

## Chapter 2

### 2.0 LITERATURE REVIEW

#### 2.1 Concrete

Concrete and steel are the two most commonly used structural materials. They sometimes complement one another, and sometimes compete with another so that the structures of similar type and function can be built in either of these materials. Concrete is made from cement, aggregate and water with the occasional addition of admixtures. Concrete has a proven track record as a successful material in the construction of highest towers, the longest tunnels, the deepest shafts and the largest man made structures, and in conditions as extreme as the Arctic tundra and Middle Eastern desert (Masterton et al; 1997).

The invention to overcome the problem of the low tensile strength of concrete by providing steel reinforcement was the starting point for concrete to become the leading construction material in this century. It was realized that steel will not corrode, even in outdoor environments, when embedded in sound concrete (Schiessel, 1996).

#### 2.2 Concrete mixes

Different concrete mixes such as designed mixes, prescribed mixes (done as weigh batching), nominal mixes (mostly done as volume batching) are used to meet the needs of construction work. In particular the concrete should have the following (Schacklock, 1974).

1. Comply with the specification requirement for structural strength which is usually stated in terms of the compressive strength of standard test specimens
2. Have satisfactory durability in the environment in which the structure is placed
3. Have a satisfactory appearance in those situations where it is exposed to view
4. Be as economical as possible.

### 2.2.1. Nominal mixes

Following the practice first established many years ago, concrete mixes are still sometimes specified in terms of volumetric proportions. The proportions of cement: fine aggregate: coarse aggregate are in terms of the bulk volumes of the individual materials. (i.e. for grade 20 concrete 1:2:4, for grade 25 concrete 1:1.5:3 and for grade 30 concrete 1:1:2). According to the ICTAD specifications (1988), the minimum cement contents for the Grade 20, 25 and 30 concrete are 320 kg, 405 kg and 552 kg per m<sup>3</sup> of volume batched concrete respectively. (These values are taking into account the cement bulking as well). Volume batching is difficult to control and nominal mix specifications provide no control over water content, so this type of specification should not be used unless site condition make it necessary (Barnbrook et al; 1976)

Experience also showed that allowance had to be made for the bulking which occurs with fine aggregates when they are damp. It is generally accepted that most concreting sands will bulk on average by about 25%. However, coarse aggregate do not bulk to any significant extent. The allowance can be increased for finer sands and decreased if the moisture content of the sand is unusually low (Shacklock, 1974).

Shacklock (1974) also mentioned that the quantity of water in the nominal mixes are judged so as to give a concrete of suitable workability for the work in hand. The fact that the required amount of water affects the final properties of the concrete very considerably, and that the quantity varies with both the selected workability of the concrete and the maximum size of the aggregate, shows the extreme weakness and the imprecision of this type of specifications.

In practice, nominal volumetric mix proportions are often associated with a particular concrete strength which is checked by the taking of test specimens. This association of the prescription form of specification with a performance requirement leads to a difficult and often unworkable specification (Shacklock, 1974).

## 2.2.2 Specified mixes

BS 5328: Part 2: 1991, recognizes four methods of specifying concrete mixes. A designed mix is specified by the designer principally in terms of strength, cement content and water cement ratio; compliance relies on strength testing. A prescribed mix is specified by the designer in terms of nature and proportion of mix ingredients; the concrete producer simply makes the concrete 'to order'. The assessment of mix proportions is used for compliance purposes, strength testing not being routinely used. The use of prescribed mix is advantageous when particular properties of concrete, for instance with respect to its finish or abrasion resistance, are required. However, a prescribed mix should be specified only when there are sound reasons for assuming that it will have the required workability, strength and durability.

A standard mix is based on ingredients and proportion fully listed in BS 5328: part 2: 1991 for several values of compressive strength up to 25 MPa, measured on cubes. The fourth type of mix is the designated mix, for which the concrete producer selects the water cement ratio and the minimum cement content, using a table of structural applications coupled with standard mixes. This approach can be used only if the concrete producer holds a special certificate of product conformity based on product testing and surveillance, coupled with certification of quality assurance.

Standard mixes are used only in minor construction such as housing. Designated mixes, although they can be used for strengths up to 50 MPa, are limited in application to routine construction. It is therefore, only in the selection of designated and prescribed mixes that a full knowledge of properties of concrete can be used (Neville, 1996).

## 2.3 Strength of concrete

Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design and is specified for compliance purposes (Neville, 1996).

