%
14.	Drying shrinkage	Part 120			max. 0.05%
15.	Potential reactivity, Note 2				
	Of Aggregates, Chemical Method		C 289	Innocuous	Innocuous
	Of Cement-Aggregate Combination		C 227	Six month expansion 0.10% max	

NOTE 2 : Aggregates may initially be assessed for its reactivity in accordance with ASTM C289 and if potential reactivity is indicated, then mortar bar tests in accordance with ASTM C227 shall be carried out.

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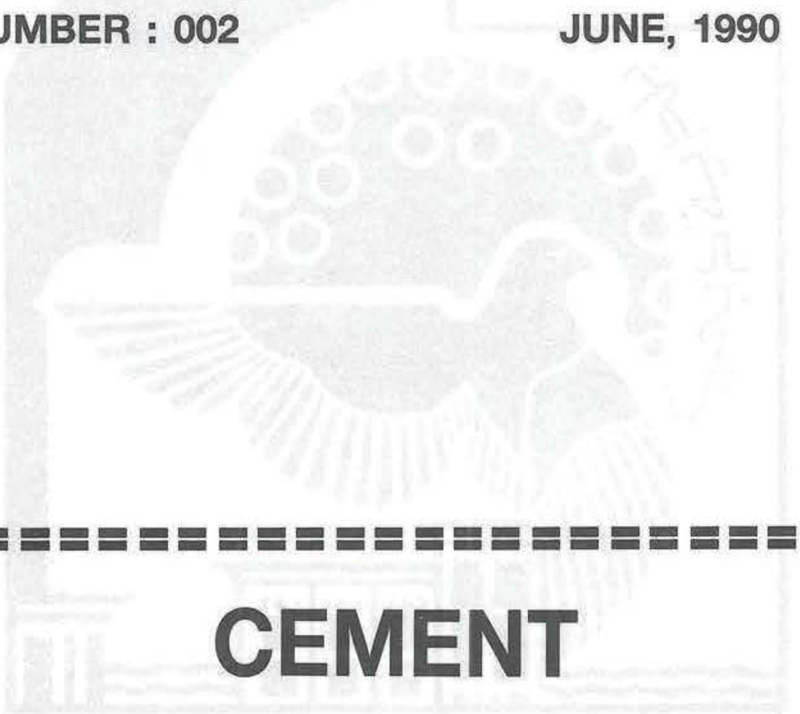

CEMENT

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ADVISORY NOTE
ON CEMENT

DUBAI MUNICIPALITY
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1. INTRODUCTION

Cements may be defined as adhesive substances capable of uniting fragments or masses of solid matter to a compact whole. Portland cement is a hydraulic cementing material for mortar and concrete. It is a product obtained by intimately mixing together calcareous and argillaceous or other silica, alumina and iron oxide - bearing materials, heating them to partial fusion at a clinkering temperature and grinding and pulverizing the resulting clinker with an addition of small proportion of gypsum.

Cement is a manufactured chemical, although it be conditioned by the natural raw materials. The properties of cement from different sources can vary substantially, even if the cement complies with the same specification. However, provided that there is effective control of the raw materials and the manufacturing process, the variation between different deliveries from the same source is not likely to be significant.

The setting of cement is a chemical reaction between cement and water, not a drying process. This reaction is called hydration. It evolves heat and is irreversible. Setting is a gradual stiffening process which is defined by arbitrary limits in the relevant standards. Strength continues to gain after hardening and may take many years to reach its ultimate value. A small proportion of gypsum which is added to the cement during the manufacture, regulates the rate of setting when the cement is mixed with water.

The main chemical phases in Portland cement are alite, which is essentially tricalcium silicate (C3S), belite, which is essentially dicalcium silicate (C2S), tricalcium aluminate (C3A) and tetracalcium aluminoferrite (C4AF). The first two of these, the C3S and C2S, are the main cementing compounds, with the C3S contributing most to strength at early ages and the C2S at later ages. The products of hydration of the calicium silicates are CSH (calicum silicate hydrate) gel (the main cementing and pore filling compound) and calcium hydroxide Ca(OH2).

2. TYPES OF CEMENT

Mainly there are two categories of cements :

Portland cements, those in which Portland cement clinker is a major constituent, and

Portland cement blends, a range of cements manufactured from Portland cement with varying proportion of pozzolonas such as ground blast furnace slag, pulverized fuel ash, etc. Such cements are sometimes specified as an alternate to sulphate resisting Portland cement, but their use is strictly to be controlled as their performance has not yet been fully evaluated in the environment prevailing in the Emirate.

This ADVISORY NOTE deals with Portland cements only.

There are many varieties of Portland cements. These are Ordinary, Moderately sulphate resisting, Sulphate resisting, Super sulphated, Rapid hardening, High early strength, Controlled fineness, Low-heat and White. Some of them are also produced with air-entrainment when desired. As their names imply, they exhibit special characteristics or properties which are of value in appropriate circumstances. They have in common the fact that they all contain the same active minerals - only the proportion of each is different.

Of the various types of Portland cements, ordinary, sulphate resisting and white types are manufactured in U.A.E. The cement plants in the country have however, the capability to manufacture any type of cement, provided the order is for a sizeable quantity. Locally available cements are generally manufactured to either BS or ASTM specifications. The commonly used types of cement are :

	BS	ASTM C150
Ordinary Portland Cement (OPC)	12	Type I
Controlled fineness Portland cement (CFPC)	12	
Moderately sulphate resisting Portland cement (MSRPC)		Type II
Sulphate Resisting Portland Cement (SRPC)	4027	Type V
Low heat Portland cement (LH)	1370	

[a] **Ordinary Portland Cement (OPC), BS 12 and ASTM Type 1**

For use when the special properties specified for any other type are not required. Develops strength sufficiently rapidly. It is not resistant to attack by sulphates, but performs better than SRC cements, BS 4027 and ASTM Type V, in terms of chloride - induced - corrosion of reinforcement.

[b] Controlled Fineness Portland Cement (CFPC), BS 12

For use when rate of heat evolution during hardening is to be medium. It makes it easier to remove excess water from the concrete during compaction. The compressive strength development is slightly less than OPC, but its performance in respect of sulphate attack and corrosion of reinforcement is similar to OPC.

[c] ASTM Type II Cement

For general use, more specially when moderate sulphate resistance or moderate heat of hydration is desired. If this cement contains 5% or more C3A, it may give as much protection against chloride - induced reinforcement corrosion as that given by OPC.

[d] Sulphate Resisting Portland Cement (SRPC), BS 4027 & ASTM Type V

Has a modified chemical composition compared with OPC to provide resistance to attack by sulphates. It's rate of heat of evolution during hardening is low to medium. It gives significantly less or no protection against chloride - induced corrosion than OPC BS 12 ASTM Types I & II.

[e] Low Heat Portland Cement (LHPC), BS 1370

For use when lower rate of heat of evolution is desired. It has lower rate of strength gain, and lower final strength than OPC. It usually offers better resistance to attack by sulphates than OPC.

