CHAPTER 7
PERFORMANCE CHARACTERISTICS OF RHA CONCRETE-
AN OVERVIEW

7.1 INTRODUCTION
The following sections provide a general outline of the present knowledge available on the durability of concrete. In particular, literature relevant to the work carried out on the behaviour of RHA blended concretes on various performance characteristics has been reviewed.

7.2 DURABILITY OF CONCRETE
Durability defines the suitability of concrete to preserve its structural performances, fixed by the designer, over a specified span of time. Hence it plays a fundamental role in determining the service life of the structures. It depends on both the concrete properties and the impact of environment.

According to ACI Committee 201 (1991), durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The concrete should be designed, without deterioration over a period of years. High performance concrete is characterized by its excellent durability rather than high strength concrete. Now-a-days concrete mixtures are proportioned not only for strength, but also for durability to increase the service life of the structure. Two ways to obtain the high performance are to reduce the flocculation of cement grains and widen the range of grain size [Mehta and Aictin, 1990]. The flocculation of cement grains can be reduced by the use of plasticizers and the grain size can be widened by addition of cement additives, and wide size distribution of aggregates. As a matter of fact porosity and permeability are the governing parameters, which account for the concrete performance [Pliskin, 1992].
Durability of concrete largely depends on the ease with which, fluids and gases can enter and move through. This property is referred as permeability or transport property of concrete. The movement of various fluids through concrete takes place not only by flow through the porous system but also by diffusion and absorption [Neville, 1995]. Deterioration of concrete is directly related to presence of aggressive solutions in water and the porosity and permeability of the concrete as well as the presence of cracks. The permeability of the concrete is perhaps more important than its strength [Orchard, 1958].

Higher early strength can be achieved in some modern cements due to more calcium hydroxide (CH) formation, but this may adversely affect the durability and cost of concrete. By the use of cement replacement of siliceous by-products, such as fly ash, rice husk ash, slag, silica fume in making mortar or concrete may improve the durability of the concrete [Mehta, 1989; Salihuddin, 1993; Zhang et al., 1996; Cook, 1986; Bagel, 1998; Amjad and Salihuddin, 1999 and Khan et al., 2000].

7.3 PORE STRUCTURE
Porosity is one of the major components of the microstructure of the cement system. It influences the strength and permeability of concrete. All aspects of strength are related to the total porosity. Whereas, permeability depends on the structure and size distribution of pores. The pore structure development in the cement pastes tends to reduce the volume of large pores during the initial stage of hydration. This reduction in large pores is due to the hydration products fill the space of least resistance and also increases the volume of small pores. The increase of small pore volumes has been attributed to the formation of hydration products around the large pore necks. Pore structure of blended cement is different to that of plain cement paste as stated by
Mehta and Manmohan (1980). In plain cement, although the total porosity is less than blended cement, the pore structure tends to be continuous [Feldman, 1983]. According to Feldman, (1983) the continuous nature of pores in plain cement paste has been attributed to the high calcium hydroxide content present, mainly as large crystal. In blended cements, the continuity of large pores is lower than plain cement and after 28 days of hydration these large pores are essentially isolated [Cook and Rao, 1987].

It is known that the pozzolanic reaction modifies the pore-structure. Hydration products formed due to the pozzolanic reactions occupy the empty space in the pore-structure which thus becomes densified. The porosity is reduced, and subsequently, the pores are refined. Mehta (1992) has shown significant reduction in the porosity of cement paste with RHA additions and refinement in the pore structure.

7.4 PERMEABILITY AND WATER ABSORPTION
Accordance to Concrete Society Technical Report 31 (1988), permeability is defined as the flow property of a porous medium, which characterizes the ease with which a fluid will pass through it, under the action of a pressure differential. Water absorption is defined as, the process whereby the concrete takes in a fluid to fill spaces within the materials [Concrete Society Technical Report 31, 1988]. Effective porosity of concrete is usually measured by water absorption.