The properties of in situ concrete are subject to considerable variability, because it is not a factory produced construction material such as steel, for example. The principal factors that affect the properties of concrete are mix proportions (especially the cement content), slump achieved (primarily depend on the water content) compaction during placing and curing after casting. The first two factors represent concrete mix constituents, and taken together will be characterized by the water / cement ratio, which is by far the greatest single influence on concrete production. However, this composite index is separated into mix and slump because the latter have more practical significance for concrete production and placing. Compactions and curing can be considered as workmanship factors.

The characteristic strength of the concrete should be specified at one age only. Unless specified otherwise, the strength test should be carried out at an age of 28 days for concrete made with a Portland-type cement (Barnbrook et al; 1976). Under normal conditions adopted in Sri Lanka, a standard deviation of about 8 is usually used for concrete mixes. This gives a current margin of about  $13 \text{ N/mm}^2$ . This means, when Grade 20 concrete is needed, under laboratory conditions, a strength of about  $33 \text{ N/mm}^2$  should be obtained as the mean strength. However, it is stated that this current margin could be reduced by about  $3.5 \text{ N/mm}^2$  when nine cubes were tested (Barnbrook et el. (1975)). Thus, the current margin required could be considered as  $10 \text{ N/mm}^2$  when 9 cubes were tested. The current margin of  $10 \text{ N/mm}^2$  is also confirmed by Dias (1991) as well

One of the major problem in making specifications for Sri Lankan practice will be to answer the question as to whether Grade 20 concrete, which is the most widely used grade in Sri Lanka, is permissible or not. Most modern codes of practice specify a minimum Grade of 25 for durability purposes if strength is measured by cube or equivalent cube strength. However, recent specifications drawn up for Sri Lankan practice – ie the Model Code and the ICTAD specifications have continued the use of Grade 20 concrete, probably basing their recommendations on the now outdated CP114 and CP 110 respectively (Dias,1991).

On the other hand, the use of Grade 20 concrete can not be rejected outright, because environmental conditions in Sri Lanka are probably less harsh than those in the UK or

Australia, for example. Furthermore, most concrete surface in Sri Lanka receive a mortar rendering, which provide additional protection. Finally, structures built out of Grade 20 concrete have not performed too badly. Hence, it may be permissible to continue the use of Grade 20 concrete, especially if it is shown that this does not violate the spirit of BS 8110 which is the code used for the design of concrete structures in Sri Lanka (Dias, 1991).

### **2.3.1 Mix constituents**

Concrete is made from cement, aggregate and water with the occasional addition of an admixtures. There is some variety in the properties of cements, even between cements of the same type but made from different raw materials and the variation in properties possible in natural and manufactured aggregate is almost limitless. Thus, concrete is always a heterogeneous material with variable properties. The section outlines the typical properties required by, or inherent in, concreting materials.

#### **2.3.1.1 Cement**

In Sri Lanka, Portland cement manufactured by cement corporation is mostly used for construction work and it shall be is accordance with BS 12(2). At present, cement is allowed to be imported which again should be complied with BS 12(1). Hence one can assure that the strength and workability of concrete related to water / cement ratio and aggregate / cement ratio as in mix design charts are acceptable as for as local cement is concerned (Samarasinge et al; 1987).

Ordinary Portland Cement (OPC) and Rapid Hardening Cement satisfying BS 12 and ASTM C150 (Specification for Portland cement) can be used for producing high strength concrete. However, different brands of OPC will have different strength development characteristics because international standards allow variation in chemical composition and fineness within certain limits. Also the performance of chemical and mineral admixtures can be affected by variations in cement characteristics. Therefore, when choosing Portland cement for use in high strength concrete, it is important to examine carefully its fineness & chemical compositions (Jayanandana et al; 1998).

### **2.3.1.2 Aggregate**

The term aggregate is used to describe the gravels, crushed stones and other materials which are mix with cement and water to make concrete. As aggregate form bulk of the volume of concrete, the selection of suitable material is important.

Of the materials in concrete, aggregate is the most variable. The overall grading of the aggregate affects the amount of water that must be added because 'fine' grading require more water than 'coarse' grading to obtain the same degree of workability. Aggregate particles which have sharp edges or rough surface, such as crushed stones, need more water than smooth and rounded particles to produce concrete of the same workability. It may be necessary to increase the cement content of a mix made with crushed aggregates or irregular shaped gravels to allow water to be added in order to make the concrete sufficiently workable without reducing the strength below the required level. However, due to interlock between aggregate particles, a crushed aggregate concrete may have higher strength than a smooth or rounded aggregate concrete with the same water / cement ratio, and this extra strength may be sufficient to offset the effect of the extra water.



