1.1 GENERAL

India has the second largest road network in the world. The total length of the road network in India is around 56,03,293 km [1]. The roads are however of mixed type: expressways, highways, paved and unpaved roads etc. The total length of expressways in India was about 1584 km only in the year 2018 [1]. Most of the fund was allocated to other important sectors like education, health, defence, etc. and the transportation sector was neglected in the past. Transportation sector can be pivotal for the economic and social development of a country. It also helps in reducing poverty by providing access to education, health, employment and social services. Therefore things started to change for good when National Highway Authority of India (NHAI) began its operations on February 1995 and was deemed responsible for management, development and maintenance of highways in India. The length of National Highways in India has increased from 70,934 km in 2010-11 to 101,011 km in 2015-16 [1]. The total road length in the year 2015-16 by categories and by type of surface in India is shown in Table 1.1 [2].

Table 1.1 Road length by categories and by type of surface in India

Category	Total Length (km)	Surfaced		Un-surfaced (km)
		WBM/WMM (km)	Bituminous or Concrete (km)	
National Highways	1,01,011	0	1,01,011	0
State Highways	1,76,166	2,550	1,67,687	5,928
District Roads	5,61,940	25,100	5,08,392	28,447
Rural Roads	39,35,337	6,82,640	15,08,339	17,44,358
Urban Roads	5,09,730	41,706	3,54,752	1,13,272
Project Roads	3,19,109	39,567	70,160	2,09,382
Total	56,03,293	7,91,563	27,10,341	21,01,389

Introduction

Flexible pavement is known as such because it undergoes plastic deformation under vehicular loads. The stresses induced due to the vehicular loads are transferred by several layers of granular (bound and unbound) materials to the subgrade beneath. These stresses are distributed over a relatively narrow area of the subgrade.

The rigid pavement is basically the plain concrete, or reinforced concrete slabs laid directly over the subgrade or a stabilized base course. The cement concrete slab has a very high modulus of elasticity; therefore, the deflection of the slab is very little under the vehicular load. It disperses the load stresses over a wide subgrade area with relatively thinner pavement, thus, minimizing the need for subsequent layers to reduce the load stresses.

Flexible or bituminous pavements have low initial cost as well as low service life, while rigid or concrete pavements have higher construction cost and higher service life. Although concrete pavements are about 1.5 times costlier than bituminous pavements, their life cycle cost, including the maintenance cost spread over the service life, is much lower. Rigid pavements are 35% cheaper than the flexible pavements over the service life of 20 years [3]. The flexible pavements are better alternatives if the pavement construction is to be done in stages and better suited for those areas where the quality of the subgrade is permeable and heavy commercial traffic is not present. However, the rigid pavements are better suited for the areas where the subgrade soil is weak and the site has poor drainage conditions. The decrease in consumption of fuel while driving on rigid pavements as compared to the flexible pavements is 3.2% for passenger vehicles and 4.5% for heavy vehicles [4]. The emission of CO_2 by the vehicles travelling on rigid pavements is less w.r.t flexible pavements [4]. The CO_2

emission during the construction of rigid pavement is also lower. The more the traffic load is, more economical is rigid pavement than the flexible pavement [5].

Many National Highways are being constructed with rigid pavement. National highways of India constitute around only 1.8% of the total Indian roads but carry more than 40% of the total traffic [1]. The Bharatmala Pariyojna was approved by Government of India on 24th October 2017. Under this scheme, the plan is to develop 34,800 km of highways over a period of 5 years, and the total cost of the project was 5.35 trillion INR [6]. With such an ambitious road development project on the anvil, it would be favourable to reduce the construction cost of the rigid pavements somehow. It can be done by introducing new construction materials which can replace constituents of the cement concrete pavement.

1.2 BACKGROUND

Concrete is one of the most regularly used materials for construction purposes. It is second only to water in terms of per capita consumption. The usage of concrete is around 3 tonnes for every person per year [7]. Concrete basically comprises of 3 main ingredients: aggregate (coarse and fine), cement and water. Aggregates are generally used as a filler as it occupies more than 70% volume of the concrete. Aggregates can also affect workability, durability, strength and shrinkage of concrete. They are the most mined material in the world. Cement is a binder which holds the aggregates together in the presence of water to form concrete. It occupies approximately 10-15% of the concrete mix by volume [8].