As mentioned earlier, the movement of various fluids through concrete takes place not only by flow through the porous system but also by diffusion and absorption. It controls the rate of entry of moisture that may contain aggressive chemicals. Concrete permeability depends largely on the volume and size of the interconnected capillary pores in the cement paste, and also on the intensity of micro cracks at the
aggregate–cement paste interface as well as within the paste itself. Low permeability of concrete can improve resistance to the movement of water, sulphate ions, chloride ions, alkali ions, and other causes of chemical attack. The permeability will decrease rapidly with the progress of the hydration.

It is generally agreed that the ingress of chloride ions into concrete leads, in many structures, to long-term deterioration. In other words, the chloride permeability of concrete is such an intrinsic property of the concrete that needs to be assessed independently, especially in the design and construction of structures to be built in a salt-laden environment. When the chloride concentration of concrete exceeds a certain threshold value, depassivation of the steel occurs and reinforcing bars start to corrode. It is therefore a convenient way to use a pozzolanic material in the production of the concrete for improving its resistance to chloride penetration and eventually reducing chloride-induced corrosion initiation period of steel reinforcement.

7.4.1 Influence of Pozzolans on Permeability and Porosity
A numerous researchers agreed that the substitution of pozzolans for part of the cement reduces permeability and porosity in concrete. The pore structure of blended cements is relatively discontinuous after 28 day of curing. The continuous nature of pores in ordinary Portland cement pastes continues with age, which is discussed earlier. The addition of pozzolan should help to reduce the permeability of concrete judging from the influence of pozzolan in hydration of concrete such as reduction of water content, the dense packing, the increased hydration of cement, as well as its pozzolanic reactions.

The presence of pozzolan leads to a greater precipitation of cement gel products than occurs in Portland cement alone, which more effectively block the pores and therefore
helping to reduce permeability. The water-soluble calcium hydroxide liberated by hydrating cement may leach out of hardened concrete and leave voids for the ingress of water. In the pozzolanic reaction, the amount of CH gets reduced, which in turn leads to reduced leaching of CH. The additional products by pozzolanic reaction, C-S-H will close the voids, which result in more dense concrete, and consequently reduce the permeability of concrete arising from a pore refining process.

7.4.2 Relationship between Strength and Porosity
The presence of entrapped air, capillary pores, gel pores, and entrained air in concrete could influence the strength properties of hardened concrete. Besides, their volume, the factors such as the shape and size of pores are also influence the strength. Rossler and Odler (1985) have shown a linear relationship existing between strength and porosity based on volume of pores larger than 20 nm in diameter. The effect of pores with size smaller than 20 nanometer diameter was found to be insignificant. Commonly, at a given porosity, smaller pores lead to a higher strength of the cement paste [Neville, 1995]. Feldman and Beaudoin (1991) also reported a linear relationship between the two parameters of hardened cement pastes.

7.4.3 Relationship between Porosity and Permeability
Porosity in itself does not lead to it being permeable to fluid even though the concrete is porous material. It is permeable to the extent it has interconnecting void spaces. Fig.7.1 shows an illustration on porosity and permeability. If the porosity is high and the pores are interconnected, they contribute fluid to transport through the capillary pores, which will results high permeability in concrete. On the other hand, the discontinuous pores structure in concrete will results in low permeability due to the fluid will ineffectively able to transport even its porosity is high.
Although the cement gel has a porosity of 28 percent, its permeability is only about $7 \times 10^{-16} \text{m/s}$. The pores are very small and numerous. Although capillary pores are fewer in number, they are much larger than gel pores which leads to a higher permeability. Water can flow more easily through the capillary pores than through the much smaller gel pores. It does pursue that the permeability of cement paste is controlled by the capillary porosity of the paste. Powers (1958) has shown the relation between both quantities referred in Fig. 7.2. Small pores carry very little water compared to the maximum continuous pore radius. The volume of large pores and the continuity of pore structure affect the permeability of cement paste. The permeability and absorption of mature blended pastes is expected to be low due to the discontinuous nature of pores.