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As the maximum size of the aggregate is reduced, the cement content of the mix will need to be increased to give the same workability with the same water / cement ratio. This is because the surface area of aggregate to be wetted is greater with the smaller aggregate size. The fine and coarse aggregates should be proportioned to obtain the required workability with the minimum amount of water. Badly proportioned constituents require an excessive amount of water to give adequate workability, and this will result in concrete of low strength and poor durability. Moreover, aggregates should be hard, durable, firm, appropriately cleaned and suitably graded. The presence of harmful substances such as dust, mud, organic imparities, chlorides or any other harmful substance should not be in larger amount than allowable limits.

### **2.3.1.3 Water**

Mixing water for concrete is usually required to be fit for drinking, or to be taken from an approved source. This is to ensure that the water is reasonably free from such impurities as

suspended solids, organic matter and dissolved salts, which are frequently contained in natural water and which may adversely affect the properties of concrete.

Water is the most consistent of the constituents of the concrete but water quantity, and in particular the water / cement ratio, is most important for the production of concrete of consistent strength. The amount of water used should be the minimum necessary to give sufficient workability for full compaction of the concrete. When deciding how much water to use, allowance must be made for absorption by dry or porous aggregates and for the free surface moisture of wet aggregates.

### **2.3.2 Curing**

The setting and hardening of cement depend on the presence of water. Drying out, if allowed to take place too soon, results in low strength and porous concrete. At the time the concrete is placed, there is normally an adequate quantity of water present for full hydration, but it is necessary to ensure that this water is retained so that the chemical reaction continues until the concrete has thoroughly hardened. If curing is efficient, the strength of the concrete increases with age; this increase is rapid at early ages and then continues more slowly for an indefinite period. Correct curing increases the impermeability and durability of the concrete, which is particularly important when it will be subject to water pressure or severe environmental conditions (Barnbrook et al., 1976). Curing increases resistance to abrasion; effective curing is thus most necessary for floors and other surfaces subject to wear. Continuous curing from the time the concrete is placed helps to ensure a hard, dense surface and to reduce the risk of crazing and dusting (Barnbrook et al; 1976).

More specifically, the object of curing is keep concrete saturated, or as nearly saturated as possible, until the originally water filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement. In the case of site concrete, active curing stops nearly always long before the maximum possible hydration has take place (Neville, 1996).

Powers in 1947 showed that hydration is greatly reduced when the relative humidity within the capillary pores drops below 80 percent. This was confirmed by Patel et al in 1988.

Meyer in 1987 has clearly established that the effect of curing on strength is a function of specimen size. Dias in 1994 has recommended that the curing is very significant main factor for durability characterize by sorptivity. Results obtained by Rasheeduzzafer et al in 1989 indicate that inadequate curing has a more dramatic effect than inadequate compaction on the time required to initiate corrosion and on the severity of sulphate attack. Dias (1994) has recommended that minimum of 7 days of moist curing is essential for concreting in hot climates.

### 2.3.2 Water cement ratio

Duff A Abram's water/cement ratio law, which states that fundamentally the strength of concrete is governed by the ratio of the weight of water to the weight of cement in a mix provided that it is plastic and workable, fully compacted and adequately cured (Taylor, 1977).

To eliminate excessive porosity, a minimum amount of water should be used. The volume of the products of hydration is nearly twice that of unhydrated cement (Powers, 1958). At water / cement ratio grater than 0.38, even if 100% hydration to occur, the products of hydration can not fill the entire volume of water filled spaces. The obvious conclusion is that the higher the water / cement ratio, the higher the porosity and the lower the strength (Jayathilaka, 1995).

However, the accurate measurement of water / cement ratio on site is difficult, due partly to variations in the moisture content of aggregates, partly to an inability to measure the quantity of water in fresh concrete under most practical conditions. However, for a given maximum size and type of aggregate and a given workability of concrete, the quantity of water per unit volume of compacted concrete is reasonably constant over a wide range of cement contents. Therefore, it is reasonable, in practice, to ensure that the cement content used exceed a particular minimum value which has been determined in such a way that the maximum water cement ratio is unlikely to exceed the value which it has been found necessary, from consideration of permeability and past experience (Shacklock, 1974).



