EFFECT OF WOOD ASH ON THE PROPERTIES OF CONCRETE AS PARTIAL REPLACEMENT OF NATURAL SAND

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DECLARATION

I, Arpit Kumar Singhal, hereby declare that the thesis **"Effects of Wood Ash on the Properties of Concrete as Partial Replacement of Natural Sand"**, which is submitted in partial fulfilment of the requirements for the award of the degree of **Masters of Engineering** in **Structural Engineering** in the **Department of Civil Engineering, Thapar University, Patiala**, is authentic record of my own independent and original research work carried out by me under the supervision and guidance of **Dr. Rafat Siddique, Senior Professor, Department of Civil Engineering, Thapar University, Patiala** and **Dr. Malkit Singh, Additional Superintending Engineer, Punjab State Power Corporation Ltd., Patiala.**

The matter embodied in that thesis has not been submitted in part or fully to any other university or institute for the award of any degree.

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CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct according to the best of my knowledge and belief.

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ABSTRACT

Sources of good quality river sand are depleting very fast all around the world and excessive sand mining is giving rise to many environmental issues. The demand of sustainable growth of infrastructure in modern times is to find an alternative material for river sand that should not only satisfy the technical specification of fine aggregate, but it should also be abundantly available. Waste wood ash is a by-product of boiler industry, which has a potential to be used as a partial substitute for natural sand in concrete. The objective of the present study was to explore the possibility of utilization of wood ash as a partial replacement of natural sand in concrete. Experimental tests were performed to evaluate workability, hardened properties, durability properties and characteristics of concrete with partial replacement of natural sand with wood ash at replacement levels of 5, 10, 15 and 20%, and all properties were compared with conventional concrete containing 100% natural sand. The properties of concrete studied were workability, density, compressive strength, splitting tensile strength, water absorption, sorptivity, chloride-ion penetration and XRD & SEM analysis. Test results indicate that at constant w/c ratio, workability of concrete decreased with inclusion of wood ash as partial replacement of natural sand in concrete. There was an significant improvement in compressive strength and splitting tensile strength of concrete containing wood ash as compared to control concrete, with concrete containing 5% wood ash showing maximum compressive and splitting tensile strength at 7, 28 and 90 days. A increase in water absorption, sorptivity and chloride-ion permeability was observed in all concrete mixes containing wood ash as partial replacement of natural sand in concrete except at 5% replacement of natural sand as compared to control mix. XRD analysis at 28 and 90 days shows that wood ash is mainly a pozzollanic material, which contribute in hydration process of cement. SEM analysis shows the progressive decrease in voids in wood ash concrete mixes as the replacement of natural sand with wood ash was increased which may be due to the filler effect of micro-fines.

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CHAPTER 1
INTRODUCTION

1.1 Excessive Sand Mining and its Environmental Impacts:

Concrete, the single most widely used building material around the globe, is a heterogeneous composite that consists of combination of readily available basic building materials including cement, water, coarse aggregate, fine aggregate, and in some cases, admixtures, fibres or other additives, according to the need. When these ingredients are mixed together, they form a fluid mass that is easily moulded into any shape. Over time, when it is cured sufficiently, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material, called concrete.

The reason behind the enormous use of concrete in the construction sector lies in its versatile, reliable and sustainable nature, because of its strength, rigidity, durability, mould-ability, efficiency and economy.

Humans have been using concrete in their pioneering architectural feats for millennia. Due to the ongoing boom in the housing sector and other developmental activities in the construction field, the demand of concrete is increasing with a very rapid pace all over the world. Worldwide, some 12 billion tons of concrete is being produced each year [UNEP (2010)]. Such volumes require vast amount of natural resources for aggregate and cement production. For instance, cement consumption around the world has multiplied three-fold in last 20 years, from 1.37 billion tons of cement in 1994 to 3.7 billion tons in 2012, mainly due to the rapid economic growth in Asia. Interestingly, China consumed about 58% of the total cement production in 2012 [UNEP (2014)].

The fine aggregate and coarse aggregates generally occupy 60% to 75% of the concrete volume and therefore, strongly influence the concrete’s freshly mixed and hardened properties, mixture proportions, and economy. It is therefore, important to obtain right type and good quality aggregate at site, because the aggregate form the main matrix of concrete. Crushed stone and gravel are most commonly used as a coarse aggregate in concrete, while natural sand or river sand as a fine aggregate in concrete.

River sand is naturally occurring granular material composed of finely divided rock and mineral particles. River sand has the ability to replenish itself. The composition of sand is highly variable, depending upon the local rock sources and conditions, but the most common constituent of sand is silica (silicon dioxide), usually in the form of quartz, which because of its chemical inertness and considerable hardness, is the most common mineral resistant to weathering. Sand in the river channel and flood plains constitutes an important raw material in the construction industry and has a variety of uses in this sector.

These raw materials of concrete, i.e., river sand and gravel, are also struggling to cope with the rapidly growing demand in many areas around the globe. The sources of good quality river sand and gravel are depleting very fast. According to United Nations Environment Program (UNEP) report, “Sand-rarer than one thinks”. published in March-2014, sand and gravel has now become the most widely used natural resource on the planet after water. These are now being extracted at a rate far greater than their renewal.

Globally, between 47 to 59 billion tonnes of material mined every year, of which sand and gravel account for the largest share from 68% to 85%. The use of aggregates for concrete all over the world can be estimated at 25.9 billion to 29.6 billion tons a year for 2012 alone. Including the aggregate used in asphalt as well as concrete pavements and other industrial uses, this estimate can go up to 40 billion tons a year. This large quantity of material cannot be extracted and used without a significant impact on the environment.

Sand mining is an activity referring to the process of removal of sand from the foreshore including rivers, streams and lakes. Sand is also mined from beaches and inland dunes and dredged from large scale removal of riverbed materials and dredging below the streambed alters the channel form and shape, that, in turn, has several consequences such as erosion of the riverbed and banks, increase in channel bed slope and changes in channel morphology. Removed sand is a direct loss to the river system. It causes deepening of rivers and estuaries and it also enlarges river mouths and coastal inlets, which may also lead to the saline-water intrusion from the nearby sea. It is also a threat to bridges, river banks and other nearby structures.

In-stream sand mining activities degrade the quality of river water. The short-term turbidity is increased at the mining site due to re-suspension of sediments and organic particulate matter. Oil spills and leakages from mining machinery and vehicles further aggravate the issue. Increase in suspended particles directly affect the water users by significantly increasing the water treatment costs and undermine the aquatic ecosystems. Sand removal turns riverbeds into large and deep pits which lowers the groundwater level in the wells of nearby areas, thus adversely affecting the local groundwater availability.

The stability of sand and gravel bed depends upon a delicate balance of the stream flow, sedimentation and channel form. Native species in streams are uniquely adapted to the stable bed structure. Unstable stream channels are inhospitable to most of the aquatic species. Bed degradation and sedimentation have negative impact on aquatic life, disturbing the species attached to streambed deposits, leading to loss of biodiversity. Degraded stream habitats also result in loss of fishery productivity.