Salihuddin (1993) also studied the relationship between the permeability and the volume of pore radius greater than 200Å of RHA and palm oil fuel ash mortar. It was found the direct relationship exists between two parameters but very poor in nature. The lines drawn are just indication of general trends. The trends show a general rise in permeability as percentage of volume of pores of radius greater than 200Å increased [Salihuddin, 1993].

### 7.5 SORPTIVITY

Sorption is due to capillary forces which are active in concrete subjected to natural wetting/ drying cycles. Sorption is a more general phenomenon than permeability since it occurs when unsaturated paste, mortar or concrete come into contact with water or air moisture. Studies on sorptivity of mortar and concrete were introduced in 1970’s [Hall, 1989]. These studies were not comprehensive but did show that the
sorptivity of mortars and concrete could be measured reproducibly and that it varied in a rational way with composition and curing history.

Today, there is a strong interest in finding better ways of assessing the material properties of concrete which affects durability. The process of deterioration in concrete is mediated largely by water. It is generally agreed that it would be a useful step forward to find a way of measuring a single material property which reflects the ability of a material to absorb and transmit water by capillarity. The sorptivity appears to be an especially useful property of this kind. The sorptivity is an easily measured material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. It is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. It determines the rate of inflow or the depth of water penetrated by allowing the dry concrete to absorb water uni-directionally under a negligible applied pressure. The first appearance of sorptivity tests in the literature of testing building materials was in 1977 in which Hall described that the cumulative absorbed volume per unit area of the inflow surface \((m^3/m^2)\), denoted by \(i\), increases as the square root of the elapsed time, \(t\); that is:

\[
i = S t^{0.5}
\] 

\[(7.1)\]

Where \(S\)= Sorptivity of the material \((m/s^{0.5})\). One could consider that this equation is an empirical relationship to specify a material property which governs the intake of water by capillary suction. It is reported that the capillary suction test, according to Hall (1977) has been adopted in the Swiss Guidelines for Testing; Test No.5: Water Conductivity (1989) and the method of absorption of water by capillarity is a tentative RILEM recommendation (1974).
7.6 PERFORMANCE CHARACTERISTICS OF RHA CONCRETE

It is a generally known fact that the addition of pozzolans can improve the properties of concrete by modifying the micro and macro-structure of cement paste. RHA due to its porous nature reduces segregation and bleeding of concrete. The reduction in bleeding water results in a stronger transition zone between solid matter and cement pastes. This will lead to a more impermeable and durable concrete [Hwang and Chandra, 1997].

7.6.1 Influence of RHA on Permeability and Porosity

The movement of aggressive solutions into a concrete mass or the removal from concrete of dissolved reaction products must play a primary role in determining the rate of progress of concrete deterioration caused by chemical attack. Permeability of concrete is therefore, fundamental in determining the rate of mass transport relevant to destructive chemical action. The pore structure of RHA (30 percent replacement) mortar is denser than control OPC and fly ash (30 percent replacement level) mortar as confirmed by the mercury porosity analysis [Salihuddin, 1993]. Zhang et al. (1996), reported that, the higher compressive strength gain and reduction of permeability in concrete incorporating RHA is probably due to the reduced porosity, reduced calcium hydroxide content and reduced width of the interfacial zone between the paste and the aggregate.

The transport of chloride ions through RHA blended concretes depends on the pore structure of the concrete. The finer particles of ashes develop discontinuous and tortuous pore in concrete structure [Bhanumathidas and Mehta, 2004]. Moreover the micro and macro pores present in the concrete are completely filled up by finer particles. Cook (1986) has reported that highly reactive pozzolana, such as rice husk ash is able to reduce the size of voids in hydrated cement pastes, thus, making them
almost impermeable even at early ages (7–28 days). Bhanumathidas and Mehta [2004] also confirmed the pore-refining capacity of RHA when present in a Portland cement concrete. The decrease in chloride permeability is promoted with an increase in fineness of the ashes [Nehdi et al., 2003].