There is a very significant influence of curing on sorptivity but that its effect on strength is minimal especially if the size of concrete elements are around 150 mm or greater (Dias, 1994).

Given that sorptivity is a measure of the quality of cover zone concrete and the fact that this zone plays a crucial barrier function in concrete durability ie in the protection of concrete (especially reinforced concrete) over time it is possible to say that curing is very important for durability (Dias, 1994).

Ben – Bassat et al, in 1990 have shown that w/c ratio and curing significantly affect the depth of carbonation, drying shrinkage, initial surface absorption, total absorption and oxygen permeability. However, the importance of curing was reduced as the water / cement ratio decreased.

Ho and Lewis (1988) showed that water / cement ratio is the decisive parameter governing carbonation depth, as opposed to water binder ratio, where blended cements are concerned.

#### 2.3.4 Compaction of concrete



The aim of the concreting process is to achieve a homogeneous mass free from voids, and the planner must ensure that the concrete mix and compaction method are selected giving due consideration to the placing condition. (Masteron et al. , 1997)

1. Compaction of concrete shall not
  - be too short so that the concrete is not dense enough
  - be too long so that segregation takes place
  - result in a loss of entrained air
  - cause the gathering of water or air at certain location
  - leave any void
  - damage the formwork or change the position of reinforcing bars
  
2. Appropriate compaction energy imposed on the concrete shall be specified in terms of compaction time, compaction spacing and power of the compaction apparatus.

Chandrakeerthy et al. (1986) has recommended that the concrete should be compacted with either immersion or shutter vibrators. Compaction is very important for concrete with a slump of 10 – 15mm, while it is of a lesser importance for a concrete with a slump of 125 – 150mm.

The difference in strength between specimens subjected to 'high' and 'incomplete' compaction has also been found by Chandrakeerthy et al, (1986). For 1:2:4 concrete, the properly vibrated concrete yielded a mean equivalent cube strength of 21.6 N/mm<sup>2</sup> and incompletely vibrated concrete one of 13.9 N/mm<sup>2</sup>. This is also confirmed by Dias in 1994. However, the effect of compaction on sorptivity is negligible (Dias, 1994).

## **2.4 Silica fume**

### **2.4.1 General**

Microsilica consisting of more than 90% of amorphous Silicon Dioxide has a quite high pozzolanic potential. This was first tested in 1947 in Norway and the large scale production was started in 1970s. The present use of concrete containing microsilica is over 5 million m<sup>3</sup>/year (Lewis, 2001). The term generally used for Microsilica in the concrete industry is silica fume. Microsilica concrete has been used in major projects either to produce high strength concrete or when enhanced durability was required (Lewis and Hasbi, 2001). Microsilica concrete has proved particularly beneficial in areas where the structures are subjected to severe environmental attack such as due to hazardous ground condition (Sulphate and Chloride attack), moisture exposure or physical degradation such as abrasion and erosion (Keck, 2001). The countries extensively use silica fume include United States of America, United Kingdom, countries in the Middle East, Hong Kong, Norway, Sweden, Denmark etc. Recently, India also started using silica fume in many large construction projects upon the realization of the advantages that silica fume could offer with enhanced durability.

## 2.4.2 The function and benefits of silica fumes

Silica fume is amorphous silicon dioxide. It is quite similar to silica dust (ground  $\text{SiO}_2$ ), but only in appearance. When available in concrete, silica fume will combine with calcium hydroxide that is released by the hydration of cement, and produce more calcium silicate hydrates. This is the pozzolanic reaction that gives higher strength and impermeability. Due to the lack of free  $\text{Ca(OH)}_2$ , it could improve the abrasion resistance in both wet and dry conditions. Silica fume is a much finer material than cement particles. Therefore, it can spread well into the mix and hence enhance the cohesive nature of concrete thus improving workability while reducing the segregation and bleeding. Since silica fumes are very fine spherical particles, those can act as a lubricant to enhance the pumpability of concrete (Lewis et al; 2001).

Since silica fume could enhance both durability and strength, it has been used in many large scale projects in the world. Few of these are given in Table 1 obtained from Lewis and Hasbi(2001), Joshi(2001) and Saini et al.( 2001).