3. SUITABILITY OF CEMENT TYPES

The most widely used cement, the world over is ordinary portland cement. In U.A.E. practice, the usual reasons for using cements other than OPC are governed by the chemistry of the ground conditions and adverse exposure conditions. For such an environment, the most desirable properties are either to reduce the effects of chemical attack on the concrete or to change the rate of gain of strength and heat evolution.

3.1 Heat Generation

The cement hydration process causes significant generation of heat. The ambient temperature and temperature of fresh concrete have an affect on heat of hydration. As the temperature of hydration is raised, the rate of evolution of heat increases, although, for each type of cement, the heat of hydration remains unaffected. Excessive heat generation produce micro-cracking and poor development of hydration products.

Problems of differential temperature stress and thermal cracking during the earlier stages of hardening can be acute in hot climates. The choice of the cement to be used is an important consideration. The rate of evolution of heat of hydration is a function of fineness of grinding of cement. Hence, fineness of cement is more critical than its compressive strength. The use of controlled fineness cement (CFPC) is more appropriate than the ordinary cement (OPC), when lower heat of hydration is required. Fineness of cement i.e. surface area of 225 to 275 m.sq./kg would normally be appropriate.

Significant generation of heat is definitely a disadvantage when large concrete sections are cast because of the temperature gradients which can be set up. Therefore, for large pours and massive construction, low heat portland cement (LHPC) conforming to BS 1370 and ASTM Type IV is used. It differs from OPC in composition and fineness of grinding. It gains strength more slowly than OPC, produces heat less rapidly, and therefore does not raise the temperature of the concrete to the same extent.

Control of cement temperature is a key factor in producing durable concrete in hot arid climates. The initial temperature of concrete should normally not exceed 38 degree centigrade. Hence the need to keep the plant and materials cool.

3.2 Tricalcium Aluminate Content

The tricalcium aluminate (C3A) is one of the rapidly reacting component of cement. Cements which contain low proportion of C3A tend to produce heat less rapidly than those with high C3A cements. Cement with a high reactivity and fast hardening rate, usually containing high amount of C3A, may increase the water demand of concrete and adversely affect the placeability of concrete due to extensive slump loss, particularly at elevated temperature. The resulting elevated W/C ratio of concrete will definitely have a negative impact on the permeability of concrete.

The fast rate of hardening of C3A rich cement at elevated temperatures may also cause the formation of a coarser, more permeable micro-structure of the hardened cement paste, allowing aggressive salt penetration more readily. Hence, the need to set maximum limits of C3A content in cement. As the BS 12 does not specify any maximum limit on C3A, a value of 13% maximum is recommended. In this respect, the use of ASTM moderately sulphate resisting cement (Type II) which has a maximum C3A limit of 8% is more advantageous.

The role of C3A in providing resistance to salt attack is discussed in para 3.3 below.

3.3 **Resistance to Salt Attack**

SRPC cement is specified to combat the effects of chemical sulphate attack. The tri-calcium aluminate (C3A) is the component of cement which reacts with sulphates to form calcium sulphoaluminate (CSA) and expands. If the reaction is with the small amount of sulphates, already in the cement, the expansion is harmless and takes place quickly before the cement is set, but sulphates in the aggregate or from ground water is released slowly and reacts with C3A after the concrete has hardened. This reaction cause solid volume to increase which may lead to disruption of concrete. Consequently, SRPC cement has a limited C3A content. ASTM Type V has a maximum tricalcium aluminate content of 5% whereas BS 4027 stipulates a limit of 3.5%. Hence SRPC cement complying with BS is to be preferred.

The tricalcium aluminate (C3A), also reacts with free chlorides present in freshly mixed concrete to form calcium chloroaluminate (C Cl A). Any C3A which has not combined with sulphates in the cement is available to combine with chlorides which might otherwise cause reinforcement to rust. This means that in reinforced concrete, C3A component is very desirable, and sulphate resisting cement may not be appropriate.

The formation of CSA in the plastic conditions is more complex in the presence of C Cl A and the resulting crystals can be some 50 times larger than when no C Cl A is present. This leads to undesirable increase in porosity. Therefore, the use of SRPC is inadvisable where sulphates and chlorides occur together as they often do. In concrete made with SRPC, it is essential to limit the total free chlorides (expressed as Cl) in the mix to the minimal level of 0.15% or less. Further, the permissible chlorides in the mix should be strictly controlled. It is important to note that SRPC do not make fully immune from sulphate attack but only make it better able to withstand moderate concentration of sulphates. Added precautions should be taken to protect the finished concrete from external salt attacks.

4. SPECIFICATIONS OF PORTLAND CEMENT

Different types of cement are made to different specifications. The user has some protection if cement complies with a recognised standard specification, but many of the properties covered by specification are of no practical significance in mix design. Cement should be tested for those properties which are important to the user. Significance of some of the cement specifications requirements to the specifier and designer of the concrete mix is briefly discussed.

4.1 Alkali Content

Cement is the principle source of alkalis which can react with certain types of silica present in the aggregates. The reaction starts when alkalis (sodium and potassium oxides) in the cement enter solution and attack reactive silica or silicates in the aggregates. As a result, alkali silicate gel is formed which takes up water with a tendency to swell. This swelling may cause abnormal expansion and map cracking of the concrete. This reaction is known as alkali aggregate reaction. Where it is believed this may exist, the alkali content (Na_2O and K_2O) of the cement can be limited to 0.6% equivalent Na_2O, if user requires this. ASTM specifications make an optional provision for this limit for all types of cement but BS make a provision only for sulphate resisting portland cement. Cements sold to these options are normally termed "low-alkali" cement. Though BS 12 specification does not specify the alkali values present in OPC cement, the same could be determined by the test method described in clause 16.2 of BS 4550 : Part 2.

4.2 Compressive Strength

Compressive strength of cement may be some guide to the potential of the cement but for more reliable guidance, it is necessary to test the strength of samples of the actual cement to be used. A 28-day strength requirement is considered to provide a better indication of cement quality than the 7-day strength.

4.3 Soundness

Free lime and magnesia (CaO & MgO) hydrates slowly and may cause expansion and disruption of the hardened concrete if they are present in excess amount. The expansion caused by these, under accelerated ageing conditions can be assessed in what is known as a test of "soundness". The limits of expansion given in the specification indirectly control CaO and MgO contents. For determining the soundness resulting from presence of MgO, the ASTM test method is considered more effective, and hence recommended.

4.4 Insoluble Residue & Loss on Ignition

These requirements are useful in exercising quality control, because they limit the contaminants / adulteration. Further, loss on ignition indicates the amount of hydration or carbonation in the storage which is considered acceptable.

