CHAPTER 9
CONCLUSIONS

9.1 GENERAL
The artificial pozzolanas are generally by-products of some of the manufacturing process. The properties of such pozzolanas depend upon the properties of the raw materials used and the production conditions prevailing in the process. Therefore the chances for change in the quality of these by-products may occur either due to change of the source of raw material or some changes introduced in the manufacturing conditions, whereas, rice husk is the by-product of agriculture industry. During 1973, Mehta obtained patent for the production of RHA which could be used as pozzolana. Since then, the use of RHA as pozzolana and the advancements made to study the behaviour of RHA blended cement concrete are significant. There are a number of industries in countries, like USA, Brazil, China, Thailand, etc, which commercially produce RHA. Even in India, there are about half-a-dozen industries commercially manufacture and successfully market RHA. But the manufacturing process is kept as trade secret for commercial reasons.

Focusing towards research on RHA as pozzolana, many researchers either used ready-made RHA or produced their own RHA following a specific production methodology. The current research work carried out at Pondicherry Engineering College was focused towards exploring various possible ranges of temperature and duration of incineration, which will impart maximum pozzolanicity to RHA. In addition, the optimum production conditions and optimum dosage of RHA in concrete production were aimed. The outcome of the present study is highly encouraging and some of the findings may be considered as significant contribution made to the field of concrete technology. The salient conclusions drawn are presented in this chapter.
9.2 GENERAL CONCLUSIONS
The following are the general conclusions for the production of reactive RHA:

1. Incinerating conditions, such as temperature and duration of incineration mainly activates the reactivity of rice husk ash.

2. Heating and cooling regime also controls the reactivity nature of RHA.

3. RHA particles are irregular in size and porous in nature.

4. As RHA particles are being soft and fragile in nature, the grinding process should be carefully controlled such that the porous nature of ash is not destroyed and the required minimum particle size is also ensured.

9.3 RESEARCH FINDINGS

9.3.1 Production of Reactive RHA
The following are the salient conclusions derived out of this research work for the production of reactive RHA:

1. In order to optimize the grinding process, the following conditions may be maintained:
   
   i. Packing density of abrasive charges (steel balls) should be at least 5.5 g/cc.
   
   ii. The volume of the abrasive charge shall not exceed 50 percent of volume of mill.

   iii. The duration of grinding may be limited to 30 minutes.

   a. Physical properties of RHA
   
   2. Fairly white colour ash is formed at temperatures of 350°C to 500°C, which indicates almost complete oxidation of carbon in the ash. The grey colour ash is formed at temperatures of 600°C to 800°C, which represents the formation of potassium poly silicate combined with carbon. Traces of pink
colour ash is produced at 800°C for prolonged incineration, more than five hours, which represents the presence of crystalline silica in ash.

3. Density of RHA indicates qualitatively its amorphous state. Higher the density of RHA higher will be its amorphous content. Density of RHA lies in the range of 1.1 kN/m$^3$ to 1.9 kN/m$^3$. Higher density is achieved in the temperature zone of 350°C - 500°C.

4. Under identical grinding process, RHA produced in various conditions exhibit widely varying fineness. Both Blaine’s and BET techniques exhibit the same trend of surface area variation. However, in Blaine’s technique the porous nature of RHA is not accounted in the determination of total surface area.

   i. The minimum fineness is achieved for RHA sample produced at 800°C-5 hours combination and its value is 11.22 m$^2$/g and the maximum fineness of 50.2 m$^2$/g is achieved for 500°C-120 minutes ash sample by BET technique.

   ii. Amorphous RHA particles are fragile in nature compared to crystalline RHA particles. Under identical conditions of grinding, ash with maximum amorphous silica content will acquire maximum fineness.

b. **Chemical properties of RHA**

5. RHA samples show wide variation in amorphous silica content under various incineration time and temperature. The combination “500°C-120minutes” acts as a nodal range with maximum amorphous silica content.

6. Amorphous silica content in various samples of RHA measured by analytical method is confirmed by electrical conductivity test.
c. Micro structural properties of RHA

7. It is noticed from the XRD analysis that RHA samples produced at lower temperatures–longer duration and higher temperatures–shorter duration had amorphous characteristics. However, the content of reactive (amorphous) silica of those RHA samples was not identical. XRD analysis gives only qualitative measurement of amorphous state of RHA. The additional inferences obtained from XRD analysis are:
   i. Crystalline material (cristobalite) is formed at temperature of 800°C.
   ii. The transition from amorphous to crystalline cristobalite occurred at 800°C. The presence of impurities, such as alkali oxides is responsible for this (reduced) transition temperature.

8. The presence of potassium is responsible for the accelerated formation of cristobalite, prior to the formation of tridymite. This is in confirmation with the earlier findings [Hanafi et al., 1980; Hamad and Khattab, 1981; Kapur, 1985 & Shinohara and Kohyama, 2004].