Physical disturbances due to human activities also lead to interruption in nesting/breeding activities. For example, in the National Chambal Sanctuary, mining of sand adversely affected ghariyals, who use sand banks for nesting and basking. They lay eggs under the sand beds, which were destroyed by sand mining related activities. The problem of environmental impacts associated with excessive sand mining has now become so serious that existence of river ecosystems is threatened in a number of locations, damage being more severe in small river catchment. As a result, many governments all over the world have banned sand mining from the rivers.

1.2 Alternatives for Natural Sand:

As the supplies of suitable natural sand near the point of consumption are becoming exhausted, the cost of this sand is increasing, which is ultimately increasing the cost of the construction. Now a day's sustainable infrastructural growth demands the alternative material that should satisfy technical requirements of fine aggregate as well as it should be available abundantly. A lot of research has been done in the past to find alternate source of fine aggregate.

The use of industrial waste product has become very popular in areas where natural sand is not abundantly available or where there is scarcity in the supply of natural sand. The Mumbai-Pune express highway was a project, where there is a difficulty in procurement of natural sand. This made the construction company to use the industrial waste product and crushed it into the form of sand and use that for making approximately 20 lakh cum of concrete necessary for the construction [Gambhir, (2006)]. However, such type of sands contains a large amount of micro-fines, particles finer than 75 microns and different chemical properties than concrete, which can have an adverse effect on properties of concrete. So, proportioning of different raw materials at the time of mix design is very important, when industrial waste product is used in concrete.

Now a day, with ongoing research and development in this field, fine aggregate with the desired properties are manufactured by industrial waste product. Use of industrial by-products in concrete has drawn a serious attention of researchers and investigators in recent years. There are many waste materials of some industries, which have been successfully used as a partial as well as full replacement of cement and natural fine aggregate. Several studies published in recent years show that fly ash, silica fume, ground granulated blast furnace slag, metakaolin, bagasse ash, scrap-tire rubber etc. can be used in concrete as partial replacement of ordinary portland cement. Moreover, waste foundry sand, fly ash, copper slag, iron slag etc., have also been used as a partial replacement of sand in concrete. Each waste product has its specific effect on properties of fresh and hardened concrete. Such efforts are the need of the time, because it will not only save the disposal cost of such waste products, but also help in keeping our environment green and clean. Moreover, the use of industrial by-products in concrete help us to make a concrete with similar or improved fresh, mechanical and durability properties as compared to conventional concrete & also make our concrete more economical. Wood ash is one of such by-products of natural waste wood from processing industry, which has a great potential to be used as a partial replacement of sand in concrete.

Wood ash can be defined as residue, tailing or waste material, produced from the incineration of wood and its products (chips, saw dust, bark) for power generation, furniture industry, and many other uses. The main source of energy as timber (wood) product is used in many small-scale boiler industries to draw the power for industrial processes, from there the wood ash is obtained. Wood ash can be bottom ash and can be fly ash. Bottom ash generally have coarse sized particles as compare to the fly ash particles. Wood can be environment friendly fuel is proper emission controls such as electrostatic precipitator is used at the outlet of the boilers. The combustion of wood produces less ash whereas the combustion of same amount of bark and agricultural wastes produces more ash content. Also, the main concern to use the wood ash as a partial/full replacement of cement and fine aggregate is the problem of its disposal that arises for almost all the industrial waste products. In current scenario, approx. 70% of the ash is dumped in the ground, 20% of ash in agricultural use as soil supplement to produce major crops & other remaining 10% of ash is used in metal forming industry, pollution control and concrete industry. A major problem is increased due to dumping of ash in land, the contamination of ground water resources is increasing due to heavy metals are present in ash, due to seepage of rain water into the ground water level lead to increase the problem so to overcome these issues, the uses of wood ash is increased in past few years.

1.3 Properties of Wood Ash:

Wood waste ash is different from sand in many aspects:

(i) Mineralogy – Natural sand is generally siliceous in nature, whereas the mineralogy of wood waste ash is both calcareous and siliceous depends upon the type of timber, from which it is made;

(ii) Micro-fine Content – The number of micro-fines (material passing 75-micron sieve) is much higher in wood waste ash as compared to natural sand;

(iii) Water absorption – Due to the higher amount of micro-fines, wood waste ash has higher water absorption as compared to sand;

(iv) Particle Size Distribution – Natural river sand is generally uniformly graded, while wood waste ash is normally badly graded or gap graded;

(v) Particle Shape – Natural sand particles are generally round in shape, while wood waste ash particles are angular in nature;

(vi) Surface Texture – Natural sand particles have smooth surface texture, while wood waste ash having rough surface texture.

As wood ash is obtained by the combustion of wood products, so many properties of the aggregate, i.e. chemical and mineralogical composition, petrographic classification, specific gravity, hardness, strength, physical and chemical stability, pore structure, colour etc., depend upon the properties of the parent wood or bark or tree from where it is obtained. Some properties i.e. shape and size of particles, surface texture, water absorption etc., change due to combustion of wood products at different temperature. The shape and size depends upon the nature of parent wood and bark also at the amount of combustion done, due to which the particle whose combustion is done at the larger extend will have smaller size and will be of round shape [Naik (1991)].

As plants vary significantly in their degree of sophistication, in the range and extent of plant process controls and in the degree to which raw feed is controlled to the plant [CCAA (2008)], so the physical properties i.e. gradation, shape and size, surface texture, micro-fine content, surface morphology, etc., of wood ash will be different for different boilers, even if the parent plants are same.

We determine the physical and chemical properties of wood ash are very important in determining their beneficial uses other than to be used in concrete. These properties are influenced by species of tree, tree growing regions and conditions, methods and manner of combustion including temperature, other fuel used with wood fuel, and method of wood ash collection [NCASI (1993) , Etiegni (1990)].

Typical physical properties of wood ash used by different researches are summarised in Table 1.1. It can be observed that specific gravity of wood ash varies from 2.13−2.54 and water absorption may be as high as 2.36%. Particles size varies from 30-230 µm.

TABLE 1.1 : Physical Properties of Wood Ash used in Different Researches

Properties	**Naik et. al.(2003)**	**Elinwa & Mahmood (2002)**	**Wang et. al. (2008)**	**Rajamma et. al. (2009)**	**Etiegni & Campbell (1991)**	**Udoeyo et. al. (2006)**
Particle Size (µm)	170	-	30-130	50	230	-
Specific Gravity	2.26	2.29	2.40	2.54	2.13	2.43
Bulk Density (kg/m^3)	545	830	700	640	760	412
Water Absorption (%)	1.15	0.37	1.4	-	-	2.36

Similarly, chemical composition of wood ash used by different researchers are summarised in Table 1.2.