5. SPECIFICATION REQUIREMENTS

TABLE 1 - STANDARD PHYSICAL AND OTHER PROPERTIES

Specification for	ASTM Cements	BS Cements
Setting time (Vicat test)		
Initial, min, max.	45	45 (60 for LHPC)
Final, hour, max.	6.25	10
Soundness		
Autoclave expansion (%) max.	0.8	
Le Chateller (mm), max.		10
Fineness		
Air-permeability (m2/kg), min.	280	OPC : 275 CFPC : 225 SRPC : 250 LHPC : 275
Heat of hydration (KJ/kg)	ASTM Type II	BS 1370 (LHPC)
7-days, max.	290	250
28-days, max.		290

TABLE 2 - COMPRESSIVE STRENGTH OF CEMENT

Average compressive strength (N/mm2) as per specifications should not be less than :

CEMENT TYPE	CONCRETE CUBES TEST AGE (DAYS)		MORTAR CUBES TEST AGE (DAYS)		
	3	28	3	7	28
Ordinary, BS 12	15	34	25	-	47
ASTM Type 1			12.4	19.3	27.6
Controlled fineness BS 12	13	29	23	-	41
Moderate sulphate-resisting ASTM Type II			10.3	17.2	27.6
Sulphate-resisting					
ASTM Type V			8.3	15.2	20.7
BS 4027	10	27	20		39
Low heat, BS 1370	5	19	10		28

NOTE : Test Temperature

BS 4550 : Methods of testing cement requires that setting time and compressive strength tests are carried out at a temperature of 20 +/- 1 degree celsius which is applicable to temperate climates. For tropical climates, test temperatures exceeding 21 degree celsius but not exceeding 35 degree celsius is permitted. When so tested, an increase in testing temperature increases the early compressive strength and reduces the setting time. Resulting altered values should be agreed upon while specifying the cement.

TABLE 3 - STANDARD CHEMICAL REQUIREMENTS

COMPOUND	ASTM TYPE			BS 12	BS 12	BS 4027	BS 1370
	I	II	V	OPC	CFOPC	SRPC	LOW HEAT
Chemical Composition Percentage by Weight							
Silica, (SiO_2), min.	-	20.0	-	-	-	-	-
Alumina, (Al_2O_3), max.	-	6.0	-	-	-	-	-
Ferric oxide, (Fe_2O_3), max.	-	6.0	-	-	-	-	-
Magnesia, (MgO), max.	6.0	6.0	6.0	4.0	4.0	4.0	4.0
Chloride, (Cl), max.	-	-	-	0.1	0.1	-	-
Sulphur trioxide, (SO_3), max.							
When C_3A is less than 8%	3.0	3.0	2.3	-	-	-	-
When C_3A is greater than 8%	3.5	-	-	-	-	-	-
When C_3A is greater than 5%	-	-	-	-	-	-	3.0
When C_3A is less than 5%	-	-	-	-	-	-	2.5
When C_3A is greater than 3.5%	-	-	-	3.5	3.0	-	-
When C_3A is less than 3.5%	-	-	-	2.5	2.5	2.5	-
Loss on ignition, max.	3.0	3.0	3.0	3.0*	3.0*	3.0*	3.0*
Insoluble residue, max.	0.75	0.75	0.75	1.5	1.5	1.5	1.5
C_3A, max.	-	8.0	5.0	-	-	3.5	-
$C_4AF + 2C_3A$, max.	-	-	25.0	-	-	-	-
Alkalis, max. $Na_2O + 0.658\ K_2O$ for low alkali cement	0.6	0.6	0.6	-	-	0.6	-

* For tropical climates 4%, because cement deteriorates more quickly there.

6. SPECIFYING CEMENT

Considering the adverse exposure conditions and harmful salt contaminants in the ground and the aggregates, it is advisable to amend the specification in certain respects with a view to improve their performance. Except as modified in Table 4, the cement should comply with BS or ASTM specifications as appropriate.

TABLE 4 - PROPOSED AMENDMENTS

Amended specification for	ASTM Type II	BS 12 OPC	BS 12 CFOPC
Tricalcium aluminate %	4 - 8	4 - 13	4 - 8
Sulphur trioxide, max.	2.5	3.0	2.5
Fineness Air-permeability	275 - 325	275 - 325	225 - 275
Heat of hydration (KJ/kg) 7-day max.	290	290	290

7. QUALITY CONTROL

7.1 Cement Delivery and Marking

Cement is to be obtained from the approved manufacturers or an approved supplier delivered direct to the site whether in bulk or in sealed bags.

When cement is delivered in bags / packages, the following particulars should be marked on each bag, both in English and Arabic,

[a] type of cement
[b] the number and date of the standard
[c] the net weight of cement contained therein
[d] the name, trade mark of the manufacturer
[e] the country of origin
[f] the date of manufacture

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Similar information should be provided in the invoice documents accompanying the shipment of bulk cement.

7.2 **Certificate**

Each consignment of cement should be accompanied by a certificate affirming that the cement complies with relevant standard. If requested, the manufacturer should include in the certificate the results of the following standard tests :

[a] fineness
[b] setting times
[c] soundness
[d] compressive strength
[e] chloride content (when applicable)
[f] alkali content, equivalent Na2O
[g] tricalcium aluminate contents
[h] total sulphur trioxide
[i] heat of hydration at 7 days

If the manufacturers test report is considered inadequate, test should be carried out as deem necessary in accordance with the standard test methods at DM laboratory. Should the result of such test show the cement does not meet all requirements, the whole consignment is rejected and removed from the site.

7.3 **Storage**

To protect cement from premature hydration after delivery, bulk silos should be waterproof and internal condensation should be minimized.

Storage facilities for bulk cement should include separate compartments for each type of cement used. Storage silo should be drawn down frequently, preferably once a month to prevent cement caking.

Paper bags should be stored clear of the ground, not more than eight bags high and protected by a waterproof structure. As significant strength losses after 4 to 6 weeks of storage in bags in normal conditions, and considerably sooner under adverse weather condition or high humidity, deliveries should be controlled and used in order of receipt.

The cement should be stored in such a manner as to permit easy access for proper inspection and identification of each consignment.

7.4 Sampling

A sample of cement taken for testing must be representative of the consignment and be taken within a week of delivery. It should be a mixture of at least twelve equal sub-samples taken from evenly spaced places throughout the consignment. For cement in bags or other packages, it should be a mixture of equal quantities taken from at least twelve bags or from each bag when there are fewer than twelve bags.

Sub-samples of bulk cement should be taken from the bulk container, or containers, during filling or emptying. The sample should weigh at least 7 kg and be sealed with a clean air-tight container. The relevant particulars should be marked clearly on the outside and the container sent to a suitably equipped laboratory. Testing should be completed within four weeks of delivery of the cement to the site.

7.5 Standard Test Methods

Methods of testing cement should be in accordance with BS 4550 Part 1 for sampling, Part 2 for chemical test and Part 3 for physical test except for the following when ASTM test methods are recommended.
Fineness by air-permeability - Method C204
Soundness, Autoclave expansion - Test Method C151

7.6 Routine Testing

The following routine tests should be carried out whenever the cement is 60 days old from the date of manufacture for assessing its quality before it is approved for use in the works.