The construction sector of India is growing at a rapid rate and cement is the essential material required in the construction sector. In fact, India is the 2nd largest producer of cement in the world. The capacity of cement plants in India was around

502 million tonnes per annum in the year 2018. It may reach about 550 million tonnes per annum by the year 2020 [9]. Such is the growth in the capacity of cement plants that India could turn into the major exporter of cement to other developing countries of the world by the year 2025.

The production of cement raises serious environmental concerns at all stages of production [10]. Some of them are pollution through noise, dust, gases and blasting. The most significant damage caused to the environment during the production of cement is by the emission of carbon dioxide (CO_2). Emission of carbon dioxide gas disrupts the natural greenhouse effect leading to global warming. Cement plants account for 10% of the global emission of CO_2 out of which 60% is emitted when limestone is heated to form lime (an essential component in cement clinker) and CO_2. The rest 40% is emitted due to the consumption of fuel in the production of cement [11]. Around 900 kg of CO_2 is liberated into the atmosphere in production of 1000 kg of cement [12]. As the consumption of cement is increasing day by day, a reduction in CO_2 emissions can be made by reducing the production of cement. The increasing demand of the cement can be tethered to by partially substituting it with sustainable materials in concrete. New materials are being researched to decrease or even abolish the production of cement. It will not only reduce the emission of carbon dioxide but also decrease the consumption of natural raw materials required for the production of cement. Some of these sustainable construction materials help to increase the performance capabilities of the traditional cement.

1.3 MINERAL ADMIXTURES

The performance of concrete is decided based on its strength, durability and fluidity. The use of cement in concrete does not guarantee the best performance of concrete. The usages of sustainable materials which can partially or fully replace cement in concrete, will not only improve the performance of concrete but will also decrease the environmental problems and the cost of concrete. Mineral admixtures are those materials which in powdered form are added in concrete before or during mixing to improve its quality. They affect the properties of hardened cement concrete. Mineral admixtures used in the appropriate amount improve workability and sulphate resistance. They also decrease the alkali-aggregate reaction, permeability and heat of hydration [13]. They are generally of two types: cementitious materials (rich in calcium oxide content) and pozzolans (siliceous or siliceous and aluminous materials). As the name suggest, cementitious materials are those materials which possess the properties of cement. Pozzolans are those materials which have very little or no cementitious value but when they are used with cement in finely divided form and in the presence of moisture, form cementitious compounds. Some of the cementitious materials researched are ground granulated blast furnace slag (GGBFS), hydraulic hydrated lime etc. and the examples of pozzolans are diatomaceous earth, microsilica, fly ash, opaline cherts, pumicites, shales, rice husk ash, sugarcane bagasse ash etc. Rice straw ash (RSA) and microsilica (MS) are the pozzolans which have been studied in this research for their effects on properties of concrete.

1.3.1 Microsilica

Microsilica also known as silica fume, is a by-product obtained during the production of silicon metal and ferrosilicon alloys. In the production of silicon metal and ferrosilicon alloys, the highly pure quartz is reduced using carbonaceous materials in electric arc furnaces. The by-product of this carbothermic reduction is microsilica. It is an ultrafine material mainly consisting of non-crystalline silicon dioxide (SiO_2 >

85%) [14]. The average size of the microsilica particle is in the range of 0.1 to 0.2 microns about 1/100th of the average size of cement particle [15]. Due to high SiO_2 content and finer size, microsilica acts as a highly reactive pozzolan in concrete. It improves the mechanical and durability properties of concrete significantly [16]. The standard specification for the usage of microsilica in concrete is ASTM C1240-15 [17]. Before 1970, microsilica was treated as waste material. When the disposal of microsilica became a matter of concern, it was found that usage of microsilica in various applications like concrete was more economical than its disposal [18]. Microsilica has been studied extensively in the past and is a proven pozzolan for high strength concrete [19]–[22]. Few real-life examples of usage of microsilica in a high strength concrete are as follows [23]:

- The Bandra Worli Sea Link, Mumbai, India
- Great Belt Link, Denmark
- Abu Dhabi Strategic Tunnel Enhancement Programme, UAE
- Mass Rapid Transit System and Deep Tunnel Sewage System, Singapore
- Coastal Defence Project, England, UK

1.3.2 Rice Straw Ash

India is the largest producer of rice in the world behind China. Rice production in India and Asia is around 20% and 90% respectively of total rice production in the world [24] as shown in Figure 1.1. The production of rice in India has increased from 107.7 million tonnes in 2002 to 168.5 million tonnes in 2017. The cultivation of rice in India is mainly done in the Kharif season with a small contribution in Rabi season. The harvesting of rice crops sown in Kharif and Rabi season is mainly done in the month of November-December and March-June respectively. West Bengal, Uttar Pradesh, Andhra Pradesh and Punjab are the leading states of India in terms of rice production [25].

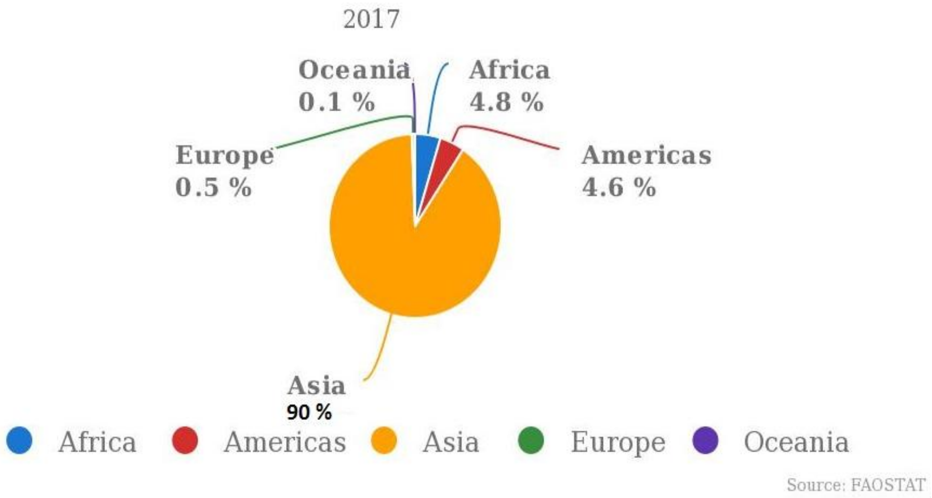

Figure 1.1 Percentage rice production in the world

Rice straw is an agricultural by-product of paddy cultivation, as shown in Figure 1.2. The annual production of rice straw in the world is 731 million tons [26]. It is highest among the agro-residues production in India [27]. The major components of rice straw are hemicellulose, cellulose and lignin [28]. The utilization of rice straw varies across different states of India. Traditionally rice straw has numerous competing uses such as animal feed, fodder, fuel, roof thatching, packaging and composting. These uses, however, will soon diminish because advanced technologies are making them unprofitable. However, the collection of rice straw is not an easy task because it is available only during harvesting season. Farmers generally use balers to collect rice straw from the field and densify it to form bales which are used as a feedstock. But the rice straw balers are costly for most of the farmers. Many technologies are being studied around the globe to bring down the cost involved in the collection of rice straw [29]. Due to high cost involved in the collection of rice straw, most of the farmers tend to dispose rice straw in the following ways:

- In Indian conditions, the rice straw of low economic value is usually left behind on the fields. Therefore, in the absence of alternate uses, farmers treat it as a waste material and resort to field burning of rice straw to ready their fields for next cultivation since the available time between reaping and sowing of crops is very less (20-25 days). It leads to emission of soot particles and greenhouse gases which damages the environment. The burning of rice straw on the field also leads to loss of plant nutrients like Nitrogen (N), Phosphorous (P), Potassium (K) and Sulphur (S) [30].
- Sometimes, the farmers also tend to dump rice straw either in the agricultural field where it is left unattended or in the open area leading to its rotting.