TABLE 1.2 : Chemical Composition of Wood Ash in Different Researches

Chemical Composition (%)	**Naik et. al. (2003)**	**Rajamma et.al (2009)**	**Elinwa & Mahmood (2002)**	**Udoeyo & Dashibil (2002)**	**Etiegni & Campbell (1991)**	**Ellinw & Ejeh (2004)**
SiO_2	32.4	41	66.4	78.92	67.20	31.80
Al_2O_3	17.1	9.30	4.09	0.89	3.89	28
Fe_2O_3	9.8	2.60	2.26	0.85	2.8	2.34
CaO	3.5	11.4	9.98	0.58	8.8	10.53
MgO	0.7	2.3	5.80	0.96	5.1	9.32
SO_3	-	-	0.45	−	0.45	-
Na_2O	0.9	0.9	0.08	0.43	0.08	6.50
K_2O	1.1	3.90	-		0.43	10.38
TiO_2	-	0.4	-	0.37	1.26	0.58
P_2O_5	-	0.9	0.48	0.4	0.9	0.45
LoI	31.6	-	4.67	8.4	14.2	27

1.4 Uses of Wood Ash

- Wood ash is used as the odour & pH control for many hazardous & non- hazardous wastes. [NCASI (1993)].
- Wood ash has been found to capture several water borne contaminates [NCASI (1993)].
- In Europe, wood ash has been used as a feedstock in the manufacture of Portland cement [Etiegni (1990)].
- For agriculture applications, the wood ash is used as a soil supplements to improve the alkalinity of soil.
- Filler materials in construction of flexible pavement for roads & highways [Eteigni and Cambells (1991)].
- Wood ash can be used as an organic fertilizer used to enrich agricultural soil nutrition. In this role, wood ash serves a source of potassium and calcium carbonate, the latter acting as a liming agent to neutralize acidic soils [Lener (2008)].
- Wood ash can also be used as an amendment for organic hydroponic solutions, generally replacing inorganic compounds containing calcium, potassium, magnesium and phosphorus. [Douglas and James (1985)].
- Wood ash is commonly disposed of in landfills, but with rising disposal costs, ecologically friendly alternatives, such as serving as compost for agricultural and forestry applications, are becoming more popular [Rosenfeld and Henry (2001)].
- Wood ash has a very long history of being used in ceramic glazes, particularly in the Chinese, Japanese and Korean traditions, though now used by many craft potters. It acts as a flux, reducing the melting point of the glaze [Rogers and Phil (2003)].
- Potassium hydroxide can be made directly from wood ash and in this form, is known as caustic potash or lye. Because of this property, wood ash has also traditionally been used to make wood-ash soap.
- The ectomycorrhizal fungi Suillus granulatus and Paxillus involutus can release elements from wood ash [Gadd (2010)].

1.5 Outline of the Thesis:

This thesis report includes five chapters:

Chapter 1 "Introduction" gives some quantitative data about excessive sand mining in the world and its environmental impacts, use of industrial by-products as fine aggregate in concrete, properties of wood ash and Uses of wood ash

Chapter 2 "Literature Review" gives an overview about the previously published literature on the effect of different wood ash as a partial replacement of river sand in concrete.

Chapter 3 "Experimental Program" gives the detail of scheme of experimentation, different raw materials used and procedures adopted for testing of raw materials, mix design, casting, curing and methodology of various tests on concrete.

Chapter 4 "Results and Discussion" gives results of properties of raw materials and mix proportioning of concrete mixes. It also includes results and analysis of workability of concrete, hardened properties of concrete, i.e., density, compressive strength and splitting tensile strength, durability properties, i.e., water absorption, sorptivity and rapid chloride-ion permeability, mineralogical and microstructural characteristics & microstructural analysis, i.e., XRD and SEM analysis, of concrete mixes, incorporating wood ash as a partial replacement of natural sand and results are compared with control concrete.

Chapter 5 Gives major conclusions drawn from the study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The effects of wood ash as a replacement of cement on the different properties of concrete have been reported since 1991. The early studies have only focused on normal strength concretes as well as mortars and it has been found out that use of inclusion of wood ash as a replacement of cement does modify many concrete properties i.e. fresh properties, hardened properties as well as durability properties. Since then, several researches have reported the effects of use of wood ash as a part of cement in normal strength concrete and mortars.

The purpose of this study is to access the current state of knowledge concerning the utilization wood ash as replacement of natural or river sand in mortar and concrete. An extensive review of the recently published studies and available research papers on the use of wood ash as a partial replacement with cement is conducted in this literature review. Studies are examined in terms of measured fresh properties, hardened properties and durability properties. The key pointes arising from the literature review are discussed property-wise. Different properties studied in literature review are workability, compressive strength, splitting tensile strength, flexural strength, water absorption and chloride-ion penetration.

2.2 Workability

Udoeyo et. al. (2006) conducted an experiment in which they studied the behaviour of wood ash as an additive in concrete with 0% to 30% WA content 5% stepped increments after 28 days curing period. They concluded that the all mix of concrete with wood ash as additive gives lesser workability as compare to the mix of concrete without wood ash for the same w/c ratio. The workability of concrete decreases with an increase in the wood ash content but the additive content level beyond 20% gives the slump value zero.

Ban and Ramli (2012) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 25% WA content 5% stepped increments after 28 & 90 days curing period. They has maintain the slump at a range of 70 ± 20 mm by adding proper dosage of superplasticizer. The result indicate that as the wood ash level increases from 0% to 10% the slump value decreases with the constant dosage of superplasticizer of 1.85%. But when the wood ash % increases beyond the 10% the mortar required higher dosage of superplasticizer to attain the slump within desired range. Mortar mix with 10, 20 & 25% wood ash content gives constant slump value 50mm at a constant superplasticizer dosage of 1.98%. This is due to Portland cement has marginally lesser specific surface value than WA. So, as the replacement level increases the total surface are to be wetted by water also increases.

Elinwa and Mahmood (2002) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 30% WA content 5% stepped increments after 3, 7, 14 & 28 days curing period. The results indicated that as the WA % increases the workability decreases although after changing the w/c ratio for different mixes from 80mm slump value at 0% ash to 40mm at 30% ash content.

Abdullahi (2006) was conducted an experiment on cement replacement with wood ash concrete mix with 0% to 40% wood ash content 10% stepped increments. He concluded that to attain the similar value of slump as of control mix, the water requirement is increased by 10, 11.7, 13.3 & 15% with the replacement level of wood ash 10, 20, 30 and 40% respectively.

2.3 Compressive Strength

Udoeyo et. al. (2006) conducted an experiment in which they studied the behaviour of wood ash as an additive in concrete with 0% to 30% WA content 5% stepped increments after 28 & 90 days curing period. They concluded that as the additive % of wood ash increases in concrete the compressive strength is deceases for 28 & 90 days due to wood ash acts as a filler not as a binder in the concrete matrix, thus with increase in wood ash the surface area of the concrete filler increases thus decreases the amount of cement to be bonded with the mix. Also, the % increase in the compressive strength for 5% to 15% wood ash from 28 days to 90 days is higher than that of at 20, 25 & 30% wood ash content due to finer filler effect & weak pozzolanic activity.

Chowdhury et.al. (2015) states that at 7 & 28 days curing period as the replacement % of wood ash increases the compressive strength decreases at both 0.4 & 0.45 w/c ratio. But there is no comparable change in value at 10% for 0.4 w/c ratio & at 15% for 0.45 w/c ratio at 28 days reading. The compressive strength value decreases from 36.8 to 31.7 MPa at 0% to 20% replacement level for 0.4 w/c ratio and for 0.45 w/c replacement level the strength decreases from 33 MPa at 0% to 27.7 MPa at 20% wood ash content.