Fineness
Setting time
Loss on ignition
Compressive strength

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1. INTRODUCTION

One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide and other potentially deleterious substances. Permeability is governed by the constituents and procedures used in making the concrete. A suitably low permeability is achieved by having an adequate cement content, a sufficiently low free-water / cement ratio, by ensuring complete compaction of the concrete, and by sufficient hydration of the cement through proper curing methods. The specifications give recommendations for the type of cement, maximum free-water / cement ratio and minimum cement content in concrete depending upon the severity of environmental conditions to which the concrete will be exposed during its working life.

The free-water / cement ratio is an important factor and should always be the value compatible with producing fully compacted concrete without segregation or bleeding. When adequate workability is difficult to obtain at the maximum free-water / cement ratio allowed, use of increased cement content, the use of additives and / or the use of plasticising or water-reducing admixtures should be considered.

Admixtures / additives generally are used to provide an economical means of improving one or more properties of fresh or hardened concrete. Among the effects sought are : reduction in bleeding, increased workability, retardation or acceleration of hydration or setting, increased strength, reduction in heat of hydration, increased impermeability, improved resistance to aggressive waters and soils, reduction of expansion caused by reactive aggregates and alkalis in cement, and reduced risk of corrosion of embedded metallic element.

2. DEFINITIONS

According to ASTM, an admixture is defined as a material other than water, aggregates, and hydraulic cement that is used as an ingredient of concrete or mortar and is added to the batch immediately before or during its mixing. A wide variety of materials comprising organic compounds, inorganic compounds and finely divided minerals are classified. These in turn are categorised as chemical admixtures and mineral admixtures.

Mineral admixtures include any insoluble material which is used as an ingredient for concrete. These include natural materials, processed natural materials, and artificial materials. They are finely divided and so form pastes to supplement portland cement paste, in contrast to soluble substances which act as chemical retardents or accelerants during the hydration of portland cement or otherwise modify the properties of the concrete mix.

The **Mineral Admixtures** are termed as **additions** according to the new terminology of Euro-Standard for cements which is being formulated. Two types of additions are defined. Type I **Additives** are considered to be inert and Type II to be having recognised cementatious value.

To define more clearly, what is meant by the words **Chemical Admixtures,** the Euro-Standard describes **Admixtures** as a material added during the mixing process of concrete in a quantity not exceeding 5% by mass of the cement content of the concrete to modify the properties of the mix in fresh and / or hardened state.

3. ADMIXTURES

3.1 General

There is now a general recognition that a chemical admixture provides a cost effective method of improving the quality and durability of concrete and in many cases enables concrete to be placed in applications which would be extremely difficult without their use. In the relatively difficult conditions of hot and arid climates, the improvements in workability which can be achieved without increasing the water / cement ratio by the use of water-reducing admixtures is an example of how much easier admixtures can make it to achieve satisfactory construction. The use of admixtures in structural concrete is often advisable and is almost essential during the summer.

The benefits to be derived from any admixture are, however, contigent on proper use and knowledge of any side effects or potential hazards that may arise. Admixtures are never to be regarded as replacement for good concreting practice and are never to be used indiscriminately.

Many proprietary admixtures are available, some containing several ingredients, and the materials involved range from simple inorganic salts to complex organic compounds or natural products. Although described by its principal function in modifying a concrete mix, an admixture may have secondary functions and may also affect other properties of concrete

3.2 Specifications

Admixtures may be classified according to the purpose for which they are used in concrete. BS 5075 : Parts 1, 2, and 3 covers specification for concrete admixtures :

Part 1 for accelerating, retarding and water reducing admixtures,

Part 2 for air - entraining admixtures, and

Part 3 for super plasticisers.

The classification of ASTM specifications is substantially similar they are C 494, C 260 and C 1017 respectively.

3.2.1 Acceptance Tests

The standards specify acceptance tests which demonstrate the ability of a particular formulation to meet stipulated performance requirements and admixture uniformity tests which demonstrate a particular consignment is similar to material that has previously been submitted to the acceptance test.

In the acceptance test, the principle has been followed of having one test concrete containing admixture at the same water cement ratio as a control mix without admixture to establish the effect of the admixture on workability and strength. For water-reducing admixture, a second mix at a fixed water reduction is used to determine minimum requirements for workability, stiffening time and strength.

The **stiffening time test,** which is carried out on mortar sieved from the concrete determines the times required for the standard needle to indicate a resistance to penetration of 0.5 N/mm2 and 3.5 N/mm2. Work has shown that the time to reach the resistance of 0.5 N/mm2 corresponds approximately to the extreme limit for placing and compacting concrete and the time to reach a resistance of 3.5 N/mm2 gives a guide to the time available for the avoidance of cold joints.

Admixtures can be used to modify the **workability** of concrete or to extend the period for which the concrete remains workable, or to reduce the accidental occurrence of cold joints. An appropriate workability test, for example the compacting factor test, can be used at various interval of time to ensure that the workability required on site is obtained. As the ambient temperature increases the rate of reduction of workability increases and the stiffening time decreases.

Effects similar to those found when the ambient temperature changes may also be observed when the temperature of the concrete materials alters due to such factors as the use of hot materials and the frictional heating effects produced by mixing for longer periods in mixers of large capacity.

BS standard does not set acceptable limits on the effects of admixture on the **shrinkage** of concrete. However, according to ASTM, the length change after 14 days drying, shrinkage should not be greater than 135 % of reference nor increase over reference be 0.010.

The presence of **chloride** in concrete presents potential hazards with some cements or when metals are embedded in concrete and therefore **chloride based admixtures should never be used.**

BS 5075 : Part 1 lays down the requirements for the various types of admixtures.

TABLE 1 - PERFORMANCE REQUIREMENTS

Category of admixture	Water reduction	Stiffening time		Compressive strength	
		Time from completion of mixing to reach a resistance to penetration of		Percentage of control mix (minimum)	Age
		0.5 MPa	3.5 MPa		
Accelerating	-----	More than 1 h	At least 1 h less than control mix	125	24 h
				100	7 and 28 days
Retarding	-----	At least 1 h longer than control mix	----	90	7 days
				95	28 days
Normal water-reducing	At least 5%	Within +/- 1 h of control mix	Within +/- 1 h of control mix	110	7 and 28 days
Accelerating water-reducing	At least 5%	More than 1 h	At least 1 h less than control mix	125	24 h
				110	7 and 28 days
Retarding water-reducing	At least 5%	At least 1 h longer than control mix	----	110	7 and 28 days

NOTE : The penetration is determined by a special brass rod 6.175mm in diameter

TABLE 2 - ADMIXTURE UNIFORMITY TEST REQUIREMENTS

Characteristic	Test Reference *	Requirement
Dry material content	D.1	(a) For liquid admixtures: to be within 3% (m/m) of the value stated by the manufacturer. (b) For solid admixtures: to be within 5% (m/m) of the value stated by the manufacturer.
Ash content	D.2	To be within 1.0% (m/m) of the value stated by the manufacturer.
Relative density	D.3	For liquid admixtures: to be within 0.02 of the value stated by the manufacturer.