Ganesan, et al. (2008), investigated that the total coulombs charge passing through RHA blended concrete specimens continuously decreases with increase in RHA content up to 30 percent. At 35 percent RHA addition, there is an increase in total charge passed value and this value is also lower than that of control concrete. This observation is true for both 28 and 90 days cured specimens. Particularly the total charge passed for 30 percent RHA blended concrete is considerably reduced (more than 70 percent reduction) both at 28 and 90 days cured concretes. Saraswathy and Wong (2007) found that as the replacement level increases the charge passed decreases. Replacement of rice husk ash drastically reduced the coulomb values. As per ASTM C 1202, RHA reduced the rapid chloride penetrability of concrete from a low to very low ratings depending upon replacement levels. The same trend was reported by Nehdi et al. (2003), in RHA replaced concrete.

Ganesan, et al. (2008), found that at 28 days curing, the percentage of water absorption increases with RHA content up to 35 percent. This is due to the fact that RHA is finer than OPC and also it is hygroscopic in nature. When the curing time was increased to 90 days the percentage of water absorption values decreased considerably with increase in RHA content up to 25 percent. Even at 30 percent RHA, the value was lower compared to that of control mixture. Obviously with prolonged curing, RHA presence leads to reduction of permeable voids. However, Ho, et al. (1988), reported that RHA performed poorer than OPC and fly ash-concrete in terms of
absorption due to its porous and high surface area. But, the permeability is less in terms of chloride penetration than OPC concrete [Ho, et al., 1988]. 10 to 20 percent cement replacement by RHA shows extraordinary improvement in chloride permeability [Hwang and Chandra, 1997].

It has been reported that at early age of curing (7 and 28 days) supplementary cementitious materials are more porous than the plain cement paste, but at the later ages (90 days) this may be reversed. And also, the pozzolanic materials increased the porosity and reduced the pore structure [Ambroise et al., 1994]. The same trend is observed by Saraswathy and Wong (2007), for RHA replacement up to 30 percent. Mehta (1992), Zhang et al. (1996), and Mahmud et al. (1996), and others all agreed that the performance of RHA blended cement has similarity with SF blended cement due to its considerable silicon dioxide content like SF. RHA is a viable alternative material to SF.

7.6.2 Influence of RHA on Sorptivity
Limited studies were carried out on the performance of RHA concrete on the sorptivity. Ganesan et al., (2008) reported that sorptivity progressively decreases with increase in RHA content up to 25 percent at 28 days of curing. At 30 percent and 35 percent RHA, there is an increase in sorptivity and these values are also lower than that of control concrete. At 90 days of curing, the sorptivity values up to 35 percent RHA are quite lower than that of control concrete. This again confirms that prolonged curing leads to a reduction in pore space. It is also observed from the sorptivity data that 30 percent RHA concrete specimens have shown 45 percent reduction in sorptivity at 28 days compared to that of control specimens. It is also reported that a
linear relationship is found to exist between sorptivity, chloride penetration and chloride diffusion coefficient irrespective of age [Ganesan et al., 2008].

7.7 SUMMARY
The durability of cement based materials is often determined by the rate of ingress of deleterious species (acids, carbon-di-oxide, sulphates and chlorides) from the aggressive environment.

Blended cement has a great potential to improve the concrete quality and many other properties of concrete. All researchers agreed that the micro-structural characteristics, such as porosity and permeability governed the quality and durability of concrete. As a matter a fact, the permeability is dependent on the continuity of pores and pore size distribution.

From the literature study, it is also found that the use of pozzolans as cement replacement has engineering potential and economic benefits. The additional products from pozzolanic reaction fill the pores, which results in more dense concrete. Consequently this reduces the permeability of concrete due to pore refining process. The blended cements reduce amount of CH, due to its low alkalinity from main and long-term reaction with CH. Therefore it can reduce the leaching of CH and obstruct further reaction from the chemical ingress. Most of the researches reported that RHA, a potential alternative to conventional blended system enhances the durability characteristics of concrete. Each percent of rice husk ash addition may improve permeability of concrete by about 0.6 times every year.
Fig. 7.1: Illustration of permeability and porosity [From Concrete Society Technical Report No.31, 1988]

Fig. 7.2: Relation between permeability and capillary porosity of cement paste [Power, 1958]