Ban & Ramli (2011) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 25% WA content 5% stepped increments. The compressive strength of mortar mix is tested on 3, 7, 28 & 90 days curing period. As the replacement % of wood ash increases the compressive strength decreases at all ages. As at 28 days the compressive strength is decreased from 44.9 MPa to 38.99 MPa. But at 90 days, when replacement level is 15% the compressive strength is increased as compared to control mix strength i.e. 48.25 MPa at 0% & 49.55 MPa at 15%.

Elinwa and Mahmood (2002) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 30% WA content 5% stepped increments. The compressive strength test is conducted on 3, 7, 14 & 28 days curing period. As the replacement % level increases the compressive strength decreases. As at 0% replacement level the compressive strength value is 16.4 MPa, 17.63 MPa, 21.74 MPa & 23.14 MPa at 3, 7, 14 & 28 days, respectively. And at 30% replacement level the compressive strength value is 4.32 MPa, 5.29 MPa, 6.54 MPa & 8.76 MPa at 3, 7, 14 & 28 days, respectively. But the relative decrement of strength value is decreases as the curing day increases.

Horsakulthai et.al. (2011) conducted the test using very finely ground ash of bagasse-rice husk-wood ash (BRWA) with 10, 20 & 40% as cement partial replacement level at both 0.45 & 0.6 w/c ratio. The results shows that concrete with 0.6 & 0.45 of w/c ratio at 7 days curing, 10% ash concrete gives slightly lower strength while the strength of 20% ash concrete have higher value as compared to control mix concrete. This is due to the filler effect of wood ash & the fast pozallanic reaction of bassage ash. At 28 days, the 10 & 20 % ash concrete gives higher strength with 103 & 108% normalized strength respectively while the 40% ash concrete gives lower strength with 85% normalized strength, as the day increases the strength also increases due to pozallanic reaction of ash. At 180 days the normalized value of 10, 20 & 40% ash are 116, 129 & 110% respectively.

Elinwa and Ejeh (2004) studied the behavior of wood ash as a partial replacement of cement between 5% & 30% at stepped increments of 5% of mortar mix paste. He observed that at all age curing age up to 60 days, the compressive strength of mortar mix with 10% wood ash content is higher than that of control mix. But at 60 days curing age, it’s value is same as that of control mix.

Naik et. al. (2003) studied the behavior of wood fly ash as a partial replacement of cement at 5, 8 & 12% level by total binder weight with curing upto 365 days. They kept the water/binder ratio constant. From the results he concluded that the strength of concrete mix without wood ash is 34 MPa & with wood ash is the range of 33 MPa to 36 MPa at 28 days for different replacement level and the strength of concrete mix without wood ash is 44 MPa & with wood ash is the range of 42 MPa to 46 MPa at 365 days for different replacement level. This shows that up to the 12% replacement level the strength is increasing. This shows the pozollanic behaviour of wood ash & cement hydration over the 28 days of curing.

Elinwa et. al. (2005) studied the behavior of wood ash as replacement with cement & an additive as metakaolin to improve the compressive strength of concrete. The replacement level is 5% stepped increments between 0% to 40%. The dosage of metakolin is 3% by total binder weight in all mix. After 28 days of curing period the concrete mix with 10% wood ash have highest compressive strength which is 37% higher than control OPC concrete. After 28 days of curing period the other mixes has including control mix reached only 20 MPa.

Rajamma et.al. (2009) studied the behaviour of wood fly ash used as a replacement of cement in mortar mix with replacement level of 10, 20, 30 & 40% of total binder weight. It was observed that the compressive strength after 28 days of curing period at 10% wood ash content gives higher value than control concrete mix while the other mix with 20 & 30% replacement level have reduced the compressive strength of cement mortar mix.

2.4 Splitting Tensile Strength

Chowdhury et.al. (2015) states that at 7 & 28 days as the replacement % of wood ash increases the splitting tensile strength decreases but the % decreases in the value is less as compared to compressive strength from 3.5 MPa at 0 to 2.53 MPa at 20% replacement.

Ban and Ramli (2011) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 25% WA content 5% stepped increments. The splitting tensile strength of mortar mix is tested on 3, 7, 28 & 90 days curing period. As the replacement % of wood ash increases the splitting tensile strength decreases for every testing day. But the % decrement at 28 days the splitting tensile strength is decreased from 4.53 MPa to 4.05 MPa. But at 90 days, when replacement level is 15% the splitting tensile strength is increased as compared to control mix strength i.e. 4.85 MPa at 0% & 5.01 MPa at 15%.

Udoeyo and Dashibil (2002) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 25% WA content 5% stepped increments. The splitting tensile strength test was conducted at 7 & 28 days of curing period. At 7 & 28 days, splitting tensile strength is decreases with an increase in the replacement level of concrete mix. The % decrement in splitting tensile strength is less than that of compressive strength. At 7 days the value of splitting tensile strength is having marginal difference for different mix as compared to control mix. But, at 28 days the replacement level up to 25% only 90% strength is decreases as compared to control mix.

Naik et. al. (2003) studied the behaviour of wood fly ash as a partial replacement of cement at 5, 8 & 12% level by total binder weight. The test is done at 7, 28, 91, 182 & 365 days curing period. At 28 & 365 days the value of splitting tensile strength of control mix is 3.8 MPa & 4.3 MPa respectively whereas at 28 days the value of splitting tensile strength of varied wood ash content mix is between 3.6 to 4.0 MPa. The value of splitting tensile strength is higher at 365 days for all varied wood ash content mix than control mix. The wood ash content 8% at an age of concrete beyond 28 days upto 365 days gives the optimal value of splitting tensile strength.

2.5 Flexural Strength

Udoeyo et. al. (2006) conducted an experiment in which they studied the behaviour of wood ash as an additive in concrete with 0% to 30% WA content 5% stepped increments after 28 & 90 days curing period. The flexural strength of concrete decrease with an increase in wood ash but the % decrease is less than the compressive strength. For concrete containing 5% WA the 28 days flexural strength is 5.20 MPa which is decrease upto 5.14 MPa for 30% WA.

Chowdhury et. al. (2015) studied that at 7 & 28 days curing period as the replacement % of wood ash increases the flexural strength decreases at both 0.4 & 0.45 w/c ratio. But there is no comparable change in value at 10% for 0.4 w/c ratio & at 15% for 0.45 w/c ratio at 28 days reading. The flexural strength value decreases from 3.65 MPa to 3.18 MPa at 0% to 20% replacement level for 0.4 w/c ratio and for 0.45 w/c replacement level the strength decreases from 3.34 MPa at 0% to 2.9 MPa at 20% wood ash content.