* Test methods are described in Appendix "D" of BS 5075 : Part 1

3.2.2 Information Needed from Admixture Suppliers

The following information should be supplied :

- long-term and short-term effects of the admixture on concrete, including the effect on different types of cement and aggregate.
- effects of over-dosage or under-dosage.
- chloride content (admixtures containing chloride should never be used for reinforced concrete).
- whether the admixtures entrains air or its effect on air content.
- storage life and any special storage requirements.
- safety precautions in handling and storage.
- its compatibility with other admixtures, and with different types of cement and aggregates.
- compliance with relevant standards of BS, ASTM, DIN, or their equivalent.
- availability on-site technical service.

3.2.3 **Site Trials**

The general behaviour or performance of an admixture in concrete should be reflected by the data obtained from the admixture acceptance tests or furnished by the manufacturers. The specific effects produced by any admixture will, however, depend to some extent on the particular concrete and circumstances of use. The performance should be evaluated by site trials with specific materials and conditions of the given concrete work in order to establish the admixture dosage which will produce the required effect without adverse effects on any other properties of the concrete. Once such an admixture dosage has been decided by these site trials it should be accurately controlled in order to ensure uniformity of behaviour.

3.2.4 **Dispensing**

Dispensing equipment should be sufficiently accurate to deliver within 5% of the specified dosage rate. To obtain satisfactory performance, the admixture should be distributed uniformly and this is best achieved either by introducing the admixture in solution in a major part of the mixing water or by adding the admixture coincidentally with the mixing water. Solid admixtures should be added in accordance with the directions of the manufacturer. The effects of some admixtures on setting times and water reduction may vary with the time of their addition during the batching and mixing operations, a standard mixing sequence for the admixtures should therefore be used. One type of admixture should not be employed with any other admixture unless the two have been shown to be compatible.

3.3 **Type of Admixtures**

3.3.1 **Accelerating admixtures.** Accelerate the setting and early strength development of concrete and increase the rate of heat evolution. Used in precasting factories where rapid gain of strength is needed. Chloride - free chemicals such as calcium format, sometimes blended with sodium nitrite or other materials are used. Can increase 12 - hour compressive strength by up to 80%. dosage normally 2.5% by weight of cement.

3.3.2 **Retarding Admixtures.** Reduce the initial rate of hydration to retard the stiffening of the concrete. Useful when long ready-mixed concrete hauls are unavoidable. Most retarders are based on hydroxy or phosphate salts. However, experience in the Emirate has shown that this type of compound can promote excessive bleeding with the resulting problems of plastic settlement / shrinkage.

It should be noted that set retarders do not prolong retention of workability which is a more useful property in the local climatic conditions. Normally retarders are combined with a plasticisers to increase workability and prolong workable life of concrete.

3.3.3 **Plasticising and Normal Water-reducing Admixtures.** Increase the workability of concrete at a given water/cement ratio. Alternatively, water content can be reduced, typically by 8 - 12 %, to maintain the same consistency and produce an increase in strength. These admixtures should not be used for cement saving purposes as specified cement quantity is necessary for durability. They are generally based on salts of ligno sulphonate or hydroxy carboxylic acids. Normal dosages are 0.5% by weight of cement. Carboxylic acid achieves slightly greater water reductions than lignosulphonates but less favourable as plasticiser. Lignosulphonates tend to delay setting and to entrain small amount of air. At double normal dosage, act as a combined retarding and plasticising agent delaying initial set by up to 2 hours. Entrain 2 to 3% air, thus reducing segregation and bleeding, and improve cohesion. Hence lignosulphonates are to be preferred.

The **mechanism of action of plasticiser** has been established with certainty. The principle active components are surface - active agents. These are absorbed on the cement particles, alter the physico - chemical forces acting at the interface of the cement particles giving them a negative charge which leads to repulsion between the particles and results in their dispersion. In addition, the charge causes the development around each particle of a sheath oriented water molecules which prevent a closed approach of the particles to one another. The particles have, therefore, a greater mobility, and water freed from the restraining influence of the flocculated system becomes available to lubricate the mix so that the workability is increased. One effect of dispersion is to expose a greater surface area of cement to hydration which progresses therefore at a higher rate in the early stages.

3.3.4 **Accelerating Water-Reducing Admixtures** Combine the principal functions of an accelerating admixture and a water-reducing (plasticising) admixture.

3.3.5 **Retarding Water-Reducing Admixtures** Combine the principle functions of a retarding admixture and a water-reducing (plasticising) admixture.

3.3.6 **Air-entraining admixture.** Promote the formation and entrapping of very small air bubbles during mixing. Impart extremely useful characteristics to the concrete in the plastic and hardened state such as increased cohesiveness of the mix, reduce bleeding, reduced shrinkage, reduced fines content, improved finishing qualities and most importantly of all increased durability with respect to salt attack. Cement content need to be increase to maintain strength, but entrained air reduces water demand for a given workability.

Air - entraining agents are vinsol resins and synthetic surfactants. Locally, however, due to the combined effects of high ambient temperature and nature of the fine dusty aggregate in use, it has been found that synthetic compounds tend to give consistent results. Dosage of 0.1% by weight of cement, but varies appreciably. Air-entraining admixtures should comply with the requirements of BS 5075 : Part 2, and / or ASTM C260. However, the performance requirement for resistance to freezing and thawing characteristic is not applicable.

3.3.7 **Superplasticising Admixtures.** These are an extension of normal plasticisers in that they can be added to concrete at a relatively high doses to produce enhance plasticising or water - reducing actions. They are used either to produce flowing concrete without segregation, or a water reduced high strength concrete. Superplasticisers generally consists sulphonaed derivatives of melamine-formaldedyde or naphthalene - formaldehyde. Normal dosages are 1.5% and 0.5% by weight of cement respectively. Normal dosages allow a water reduction of 20 - 30 % for the same consistency. Hence they are referred to as **high range water-reducers.**

The advent of superplasticisers has made it possible to produce concrete with high workability but with no reduction in strength. Within a few minutes of its addition concrete begins to flow easily and becomes self-leveling, remains cohesive, and thus not bleed or segregate. From an initial slump of about 50mm, superplasticized concrete attains a slump in excess of 200mm.

This increase is only **transient,** however, and is generally not maintained beyond a period of about 30 to 60 minutes. Consequently, there is a great reduction in the workability of concrete in the interval between mixing and placing. In ready-mix operations, therefore, it is suggested that the superplasticizer should be added at the point of discharge of concrete.

Factors that affect slump loss in concrete include initial slump value, type and amount of superplasticizer added, type and amount of cement, time of addition of superplasticizer, humidity, temperature, mixing criteria, and the presence of other admixtures in the mix.