Figure 1.2 Rice straw after harvesting

El-Sayed et al. (2006) [31] states that rice straw is produced in significant quantities on a global basis. They are a waste product causing pollution and problems with their disposal. He further mentions that when rice straw is burnt, the resulting rice straw ash (RSA) is highly pozzolanic and satisfies the requirements of ASTM Class N, F, and C pozzolan. Nearly 16.5% by weight of rice straw gets converted into ash after burning [32].

1.4 POTENTIAL FOR UTILIZATION OF RICE STRAW ASH IN INDIA

India is a developing country as per the World Trade Organization (WTO). Around 2/3rd of the total population of India lives in rural areas, as shown in Figure 1.3. According to World Bank, per capita income of India was 1800 USD in the year 2017 which was way behind per capita income of more developed countries like USA (59,501 USD), Singapore (54,530 USD), South Korea (28,380 USD) and China (16,660 USD). To overcome this huge deficit in per capita income and shed the tag of ‘developing country’ by the year 2047, Government of India has taken several steps to improve the infrastructure of the country like better transportation, housing for the entire population, better education and health facilities etc. Therefore, in India, use of alternative construction material which is cheap as well as abundantly available would allow for the construction of more rigid pavements in a given budget. Rice straw is cheap as well as abundantly available in India. Therefore, usage of rice straw ash would not only decrease the construction cost of the rigid pavements but may also improve its quality.

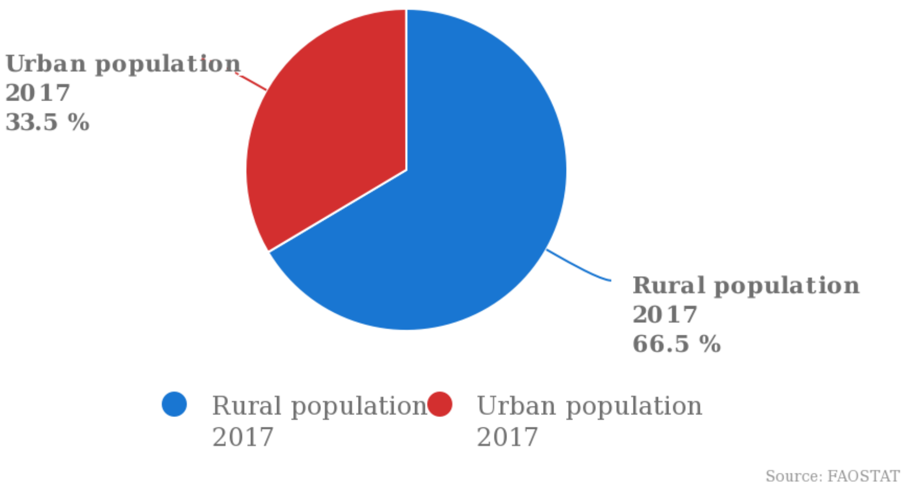

Figure 1.3 Rural and Urban population in India

Most of the pozzolans like fly ash, rice husk ash, microsilica, wollastonite, GGBFS, wheat straw ash, sugarcane bagasse ash etc., were studied for use in general purpose concrete (<M25 grade), except for few like flyash, rice husk ash, microsilica and wollastonite which were studied for Pavement Quality Concrete (PQC). Similar to the study on these pozzolans, there is a need to study the potential of Rice Straw Ash (RSA) as a mineral admixture for part replacement of OPC in general purpose concrete as well as PQC because rice straw has a good bulk which can be converted into ash by adopting inexpensive methods of burning. The resulting cementitious material shall be cheaper, resulting in more affordable concrete for pavement construction. El-Sayed et al. (2006) [31] reported that open-air burnt RSA has about 82% silica content. According to them, the silica content of RSA was at par with that of microsilica. Therefore, the structural benefits associated with microsilica as an active pozzolan are likely to be available with RSA to a large extent, along with the added benefit that RSA is significantly cheaper, thereby, making possibilities for significantly cheaper cementitious material as well as PQC.