Ban and Ramli (2011) conducted an experiment in which they studied the behaviour of wood ash as a partial cement replacement in the production of mortar mix with 0% to 25% WA content 5% stepped increments. At 3 & 7 days for 5% replacement level the value of flexural strength is increases 6.18 MPa & 7.65 MPa respectively as compared to control mix 5.71 MPa at 3 days & 7.34 MPa at 7 days. Afterwards % decreases as the wood ash % in the concrete increases 7.34 MPa at 0% to 6.06 MPa at 25%. But the value of flexural strength at 90 days was shocking. Up to 10% replacement the value of flexural strength increases from 9.52 MPa at 0% to 9.73 MPa at 10% & afterwards up to 25% it decreases from 9.52 MPa at 0% to 7.09 MPa at 25%.

Naik et.al. (2003) studied the behaviour of wood fly ash as a partial replacement of cement at 5, 8 & 12% level by total binder weight with curing up to 365days. They kept the water/binder ratio constant. At 28 & 365 days the value of flexural strength is 4.1 & 4.4 MPa respectively for control mix concrete. As compared to control mix concrete, the concrete mix with varied WA at 7 days gives higher value of flexural strength whereas in all these flexural strength value the mix with 5% WA has higher value. The wood ash content of 8% at an age of concrete beyond 28 days & up to 365 days gives the optimal value of flexural strength among all concrete mixes.

Rajamma et.al. (2009) studied the behaviour of wood fly ash used as a replacement of cement in mortar mix with replacement level of 10, 20, 30 & 40% of total binder weight. The result shows that the flexural strength value is gradually decreases as the wood ash replacement level increases. The range of flexural strength values at 10, 20 & 30% of wood ash mortar mix is 60.6-71, 59.6-61.7 & 45-48.6% respectively. They concluded from these results that the optimal value of wood ash is 20% for sufficient strength.

2.6 Water Absorption

Udoeyo et. al. (2006) states that the specimens of concrete absorb more water with an increase in the ash content. As at 5% of wood ash, water absorption is 0.14% & at 30% wood ash, water absorption is 1.05%. So, the wood ash concrete can be used where level is high as wood ash concrete absorb less than 10% which is the optimum value.

Ban and Ramli (2011) conducted the water absorption test on mortar specimen with 0% to 25% replacement of cement with wood ash. The results are indicates that the 5, 10 & 25% wood ash, the value of water absorption is significantly increases as compare to control mix. But there is no change in the value of water absorption at 15% & 20% wood ash. So, the wood ash concrete can be used where level is high as wood ash concrete absorb less than 10% which is the optimum value.

Elinwa and Ejeh (2004) studied the effect of wood ash as a partial replacement of cement in mortar mix for water absorption test. They made 2 mortar sample with mix proportion (1:3) with 0.6 w/b ratio, first sample is having no wood ash & second sample is having 15% wood ash as cement replacement. The average value of water absorption mortar mix with 0 & 15% replacement level were 0.8 & 1.25% respectively which is far lesser than 10% which is maximum acceptable value.

2.7 Chloride-ion Permeability

Wang et. al. (2008) studied the behavior of wood fly ash and coal blended fly ash as a partial replacement of cement binder up to the level of 25% of total binder weight. In their experiment they used various types of fly ash:-wood fly ash, wood C fly ash & wood F fly ash .When 80% of class C and class F is blended with 20% of pure wood fly ash. Rapid chloride permeability test was conducted after moist cured for 56 days in accordance to ASTM C 1202-91. The results shows that at the replacement level of 25% wood ash have not result in a significant change in the permeability property of concrete. The chloride permeability of concrete is significantly lowered down when blended wood F fly ash is used in concrete. The chloride permeability of concrete is slightly increased when replacement level of 25% wood ash used as compare to control OPC mix concrete which is due to wood ash used in concrete is having coarse particle size (30-130μm).

Horsakulthai et. al. (2011) conducted the test using very finely ground ash of bagasse-rice husk-wood ash (BRWA) with 10, 20 & 40% as cement partial replacement level material on the chloride permeability test on concrete. From the test results they concluded that the use of ash in concrete increases the chloride permeability property of concrete & decreases the chloride diffusivity coefficient. The chloride diffusion coefficient is reduced by 30-40, 65-70 & 75% when the replacement level of cement with wood ash is 10, 20 & 40% respectively in comparison to control OPC binder mixes. The gradual reduction of coefficient is due to coarser particle size of wood ash.

CHAPTER 3
EXPERIMENTAL PROGRAM

3.1 General:

The chapter describes the details of experimental program and methodology for the evaluation of fresh properties (Workability), hardened properties (density, compressive strength and splitting tensile strength), durability properties (chloride-ion permeability, sorptivity and water absorption) and mineralogical & microstructural characteristics (X-Ray diffraction, i.e., XRD and Scanning Electron Microscopic, i.e. SEM) of concrete mixes made with varying percentages of wood ash as partial replacement of natural sand. In this chapter, procedures adopted for physical testing of constituent materials, i.e., cement, coarse aggregate, natural sand and wood ash, used for making concrete are described. This chapter also includes procedure adopted for mix design of concrete, details of test specimens to carry out different tests, procedure of casting as well as the test procedures adopted, age of specimen at testing, are also discussed in this chapter. Flow chart showing a general overview of the experimental program is given in Fig. 3.1.