The rate of slump loss can be decreased by adding a higher than normal dosage of superplasticizer, by adding the superplasticizer at different times or by including some type of retarder in the formulation. Inclusion of a retarder in small amounts seems to offer advantages such as economy and better control at the point of mixing.

These admixtures should comply with the requirements of BS 5075 : Part 3, and / or ASTM C 1017. The British Standard covers two types :

[a] Superplasticising admixture, and

[b] Retarding superplasticising admixture.

In the acceptance tests, provision has been made for the diverse applications of superplasticising admixtures in practice, some relevant to the use to produce very high workability, whilst the other to obtain very large reductions in water content.

In the first of these applications, it is usually the intention to produce flowing concrete without drastic alteration of the mix designs employed for normal concrete. Excessive bleeding, segregation, retardation or air-entrainment are undesirable. In the second application, a large reduction in water content is required without loss of workability or excessive alteration in the stiffening time. The compressive strength after 24 hour is expected to be considerably greater than that of a mix containing no admixture. This does not necessarily apply to retarding superplasticising admixtures.

The principle has been followed of having one test mix concrete 'A' at the same water / cement ratio as a control mix to establish the effect of the admixture on workability, and strength. In the second test mix 'B', a fixed water reduction of 16% made and the concrete is tested against specified requirements for workability, stiffening time and strength. An upper limit is placed on the air content of the concrete in both test mixes.

Workability can change rapidly immediately after mixing. However, tests have shown that a relatively stable state is attained within 10 min to 15 min from the completion of mixing and this time has been selected for establishing initial workability. In the case of flowing concrete, there is usually a tendency for the effect of the superplasticising admixture and workability to diminish steadily with time and, in order to ensure adequate retention of the initial high workability, a requirement for loss of workability on standing has been introduced.

Admixtures should comply with the performance requirements detailed in Table 3.

TABLE 3 - PERFORMANCE TESTS & REQUIREMENTS

Property	Test Reference	ADMIXTURE Superplasticising	 Retarding Superplasticising
FOR HIGH WORKABILITY TEST MIX CONCRETE "A"			
Flow	B.3	510mm to 620mm	510mm to 620mm
Loss of workability on standing	B.2 B.5	At 45 min the slump shall be not less than that of the control mix concrete at 10 min to 15 min. At 4 h the slump shall be not more than that of the control mix concrete at 10 min to 15 min.	At 4 h the slump shall be not less than that of the control mix concrete at 10 min to 15 min.
Minimum compressive strength as % of control mix concrete :	B.7		
at 7 days and 28 days		90	90
FOR WATER REDUCED TEST MIX CONCRETE "B"			
Slump	B.2	Not more than 15mm below that of the control mix concrete	Not more than 15mm below that of the control mix concrete
Stiffening time relative to control mix concrete :	B.4		
for 0.5 N/mm2		Within 1 h	1 h to 4 h longer
for 3.5 N/mm2		Within 1 h	---
Minimum compressive strength as % of control mix concrete :	B.7		
at 24 h		140	---
at 7 days		125	125
at 28 days		115	115

Note 1: The strength requirements take into account usual variation in cube testing and limited increase in air content

Note 2: The test methods are described in appendix B of BS 5075 : Part 3.

Note 3: The uniformity tests and requirements should comply with Table 2.

3.3.8 Other Admixtures

There are a large number of **hybrid** admixtures available in proprietary products which have a range of functions and some specific specialised roles e.g. water repellent admixtures, and corrosion inhibiting admixtures, and pore blockers.

4. ADDITIVES

4.1 General

As stated earlier, the additives are minerals. In powdered form, these have been used for many years in concrete to improve workability and to alleviate bleeding. Materials for these purpose included :

- cementitious material such as natural cements, hydrated lime, hydraulic lime, and blast-furnace slag,
- pozzolanic materials, such as fly-ash, diatomaceous earth, calcined shale, and volcanic ash, and
- inert materials, such as clay, talc and stone dust.

The types of mineral admixtures used at the present time generally are limited to those having pozzolanic properties and the blast-furnace slag from the cementitious category.

pozzolana is a natural or artificial material containing silica in a reactive form. A more formal definition of ASTM describes pozzolana as a siliceous or siliceous and aluminous material which in itself posses little or no cemetitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Hence, they are also called as **latent hydraulic binders.** It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide (liberated by the hydrating portland cement) in the presence of water to form stable calcium silicates which have cementitious properties. In considering pozzolana in general, one should note that the silica has to be amorphous, as crystalline silica has very low reactivity. In addition to reacting with calcium hydroxide, pozzolanas react with C3A or its products of hydration.

Mineral admixtures of low pozzolanic reactivity include such materials as ground calcined clay, ground quartz, ground limestone, hydrated lime, and talc. These materials were used primarily to improve workability prior to the advent of the use of chemical air-entraining agents. Their value is based upon their ability to form soft, plastic pastes which separate and lubricates the aggregate particles in the fresh mortar or concrete mixture. Increasing the ratio of surface area of solids to volume of water in the paste provides an effective method of reducing the degree of bleeding. At a given slump, it effects a wider separation of the aggregate particles in the concrete, thereby the increasing the workability. These **inert fillers** vary in their ability to increase workability and reduce bleeding which require that the mineral particles should be of spherical shape so that surface area is not great.

4.2 **pozzolanas**

4.2.1 **Fly Ash**

Fly ash, known as pulverised fuel ash (pfa) is the ash precipitated electro-statically from the exhaust fumes of coal-fired power stations and is the most common artificial pozzolana. The fly ash particles are spherical which is advantageous from water requirement point of view and are of at least the same fineness as cement.

The amount of fly ash used in concrete has varied, 5 percent or less of the total cementitious material, when employed solely for the purpose of improving workability, to between 15 and 50 percent, when utilised for its pozzolanic properties. The pozzolanic activity of fly ash is in no doubt, but it is essential that it has a constant fineness and a constant carbon content. BS 3892 lays down a maximum loss on ignition of 7 percent while the ASTM C618 allows 12 percent. The BS provides 3 zones of fineness so that uniform supply is assured. The residue on the 45 micron sieve has been used as a convenient basis of classification of size.

The main requirements of ASTM C618 are :

Silica, alumina, and ferric oxide all together - 70%.

Sulphur-trioxide, maximum - 5%.

Maximum alkali content expressed as Na_2O - 1.5%.

Soundness, autoclave expansion maximum - 0.50%.
(a measure of MgO constituent)

BS 3892 specifies a maximum MgO content of 4 percent and SO_3 content of 2.5%

Fly ash interground with portland cement clinker are available in British Standard Specifications, they are :

BS 6588 portland pulverised fuel ash cement in which fly ash addition is in the range of 15 - 35 percent.

BS 6610 pozzolanic cement with pulverised fuel ash as pozzolana, in which pfa addition is in the range of 35 - 5o percent.