9. Above 600°C of incineration, RHA particles are larger in size than that produced below 600°C. Sodium and potassium salts react with silica to form eutectic mixture (i.e. the melting point of the mixture is lower than its individual components). The melting point of these eutectic mixtures is in the range of 600°C - 700°C. At this temperature the particles are fused together to become larger in size. This is in confirmation with Armesto et al, (2002).
d. Energy consumption

10. In general, the energy consumption should be directly proportional to the temperature and duration of incineration. However, the heat energy released by the ignited medium will ensure self sustainability, which will be dependent on the calorific value of the medium, temperature level, and duration. The present study reveals the following in this aspect:

i. Every kilogram of husk releases about 3.5 kWh of heat energy. In the furnace, this heat energy is optimally utilized if the incinerating temperature is high, say at 800°C. When the temperature is low (say 350°C), the advantage derived out of the incinerating husk becomes the least (vide Fig. 4.37).

ii. Up to 500°C of set temperature, the electrical energy required to maintain over the set duration (say up to 150 minutes) remains fairly uniform. That is, self sustainability of temperature is ensured up to 500°C. Beyond this temperature the self sustainable condition ceases to exit.

iii. Up to 500°C and 150 minutes of incineration, the total energy consumption is the minimum and it remains nearly constant at 1kWh.

e. RHA-OPC reactivity

11. In general, RHA mortar specimens attain higher strength than reference mix at all ages. The variation of strength gain of RHA mortar specimens reflects similar behaviour noticed in fineness, amorphous silica content and soluble silica content tests.
12. From the overall characteristics of ash samples, three zones of temperature range, that is, 350°C–450°C; above 450°C & below 600°C; and 600°C–800°C have been identified. The ash samples produced over these three zones of temperature possess unique and distinct characteristics (vide § 4.10).

**f. Optimum incineration condition**

13. Incineration condition, 500°C -120 minutes is found to be the optimum combination for the production of ash with maximum pozzolanicity, the least production energy, maximum amorphous silica content, maximum fineness, and maximum density.

**9.3.2 RHA- OPC Hydration Mechanism**
The following conclusions were derived based on the behaviour of RHA on the compressive strength of concrete mixtures:

1. Consistency of RHA blended pastes increases with increase in RHA content.
2. Addition of RHA tends to increase the initial setting time of OPC-RHA blend. However, final setting time is reduced with addition of RHA. This behaviour is line with the observations made by Ganesan et al., (2008).
3. RHA mortar cubes show higher compressive strength than reference mixtures at all ages right from day one to sixty days.
4. Microscopic studies confirm the formation of relatively denser hydrated products of C-S-H in OPC-RHA hydration mechanism as the voids are occupied by the hydration products.
5. The use of higher binder content at low water to binder ratio required higher super plasticizer dosage. Rice husk ash being very fine pozzolana increased the super plasticizer dosage to maintain comparable workability.
6. Rice husk ash addition has contributed to strength improvement of concrete at all ages from three days to sixty days.

7. With regard to strength gain, the rate of strength gain in RHA-OPC concrete increases with RHA content (up to 20 percent). At 20 percent replacement level, all mixtures exhibited the maximum strength gain.

8. At 30 percent replacement level, compressive strength comparable/equivalent to that of reference mixture was attained for all mixtures.

9. Compressive strength of reference concrete mixtures varied from 49 to 80 MPa. Whereas, the compressive strength of RHA concrete mixtures varied from 55 to 92 MPa.

10. The maximum compressive strength achieved in this work is 92 MPa and the maximum relative strength attained in RHA blended concrete is 125 percent.

11. Rice husk ash proves to be highly reactive pozzolan which contributes to higher strength right from as early as three days. This is in good accordance with the findings of Bui et al., (2005).

9.3.3 Performance Characteristics of RHA- Concrete

The following conclusions were derived based on the performance characteristics of RHA blended concrete mixtures:

1. Performance characteristics, such as chloride permeability, saturated water absorption and sorptivity of RHA blended mixtures show significant improvement with increase in RHA content.

2. As high as 30 percent OPC can be replaced with rice husk ash without any adverse effect on durability properties.
3. Replacement with 30 percent of RHA leads to substantial improvement in the permeability properties of blended concrete when compared to that of OPC concrete which are,
(a) about 38 percent reduction in water absorption at 28 days,
(b) about 58 percent reduction in chloride permeation at 60 days and
(c) about 45 percent reduction in sorptivity at 28 days.
4. A linear relationship exists between water absorption, sorptivity and chloride permeability properties of RHA blended concrete irrespective of water binder ratio, age, and cement content (vide Figs.8.11 &8.12).
5. Permeability characteristics of RHA blended concrete mixtures bears inverse relationship with the compressive strength (vide Figs.8.13 to 8.15).
6. The compressive strength of RHA blended concrete mixtures is well correlated with the chloride permeability (vide Fig.8.13).

**a. Optimum usage of RHA**

7. At 20 percent RHA addition, maximum compressive strength is achieved for all mixtures and performance characteristics are significantly improved.
8. At 30 percent RHA addition, compressive strength of RHA blended concrete remains equivalent to that of reference mixture and the performance characteristics are better than that of 20 percent replaced mixture by about 12 percent.
9. Considering the strength aspect, cost effectiveness, and performance characteristics, 20 percent replacement of cement by RHA addition is to be the optimum dosage in concrete making.
10. The cost of production of RHA was estimated as Rs.18 per kg. The cost analysis was done based on laboratory conditions. When compared to the
cost of micro-silica, the use of RHA may reduce the cost of supplementary cementitious material by about 40 percent.