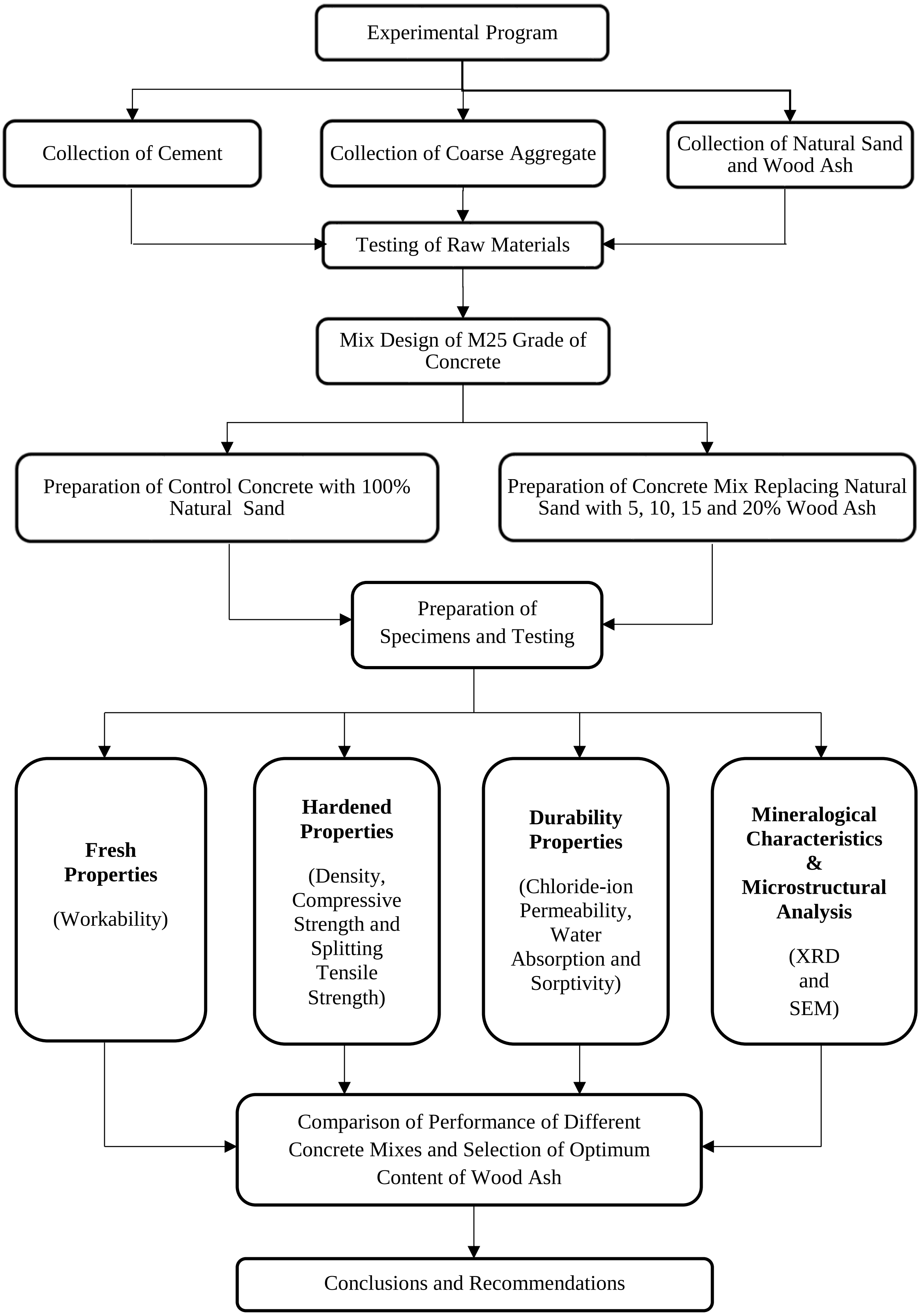


Fig. 3.1 : Flow Chart of Experimental Program

3.2 Testing of Constituent Materials:

3.2.1 Cement :

Ordinary Portland Cement of Grade 43 (OPC 43), manufactured by UltraTech Cement Limited, was used in all concrete mixes. Physical properties of cement, i.e., fineness, soundness, standard consistency, initial and final setting time, compressive strength, specific gravity, are evaluated by the procedures given in Bureau of Indian Standard specifications. Fineness of cement was tested as per procedure given in BIS 4031(Part 1):1996, by sieving through 90 micron sieve. Soundness was tested as per the procedure of BIS 4031(Part 3):1988, by Le-Chatlier apparatus. Standard consistency and initial and final setting time are tested as per BIS 4031(Part 4):1988 and BIS 4031(Part 5):1988, respectively, by Vicat apparatus. Compressive strength of cement is tested as per the procedure of BIS 4031(Part 6):1988. 1:3 cement mortar cubes were made having dimensions 70.6mm×70.6mm×70.6mm using standard sands conforming to BIS 650:1991. These cubical specimen were tested at compression testing machine (CTM) conforming to BIS 516:1959 at loading rate of 70kN/minute to evaluate compressive strength of cement-mortar cubes at age of 3, 7 and 28 days. Specific gravity of cement was tested as per the procedure of BIS 4031(Part 11):1988, using density bottle method. All the physical properties of cement must satisfy the requirements given in BIS 8112:1989.

3.2.2 Coarse Aggregate:

A combination of 20mm nominal size aggregate and 10mm nominal size aggregate is used as coarse aggregate in this experimental program. Both types of coarse aggregate were locally procured. Physical properties of both types of coarse aggregate, i.e., sieve analysis, specific gravity, water absorption and bulk density, are evaluated by the procedures given in Bureau of Indian Standard specifications. Aggregates were sieved through a set of sieves to obtain sieve analysis as per the procedure given in BIS 2386(Part 1):1988 and compared with the requirements given in BIS 383:1970. Specific gravity, water absorption and bulk density of coarse aggregate were tested as per the procedure given in BIS 2386(Part 3):1963. For calculation of specific gravity of both type of coarse aggregate, water basket method was used.

3.2.3 Natural Sand:

Locally procured natural sand was used as fine aggregate in concrete. Physical properties of natural sand, i.e., sieve analysis, specific gravity, water absorption and bulk density, are evaluated by the procedures given in Bureau of Indian Standard specifications. Natural sand was sieved through a set of sieves to obtain sieve analysis as per the procedure given in BIS 2386(Part 1):1988 and compared with the requirements given in BIS 383:1970. As per the requirements of BIS 383:1970, zone of the sand was determined and fineness modulus was calculated. Specific gravity, water absorption and bulk density of natural sand was tested as per the procedure given in BIS 2386(Part 3):1963. Specific gravity of natural sand was calculated by pycnometer method.

3.2.4 Wood Ash:

Wood Ash was collected form a boiler situated in district Meerut, U.P. Wood Ash was sieved through a set of sieves to obtain sieve analysis as per the procedure given in BIS 2386(Part 1):1963, so as to compare its particle size distribution with natural sand. The sieve analysis results of wood ash were also compared with the grading requirements for crushed sands given in BIS 383:1970. Like natural sand, zone and fineness modulus of wood ash was determined. Specific gravity, water absorption and bulk density of wood ash was tested as per the procedure given in BIS 2386(Part 3):1963. Pycnometer method was used for specific gravity test. To have an idea about different minerals present in wood ash, X-ray diffraction (XRD) technique was used. Scanning Electron Microscope (SEM) analysis was used to know about the particle shape and surface texture of the fine ash particles. Energy Dispersive Spectra (EDS) was used to know approximate chemical composition of wood ash.

3.3 Mix Proportioning of Concrete Ingredients:

All-In aggregate grading for 20mm nominal size aggregate as the requirements given in BIS 383:1970 is used to fix the proportion of aggregate in concrete. Trial and error method was used to fix the proportion of 20mm nominal size aggregate, 10mm nominal size aggregate and natural sand in concrete based on their individual gradations. Based upon this all-in aggregate grading, percentage of 20mm nominal size aggregate, 10mm nominal size aggregate and natural sand was fixed, which was to be used in the calculation of quantities of coarse aggregate and fine aggregate at the time of mix design.

Mix design of concrete was done as per BIS 10262:2009. Grade of control concrete was chosen as M25 and target slump was 100mm. Conditions for exposure were taken as moderate. As per the procedure of BIS 10262:2009, first of all, target strength was calculated assuming suitable value of standard deviation. Estimated water content was calculated for the desired workability and free w/c ratio was chosen from experience as per the target strength of concrete to be achieved. From estimated water content and free w/c ratio, cement content was calculated. Based on the volume of aggregate in concrete, quantity of coarse as well as fine aggregate was calculated as per their specific gravity and proportion fixed as per all-in aggregate grading. Coarse aggregate and fine aggregate quantities calculated were based upon the SSD (Saturated Surface Dry) condition. Thus, necessary water corrections must be applied based upon the moisture content of coarse aggregate and fine aggregate at the time of casting.

Based upon the quantities of different ingredients in control concrete, mix proportions of concrete mixes with wood ash were calculated. Concrete mixes with replacement of natural sand with 5, 10, 15 and 20 wood ash were designated as CWA5, CWA10, CWA15 and CWA20, respectively.