1.5 RESEARCH OBJECTIVE

In the few studies done in the past on usage of rice straw ash as a partial replacement of cement in general concrete, the ash was produced under controlled burning of rice straw at high temperatures, and then the ash was ground to finer size [33], [34]. It can be concluded from some of the previous studies that the production of rice straw ash using enhanced burning techniques increases its qualities [26], [30], [35]–[37]. However, the enhanced techniques (burning at high temperatures and mechanical grinding) used for the production of rice straw ash can be costly and are not readily available everywhere. The absence of sufficient literature on the potential uses of RSA as a pozzolan in PQC presented many challenges which gave the urge for this investigation. Therefore, this thesis explores the production of M40 grade PQC with new cementitious material obtained by admixing RSA as pozzolan (when produced as a result of uncontrolled burning and without any further processing like pulverization) with OPC and comparing the results with the cementitious material of an established pozzolan like microsilica. Simultaneously, results of admixing both these pozzolans with OPC were compared with the control mix produced with OPC alone. Towards meeting these objectives, the present study was divided into eight segments as itemized below:

1. To investigate the material properties of rice straw ash, microsilica, OPC, aggregates and chemical admixture.
2. To study the physical properties of cement pastes of OPC admixed with rice straw ash and microsilica and investigate their mineralogical behaviour.
3. To investigate the compatibility of chemical admixture with cement paste admixed with rice straw ash and microsilica.
4. To evaluate the physical properties of mortar of OPC admixed with rice straw ash and microsilica.
5. To find the right proportion of materials by concrete mix design for M40 grade PQC.
6. To study the mechanical properties of concrete of OPC admixed with varying proportions of rice straw ash and microsilica and to evaluate their mineralogical as well as microstructural behaviour.
7. To study the durability properties of concrete of OPC admixed with RSA and MS.
8. To assess the structural design and rate analysis of rigid pavements of different concrete mixes for cost comparison.

1.6 OUTLINE AND STRUCTURE OF THESIS

The thesis is divided into nine chapters, which are concisely described as follows:

Chapter 1 deals with the introduction of present research work. This chapter also provides a background of the present study. It also shed some light on the mineral admixtures used in this study, followed by the potential of utilization of rice straw ash in India. Ultimately the objective of this research has been explained.

Chapter 2 deals with past literature related to the usage of mineral admixtures in the cement paste, mortar and concrete.

Chapter 3 describes the research methodology adopted for study on the materials used including their chemical, microstructural and mineralogical analysis. It also describes the sample preparation of paste, mortar and concrete for investigations on their various properties.

Chapter 4 deals with the discussion about the properties of the materials used.

Chapter 5 presents the results and discussions of the study on the physical properties of pastes and mortars of OPC admixed with rice straw ash and microsilica.

Chapter 6 shows the effects of admixing rice straw ash and microsilica to OPC on mechanical properties of concrete. It also deals with the mineralogical and microstructural analysis of the admixed concrete.

Chapter 7 deals with the effects of admixing rice straw ash and microsilica to OPC on durability properties of concrete.

Chapter 8 deals with the structural design and cost comparison of rigid pavements using unprocessed rice straw ash, microsilica and cement.

Chapter 9 presents the key findings of the study. The recommendations based on the results of this study have also been made. Scope for future work is also described.

1.7 CHAPTER SUMMARY

Chapter one provides a brief introduction of the condition of the transportation sector of India and discusses the advantages and disadvantages of flexible and rigid pavements. It also discusses the availability of rice straw in abundance around the world, which can be burnt to produce ash. It tells that rice straw ash is highly pozzolanic and can be used for partial cement replacement in admixed concrete. This chapter also gives a brief introduction to the microsilica as a mineral admixture and potential for utilization of rice straw ash in India. Chapter one supports the main goal of the present study to test the suitability of using unprocessed rice straw ash in PQC, which has not been addressed in the past. It also gives an overview of what is to come in the subsequent chapters.