Pulverised fuel ash could also be used as an additional ingredient of concrete mix and added directly into the mixer, to replace a part of conventional portland cement.

Pfa should not be used in conjunction with cement complying with BS 4027 in concrete required to be resistant to sulphates.

4.2.2 Microsilica

Microsilica (MS) as it is known in the UK, or condensed silica fume (CSF) elsewhere, is a by-product resulting from the reduction of quartz with coal in electric arc furnaces in the production of silicon and ferrosilicon alloys, which produces a microsilica with 90 - 95% silicon dioxide. Microsilica is basically a pozzolana similar to pulverised fuel ash only much finer and purer. Microsilica comprises microspheres of very pure amorphous silicon dioxide. When microsilica is collected in the filters at the production plant it has a surface area of 18,000 m2/kg and a bulk density of around 250 kg/m2. In this form it is very difficult to handle and it is modified : Densification, Micropelletisation, and Slurrification.

To obtain the best properties and performance from a microsilica concrete, it is essential that the microsilica is properly and thoroughly dispersed throughout the mix to ensure that the full surface area, and hence the greatest reactivity is available to the hydration reaction in the concrete. Superplasticisers are remarkably efficient at dispersing the microspheres within the matrix.

The **benefits** derived through the introduction of microsilica is for greater than conventional concrete. Microsilica concrete (MC) produces strength for in excess of that attainable in conventional concrete. The high strength, low permeability and improved chemistry of MC provides many other benefits in hardened concrete, in particular, total elimination of alkali aggregate reaction, reduced chloride ion penetration by 50 - 100 percent.

In fresh concrete, the microspheres act like ball bearings in the mix which makes pumping and general placeability far easier. The water content of the mix is also reduced as the ball bearings act as a lubricant. The fineness of microsilica enables an extremely high quality surface finish to be produced from MC. The fineness of the microstructure also improves the bond of MC to steel reinforcement and other concrete

4.3 **Ground Granulated Blastfurnace Slag (GGBS)**

Blastfurnace slag, a by-product of iron manufacture, can have excellent cementitious properties when combined with portland cement. These are produced by grinding granulated blastfurnace slag with portland cement clinker.

If rapidly cooled blastfurnace slag is ground to cement fineness it acts a slow setting cement in its own right. However, for practical purposes the rate of hardening is too slow and so it is necessary to combine the slag with portland cement clinker which act as an activator. The combination of blastfurnace slag and portland cement is known as Portland Blastfurnace Cement (PBFC).

BS 146 PBFC, in which the slag content is upto 65%.

BS 4246 low heat PBFC in which the slag content range from 50-90%

In 1986, a British Standard for separate GGBS was published, namely : BS 6699 "Specification for ground granulated blastfurnace slag for use with portland cement". The use of GGBS added at the concrete mixer has become a well established and widely-used practice which provides the user of concrete with much greater flexibility for optimising the blend proportion to suit specific applications than can be achieved using factory-blended Portland blast-furnace cements.

The use of GGBS shall conform to BS 8110, Structural use of concrete.

4.4 **Closure**

Mineral additives are **Quality Enhancers** and **Cement Replacers** in concrete works.

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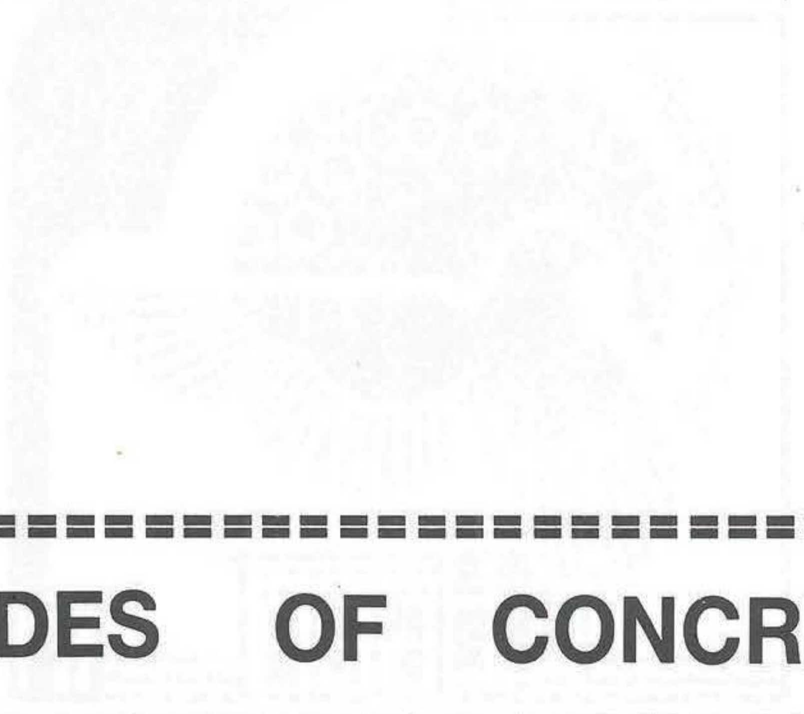

GRADES OF CONCRETE

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1. INTRODUCTION

Since the 1970's, there has been a rapid growth in the construction sector in the U.A.E. This rate of growth has in many cases been brought about by the extensive use of reinforced concrete as a construction material. While being one of the most versatile of construction materials, the long-term durability of reinforced concrete has been adversely affected by the application of specifications ill-suited to prevalent conditions as well as defective construction practices producing structures which showed an alarming degree of deterioration within a short span of 5-10 years. The deterioration is accentuated by the geomorphic and climatic environmental conditions which are characterized by available aggregate resources, high temperature-humidity regimes, and severe ground and ambient salinity.

The main causes of concrete deterioration are attributable to corrosion of reinforcement, sulphate attack, salt weathering, and cracking due to shrinkage, thermal gradients and alkali-aggregate reactivity. The mechanism of all these factors are linked to environmental effects, atmospheric and / or geomorphic. Disintegration due to one factor initiates and sometimes accelerates another form of attack, and the total deterioration is cumulative in a complex way. The interactive situations and the cross correlation of deterioration characteristics complicates a quantitative assessment of the concrete deterioration problem. However, the most serious modes of concrete deterioration are concrete spalling due to reinforcing bar corrosion and expansion cracking due to sulphate attack. Both these attacks are the visible manifestations of excessive salt inclusion in the concrete mix through the aggregates, mix water, and subsequent ingress through cracks and pores.

Since early 80's, there has been considerable improvement in the working practices and the quality of mix material. Many factors have been taken into account and the field of concrete technology has advanced markedly in the intervening years.

2. CLIMATE AND GEOCHEMISTRY

The climate and nature of surface soils are much less favourable to the construction of durable concrete structures. In general, temperatures are very high particularly in summer. The daily and seasonal range of temperatures, as well as the effects of air conditioning also lead to substantial thermal movements which have to be allowed for when structures are designed. The rate of evaporation of water during the day makes effective curing of concrete difficult.