Country	Project	Description	Reasons for using silica fumes
USA	311, South Wacker, Chicago, 70 storey 293 m high skyscraper in 1990	Silica fume concrete of 80 MPa was used with very low water contents such as 160 $\text{kg/m}^3$ .	To achieve high strength and also to enhance the pumpability
USA	US Borax California, the slabs were subjected to chemical spillage containing 5% sulphuric acid in 1986	50 MPa concrete was produced with 10% silica fumes.	To improve the durability quite significantly and also to reduce resistance to sulphate attack
USA	Kinzna dam, Pennsylvania in 1983	86 MPa concrete with 15% silica fumes	To improve the resistance to wet abrasion. The erosion was reduced by 40 times of normal concrete.
United Kingdom	Mayer Parry scrap metal reprocessing unit in 1992	80 MPa concrete with 10% silica fumes	To improve the resistance to dry abrasion. The erosion was reduced by 15 times of normal concrete.
Norway	Gullfaks off shore platforms	Grade 65 and 70 concrete was produced with 2% silica fumes.	To improve the workability and pumpability of concrete.

Abu Dhabi	Baynuah Tower (building) of 156 in height in 1992.	80 Mpa concrete with 10% silica fumes	To improve the durability and Chloride, Sulphate resistance in harsh environment of the Gulf region.
Hong Kong	Tsing Ma bridge, a suspension bridge with 200m tall towers and 2,167m length.	High strength concrete with 25% flyash and 5% silica fumes	To produce high strength concrete to suit stringent and comprehensive performance criteria.
India	Bandra – Worli sea link of length 5.86Km.	60 MPa concrete with 10% silica fumes	To reduce shrinkage cracking associated with high cement content and also to improve durability.
India	Viaduct in Mumbai.	75 MPa concrete with 10% silica fumes.	To ensure long term durability of the structure. This concrete has also given an excellent finish for the insitu and precast products.

**Table 2.1:** Application of concrete containing silica fume in many parts of the world

The details given in Table 1 indicate that silica fume has been used for both durability and high strength. Generally, silica fumes are added as an additional cementitious material as a percentage of the original cement content. When the silica fume content is 10%, it means that the weight of silica fume will be 40 kg/m<sup>3</sup> in a concrete containing 400 kg of cement per m<sup>3</sup>. The details given in Table 1 indicates that in the above projects, silica fume were used from 2%-10% by weight. The guidelines given in Table 2 are suggested by Lewis (2001) for the use of silica fume.

Application	Percentage of silica fume by weight of cement
Pumping aid	2-3
Improved quality	4-7
Strength	7-15
Under water construction	12-15
Sprayed concrete	8-12

**Table 2.2:** The contents of silica fumes suggested for different applications

It was shown by Keck (2001) that about 7.5% silica fume by weight could reduce the chloride permeability by about 95% and could be used in the marine structures quite effectively. Silica fume (5% by cement weight) was used for reducing the drying shrinkage of bridge deck concrete in USA (Ramey & Cope, 2001). In Norway, 5% silica fume concrete was used to ensure good compaction of concrete, high chloride resistance and high strength (Fidjestol, 1993). Silica fume was found to be an excellent material to reduce the rebound of shotcrete in addition to improved durability. The silica fume content was about 8 % (Fidjestol, 1993)

Although silica fume has all these advantages, it is suggested by Neville (2001) that if it is intended to be used in a project, it should be clearly specified in the specification whether it is permitted and if permitted, where and how to use it. This is because, it is generally considered as a costly material and hence the benefits should outweigh the extra cost (Neville, 2001).

## 2.5 Durability



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During the third quarter of the last century, a tremendous boom in construction activities occurred in the Western World, pushing the development of building materials and construction technology. Research and development were mainly geared towards optimization of load design and load bearing capacity, and did not take into account that at least some of these developments had negative effect on robustness, sensitivity to bad execution and duration of concrete structures (eg: pure strength oriented development of cement properties, increase of permissible stress, minimization of dimensions, reductions of cover etc) (Shies et al; 1996).

Although the initial concern about the concrete properties was regarding strength, there is now much concern about concrete durability. Here, too, the principal worldwide focus regarding concrete durability is on the protection of embedded steel (which is present in most concrete) from corrosion, although there is also some attention given to the protection of concrete itself (from phenomena such as sulphate attack and alkali aggregate reactions).

A durable concrete is one that performs satisfactorily in the working environment during its anticipated service life. The materials and mix proportions specified and used should be such as to maintain its integrity and, if applicable, to protect embedded steel from corrosion.