3.4 Mixing of Ingredients and Casting of Samples:

3.4.1 Mixing of Ingredients:

Laboratory drum mixer was used for the preparation and mixing of all concrete mixtures. A drum mixer is a mechanical device, which uses a revolving drum to combine cement, coarse aggregate, fine aggregate and water to form a homogenous mass. Both, coarse aggregate as well as fine aggregate, were in dry conditions. So, necessary water corrections were applied before the mixing operation. All the ingredients, i.e., cement, coarse aggregate, fine aggregate and water, were weighted with an accuracy of 1.0 gram. Drum mixer was started and firstly, coarse aggregate and fine aggregate were dry mixed thoroughly. After that, cement was added in the drum mixer and it was rotated till a uniform mass was obtained. In the end, water was added very carefully, so as to prevent any loss of water during the mixing operations. The drum mixer was rotated till we got a concrete mass with uniform colour and consistency. Care was taken during the whole operation so as to ensure the proper mixing of all ingredients. Workability of all concrete mixtures was checked immediately after the finishing of mixing operation.

3.4.2 Sample Preparation:

All the concrete specimens were casted in steel moulds. All the moulds were cleaned and oiled properly before the mixing of concrete ingredients. They were properly tightened to correct dimensions before casting operations. Care was taken to ensure that there must not be any gap left so as to prevent the leakage of slurry. Concrete specimens were compacted in two layers using vibrating table. After the casting operations, concrete specimens were left in the casting room for approximately 24 hours, after which they were de-moulded and placed in the curing tank. The detail of the specimens casted to perform various tests is given below:

- *Compressive Strength*: Cubical specimens of dimensions 150mm×150mm×150mm were casted for testing of compressive strength of concrete.
- *Splitting Tensile Strength*: Cylindrical specimens of diameter 150mm and height 300mm were casted for testing of splitting tensile strength of concrete.
- *Water Absorption*: Cubical specimens 70.6mm×70.6mm×70.6mm were casted for testing of water absorption of concrete.
- *Sorptivity:* Cylindrical specimens of diameter 100mm and height 50mm were casted for testing of sorptivity of concrete
- *Rapid Chloride-ion Permeability*: Cylindrical specimens of diameter 100mm and height 50mm were casted for testing of rapid chloride-ion permeability of concrete.

3.5 Test Procedures:

3.5.1 Workability:

Workability of concrete is the ease with which concrete can be properly mixed, transported, compacted and finished, with minimum loss in homogeneity. Slump test is the most extensively used test to measure workability of concrete all around the world in construction sector. Workability of the concrete was evaluated by slump test as per Indian Standard Specifications given in BIS 1199:1959. A mould in the form of frustum of a cone with bottom diameter 200mm, top diameter 100mm and height 300mm was filled with four approximately equal layers, tempering each layer with a standard tempering rod with 25 strokes. After filling and levelling the surface, mould was removed by lifting it in vertical direction, allowing concrete to subside. Results of the workability testing were reported as slump in mm, which is the difference between height of the mould and that of highest point of subsided concrete mass.

Fig. 3.2 : Slump Test of Concrete

3.5.2 Compressive Strength:

Compressive strength is regarded as the most important property of hardened concrete. Compressive strength test was done as per Indian Standard Specifications, according to the procedure given in BIS 516:1959. Compressive strength of concrete was evaluated at age of 7, 28 and 90 days using standard cube specimens of 150mm×150mm×150mm. Compression Testing Machine (CTM) of 5000 kN capacity was used for the testing of compressive strength of concrete. Concrete specimen were demoulded 24 hours after the casting and placed in the curing tank to ensure sufficient curing. At each specified age, specimen was placed centrally between the bearing plates of CTM and load was applied continuously and uniformly at specified loading rate of 140 kg/cm^2/min. the load was increased until the specimen broke and the maximum load taken by each specimen was noted down. The compressive strength was calculated according to the following formula:

$$\sigma = P/A$$

where,

σ = Compressive Strength (N/mm^2)

P = Maximum load sustained by the cube (N)

A = Area of cross section of cube (mm^2)

Results of the compressive strength testing were reported as average of compressive strength of 3 specimens at 7, 28 and 90 days for each concrete mix in N/mm^2.

Fig. 3.3 : Compressive Strength Test on Compression Testing Machine

3.5.3 Density of Concrete:

Density of concrete is an important aspect, as it plays a major role in the calculation of dead weight of a structure. At the time of demoulding of cubical specimens of 150mm×150mm×150mm used for testing of compressive strength, mass of 3 random cubes was taken using a weighing balance of 10 kg capacity with an accuracy of 1.0g and 1-day density of concrete was calculated from the following formula:

$\rho = M / V$

where,

ρ = Density of concrete in kg/m^3

M = Mass of 150mm×150mm×150mm cube in kg

V = Volume of cube in m^3

3.5.4 Splitting tensile Strength:

As concrete is strong in compression, but very weak in tension, so it is necessary to determine the tensile strength of the concrete so as to prevent cracking in tension zones. Splitting tensile strength is an indirect method to determine tensile strength of concrete. Splitting tensile strength test was done as per Indian Standard Specifications, according to the procedure given in BIS 5816:1999. Splitting tensile strength of concrete was evaluated at age of 7, 28 and 90 days using standard cylindrical specimens of 150mm diameter and 300mm height. Concrete specimen were demoulded 24 hours after the casting and placed in the curing tank to ensure sufficient curing. Compression Testing Machine (CTM) of 5000 kN capacity was used for the testing of compressive strength of concrete. For the evaluation of splitting tensile strength, each specimen was placed centrally between the bearing plates of CTM with suitable packing strips at top and bottom to ensure proper distribution of load as shown in Fig. 3.4. Load was applied continuously and uniformly at specified loading rate of 1.2 $N/mm^2/min$ to 2.4 $N/mm^2/min$. The load was increased until the specimen cracked along the vertical plane and the maximum load taken by each specimen was noted down. The splitting tensile strength was calculated according to the following formula:

$$\sigma_{st} = 2P/\pi DL$$

where,

σ_{st} = Splitting Tensile Strength (N/mm^2)

P = Maximum load sustained by the cylinder (N)

D = Diameter of cylinder (mm)

L = Length of cylinder (mm)

Fig. 3.4 : Splitting Tensile Strength Test of Concrete

Results of the splitting tensile strength testing were reported as average of splitting tensile of 3 specimens at 7, 28 and 90 days for each concrete mix in N/mm^2.

3.5.5 Water Absorption:

Pore structure of concrete plays a very important role to have an idea about the durability aspects of concrete. Water absorption of concrete is an indicator of how dense the microstructure of concrete is. Water absorption of concrete was evaluated at various specified ages as per the procedure given in ASTM C 642–13.