2.1 Ambient Climatic Conditions Prevailing in Dubai

The prevailing local conditions are as follows :

Maximum ambient temperature	48 deg. C
Minimum ambient temperature	7 deg. C
Minimum barometric pressure	998 mb
Maximum barometric pressure	1020 mb
Maximum ambient humidity	100 %
Minimum ambient humidity	6%
Maximum wind velocity	125 km/hr
Average yearly rainfall	80 mm
Maximum precipitation in any one storm known to date	220 mm

The climate of Dubai is relatively mild from November to April and hot from May to October with high relative humidity. Under certain combinations of the above climatic conditions considerable condensation may take place. Particular attention should be paid to the prevailing corrosion conditions. A considerable amount of salt is contained in the atmosphere which together with the extremely high ambient humidity, can produce severe corrosion problems. Distribution of rainfall is irregular and the precipitation amounts are normally of no significance, but attention should be paid to the fact that sudden heavy rainfall in a very short period of time can occur. The prevailing wind directions are from the North and West. Strong winds are common with maximum gust velocities exceeding 160 km/hr and sand storms and dust storms occur in the summer months / winter shamals.

2.2 Geochemistry

Dubai city and immediate hinterland illustrate the harsh environmental conditions of a typical Middle East coastal province. The vicinity of Dubai consists of three laterally disposed geomorphological units : beach sands, sabkha, and dune field. The dune field about 25 to 30 km from sea is found to contain rock outcrops with material below having rather very low levels of deleterious salts while the beach and sabkha zones are contaminated with aggressive chloride and sulphate salts in soils, and sub-soil ground water. The water table varies from near surface to approximately 3 meter below ground level. Such contamination is a major factor in the design of concrete mixes and it may call for provisions of special protection of concrete.

3. FUNCTIONAL REQUIREMENT

Concrete usually has to meet one or more of four functional requirements: strength, durability, fire protection and thermal insulation. Both cement and aggregates are important in relation to strength and durability but fire protection and thermal insulation depend exclusively on type of aggregate used.

Materials used should satisfy the designed requirements for the safety, structural performance, durability, and appearance of the finished structure taking full account of the environment to which it will be subjected. The amount of potentially harmful impurities in the constituent materials should be taken into account so that they are within permitted limits.

4. SPECIFICATIONS

The British Standard, BS 5328 covers methods for specifying concrete suitable for all applications and the means of checking compliance with the specifications. BS 8110 deals with the structural use of concrete in buildings and structures and gives advice on the selection of the materials and mixes to be used in particular situations and gives more requirements relating to workmanship in the production and placing of concrete.

4.1 Materials

Generally, materials to be used should comply with the approved Standards. Materials or techniques not covered by any Standard may be used provided full account is taken of their effects on design requirements and that there are satisfactory data on their suitability and assurance of quality control as well as possible interaction between the materials and the effect of environmental conditions and requirements for the finished concrete.

4.1.1 **Cements** - The portland cements or combinations of portland cement with ground granulated blast furnace slag cement (g.g.b.f.s.) or pulverized-fuel ash cement (pfa) should comply with appropriate British Standards, or ASTM specifications, or **DM NOTE NUMBERS 002 & 003,** as specified.

If a cement has a special property, then other properties of it, may restrict its use. Heat of hydration, for example, is linked with the rate of strength development; if a high early strength is obtained the user must be aware that heat will be evolved quickly, and this may not always be desirable.

Generally, pfa and g.g.b.f.s. cements impart certain beneficial characteristics to concrete viz., decrease permeability, increase resistance to sulphate attack and to the disruptive effect of alkali-silica reaction, but rate of strength development is slow and call for extended periods of curing.

4.1.2 **Aggregates** - The aggregates should comply with BS 882 or ASTM C33 or **DM NOTE NUMBER 001** as specified.

4.1.3 **Water** - Water should be clean and free from harmful matter in such quantities as would affect the properties of the concrete in the plastic or hardened state. Use of potable water is generally safe. As a rule, water with pH of 6.0 to 8.0 which does not taste saline is suitable for use. There is, however, one situation when drinking water is unsuitable as mixing water : this is when there is a danger of alkali-aggregate reaction and the water has a high concentration of sodium or potassium.

Mixing water should comply with the physical and chemical requirements set out in Tables 2 and 3 of **DM ADVISORY NOTE NUMBER 005.**

4.1.4 **Admixtures** - Admixtures should comply with either British Standard BS 5075 : Parts 1, 2 and 3; or ASTM C494, C260 and C1017; or **DM ADVISORY NOTE NUMBER 003** as specified.

Admixtures should not impair the durability of the concrete nor combine with the ingredients to form harmful compounds nor increase the risk of corrosion of the reinforcement.

Chloride and chloride based admixtures should not be used as they promote corrosion of reinforcement.

Some admixtures, in particular superplasticizer contain rather high percentage of reactive alkalis and this has to be taken into consideration along with those present in the other mix constituents so as to guard against alkali-aggregate reaction.

Admixture manufactures should declare the values of chloride and alkali content, if any, present.

5. WATER / CEMENT RATIO AND CEMENT CONTENT

Water / cement ratio is defined as the ratio of free-water in a mix to the cement content. Free-water in a mix is defined as the amount of water readily available in freshly mixed concrete. Allowance must be made for absorption and moisture content of the aggregates. In other words, the free water is that in excess of the water required for the aggregates to be brought to a saturated and surface dry condition.

The free water cement ratio and cement type are fundamental in determining how durable well made and well cured concrete can be under the prevailing conditions of exposure, though cement content may also play its part. It is therefore usual to specify a minimum cement content as well as the maximum free water cement ratio. Great emphasis is placed upon achieving the water cement ratio and cement content values quoted in the specifications for typical exposure conditions.

The cement content of the mix should not only be enough to give the required durability, but it may need to be increased to more than this amount to give the required workability with the appropriate maximum water cement ratio specified.

The heat generated when concrete hardens, and both the thermal contractions and the shrinkage which take place when it cools or dries, are increased by richness of the mix and hot climate. As a result, rich mixes can generate considerable stress which may lead to distortion and cracking of members if members are restrained. For these reasons, it is usual to limit the cement content to a maximum of 450 kg/m3 in the concrete mix. Alternatively, a low heat Portland cement (BS 1370) or controlled fineness OPC (BS 12) is chosen.

6. CONCRETE STRENGTH

Knowledge of the concrete strength is required both for assurance of its structural adequacy and for contractual assurance that it complies with the client's specification. It is probably due to this second requirement that so much attention has been paid to the variability of the strength of concrete.

Concrete can be produced having a wide range of properties including strength, depending on the materials and mix proportions used. The quality of concrete to meet requirements for strength, durability and other properties can be specified either in terms of mix proportions or performance.

Many factors influence the compressive strength of concrete to a varying degree viz. age at test, curing conditions, type and strength of cement, type and grading of aggregates, but free water / cement ratio is the major factor influencing strength.