To achieve this, it is necessary to consider many interrelated factors at various stages in the design and construction process. Thus, the cover to steel is considered at the structural design stage involving consideration of the environmental conditions. Characteristics influencing the durability include its permeability and resistance to the ingress of the potentially deleterious substances. There are 3 fluids principally relevant to durability which can enter concrete: water pure or carrying aggressive ions, carbon dioxide and oxygen. They can move through the concrete in different ways, but all transport depends primarily on the structure of the hydrated cement paste. Durability of concrete largely depends on the ease with which fluids, both liquids and gases, can enter into, and move through, the concrete; this is commonly referred to as permeability of concrete. Permeability refers to flow through a porous medium. Now, the movement of various fluids through concrete take place not only by flow through the porous system but also by diffusion and sorption, so that our concern is really with penetrability of concrete. Penetrability of concrete is governed by the constituents, their proportions and the procedure 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 concrete and by sufficient hydration of the cement through proper curing method.

It is unfortunate that the concrete has to be reinforced with embedded metal when used to resist tension or flexural loading. It is the potential corrosion of this embedded metal that is the prime cause of the majority of the structural concrete deterioration that is now becoming evident. Indeed, it has been estimated that in 1998, the value of building and civil engineering repairs and maintenance carried out in the UK was of the order of £ 15 billion of this approximately £ 500 million per annum is spent on concrete repair (Mays, 1999).

With such vast sums of money involved, it is important that the construction industry recognizes the unwitting errors of the past and puts to good effort the lessons that have been learned for new construction.

77714

### 2.5.1 Sorptivity testing of concrete

Durability however is a long term property. Hence, appropriate indices have to be chosen for characterizing it. One such index that is gaining increasing acceptability is sorptivity (Hail, 1989), especially since it is concerned with the surface areas of concrete which protect the steel reinforcement, and also because sorptivity testing reflects to a reasonable extent some of the process by which actual deterioration of concrete will take place on site.

Dias (1994) obtained the volumes of water (from measured masses) absorbed per unit surface area, after various durations up to 49 hours, by cylinders coated on their curved surface and absorbing water through one flat face. A linear relationship can be obtained when plotting volume absorbed per unit surface area against the square root of time. The slope of this line is defined as the sorptivity of the specimen. Although, sorptivity is sensitive to specimen preconditioning there is some evidence that repeatability in sorptivity results can be obtained even if preconditioning, varies to some extent. (Dias, 1994). The durability of concrete is generally affected by the corrosion of reinforcement. Thus, the quality of concrete in the cover region is quite important to enhance the durability. It is generally accepted that the sorptivity of concrete could give a very good indication of the quality of concrete. Although, in general, permeability is taken as the indicator of a concrete's ability to transport water (or oxygen and carbon dioxide), more precisely there are two mechanisms controlling the uptake and transport of water. Permeability, which is a measure of the flow of water under pressure in a saturated porous medium, and sorptivity, which characterizes the materials ability to absorb and transmit water through it by capillary suction. Whilst permeability is an important parameter for water retaining structures, a more important parameter (which is directly related to durability) for above ground structures is sorptivity.

Hence, sorptivity may be more convenient index of durability than is air permeability. It has also being argued that sorptivity, being sensitive to changes in mix constituents and workmanship factors, is a good index of concrete quality in general (Dias, 1995).

## 2.6 Summary

In BS 8110: Part 1: 1985, the enhancement of durability was achieved by using higher strength concrete. In obtaining higher strength with adequate quality controlling measures, weigh batching of constituent materials should be adopted. With this it is possible to use design mixes since any cement to aggregate ratio is achievable with weigh batching.

In Sri Lanka, still volume batching is often used due to non availability of weigh batching equipments with many small scale contractors. One nominal mix that is often used is 1: 2: 4 cement, sand and 20mm coarse aggregates. However this may give only a strength of about 20N/mm<sup>2</sup>. However the minimum grade recommended in BS 8110: Part1: 1985 is Grade 25.

The mix of 1:1.5:3 of cement sand and 20 mm coarse aggregates is also not often adopted since is considered as an expensive mix. Therefore, there is an urgent need to develop cost effective mixes that could be practically used for Grades 25 and 30 concretes. This could be considered as a short term solution until weigh batching could be adopted in majority of construction sites in Sri Lanka.



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Durability of concrete was improved by using other product like silica fume in many other parts of the world. However, this is not used very much in Sri Lanka. Therefore, it is useful to determine the possibility of using silica fume with locally available aggregates.

Therefore, in this research study, the development of economical nominal concrete mixes and the use of silica fume for enhancing the durability and the concrete strength was determined.