As per the standard procedure, there are no specifications given regarding the shape and size of the specimens for water absorption test, except that the volume of each individual specimen shall not be less than 350 cm^3, with weight of more than 800g and each portion shall be free from observable cracks, fissures and shattered edges. Water absorption test was performed at 7 and 28 days, after initial curing of 28 days on cubical specimens of 70.6mm×70.6mm×70.6mm. Oven dry mass and saturated mass of the concrete specimens were determined as per the standard procedures given in ASTM C 642 – 13. water absorption of concrete was calculated using the following formula:

$$\text{Absorption after Immersion (\%)} = [(B - A)/A] \times 100$$

where,

B = Oven Dried mass of specimen in air (g)

A = Mass of surface-dry specimen after immersion in air (g)

Results of water absorption testing were reported as average of water absorption of 3 specimens at 7 and 28 days after initial curing of 28 days for each concrete mix in %.

3.5.6 Sorptivity:

Movement of liquids through interconnecting pores plays a very important role to determine the durability of concrete. Sorptivity of concrete is rate of absorption of water by one dimensional capillary action. Sorptivity of concrete was evaluated as per the procedure given in ASTM C 1585 – 04. Rate absorption of water test was performed at 7 and 28 days, after initial curing of 28 days on standard cylindrical specimens of 100mm diameter and

50mm height. Each specimen was prepared as per the procedure give in ASTM C 1585 – 04. Sides of the specimen were sealed with epoxy coating and adhesive tape was wrapped over the outer curved surface. Mass of each specimen was taken and it was recorded as initial mass. The schematic diagram of the experimental procedure is given in Fig. 3.5. As soon as the specimen was placed in water, a stop watch had been started and mass of the specimen was taken after 5, 10, 20, 30, 60, 120, 180, 240 and 360 minutes. At each specified time slot, specimen was lifted and its surface in contact with water was surface dried with the help of a towel and its mass was recorded.

Fig. 3.5 : Sorptivity Test of Concrete Samples

For calculation of Sorptivity of concrete specimen, first of all, rate of absorption of water, I, was calculated using change in mass of the specimen divided by the product of the ross-sectional area of the test specimen and density of water. For this purpose, density of water shall be adopted as 0.001 g/mm^3 and the unit of I comes out to be mm^3/mm^2 or mm.

$$I = m_t / (a*d)$$

Where,

I = Rate of absorption (mm^3/mm^2 or mm)

M_t = the change in specimen mass at time t (g)

a = Exposed area of the specimen (mm^2)

d = Density of water (g/mm^3)

Now, rate of absorption of water, I, was plotted against square root of time in min, $t^{0.5}$ and curve was obtained. By linear regression analysis, slope of the curve was obtained. This slope of the curve is regarded as Sorptivity with units $mm^3/mm^2/min^{0.5}$ or $mm/min^{0.5}$. Results of sorptivity testing were reported as average of sorptivity of 2 specimens at 7 and 28 days after initial curing of 28 days for each concrete mix in $mm^3/mm^2/min^{0.5}$.

3.5.7 Rapid Chloride-ion Permeability Test:

Rapid chloride-ion permeability test is a very fast method to determine durability of concrete. In this test, durability of concrete specimen is determined in terms of their electrical conductance. Rapid chloride-ion permeability test was evaluated as per the procedure given in ASTM C 1202 – 10. Rapid chloride-ion permeability test was performed at 28 days on standard cylindrical specimens of 100mm diameter and 50mm height. Each specimen was prepared as per the procedure give in ASTM C 1202 – 10. Each specimen was placed in between two solutions in a standard set up, with 3% NaCl solution on one side and 0.3N NaOH solution on other side and a potential difference of 60V is applied between the two terminals. The test set up is shown in Fig. 3.6.

Fig. 3.6 : Rapid Chloride-Ion Permeability Test

Total charge passed in Coulombs was noted down after the duration of 6 hours. Results of rapid chloride-ion permeability test were reported as average charge passed for 2 specimens at 28 days in Coulombs.

TABLE 3.1 : Chloride-ion Permeability Based on Charge Passed (ASTM 1202)

Charge Passed (Coulombs)	**Chloride-ion Permeability**
> 4000	High
2000 – 4000	Moderate
1000- 2000	Low
100 – 1000	Very Low
< 100	Negligible

3.5.8 X-ray Diffraction (XRD) Analysis:

X-ray diffraction is a technique to know about the various changes in cement phases qualitatively as well as quantitatively, when any new material is introduced as replacement of cement and fine aggregate. The basic idea is to find out the effect of addition of a new material as partial replacement of cement or fine aggregate on hydration of cement. For X-ray diffraction testing, small pieces of concrete from core of cubes were collected at the time of 28 and 90 days compressive strength testing. Cement paste was separated from coarse aggregate and it was crushed to form a fine powder. The fine powder was then sieved through a sieve of 60 micron and portion of the powder passing 60 micron was used for X-ray diffraction testing. X-ray diffraction pattern was recorded with X-ray diffractometer with CuKα radiation (λ=1.54 Å) at diffraction angle 2θ ranged between 10° to 80° in steps of 2θ=0.013°. Different phase present in the cement paste at 28 and 90 days were identified analysing the peaks of X-ray diffraction patterns with the help of "X'Pert HighScore Plus" software tool.

3.5.9 Scanning Electron Microscope (SEM) Analysis:

Scanning Electron Microscope (SEM) technique was used to study various microstructural changes occurred in the concrete, using wood ash as partial replacement of concrete. For Scanning Electron Microscope (SEM) testing, small pieces of concrete from core of cubes were collected at the time of 28 days compressive strength testing. These pieces of concrete are analysed at different magnifications to study the microstructure of each concrete mix at 28 days.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 General:

In this chapter, results of the various experimental investigations are presented and discussed. In first section, results of physical testing of cement, coarse aggregate, natural sand and wood ash are given. For cement, Physical testing included determination of fineness, soundness, standard consistency, initial and final setting time, compressive strength of cement mortar cubes and specific gravity. For coarse aggregates, sieve analysis, specific gravity, water absorption and bulk density of both 20mm and 10mm nominal size of aggregate were determined. For fine aggregate, different tests conducted were, sieve analysis, specific gravity, water absorption, silt content and bulk density. For wood ash, along with other physical testing, X-ray diffraction (XRD), energy dispersive spectra (EDS) and scanning electron microscope (SEM) analysis was also done. In next section, mix design of M25 grade of concrete is given and mix proportioning of different concrete mixes is fixed. All-in aggregate grading of combined aggregate is also given. The natural sand was partially replaced at rate of 5, 10, 15 and 20% with waste wood ash and various tests conducted to evaluate the effect of replacement of sand with wood ash on workability, density, compressive strength, splitting tensile strength, water absorption and sorptivity and chloride-ion permeability of M25 grade of concrete. The comparison between these properties of different mixes are also presented and discussed. X-ray diffraction (XRD) and scanning electron microscope (SEM) analysis is also discussed to study the various mineralogical as well as microstructural changes due to the inclusion of wood ash as a partial replacement of natural sand.

4.2 Properties of Raw Materials:

4.2.1 Cement:

Ordinary Portland Cement of Grade 43 (OPC 43), manufactured by Ultra-Tech Cement Limited, was used for making all concrete mixes. The cement was uniform in colour and free from any hard lumps. Physical properties of cement are given in Table 4.1.

TABLE 4.1: Physical Properties of Ordinary Portland Cement of 43 Grade

Physical Requirement	**Test Result**	**Specification as per IS 8112:1989**
Fineness (% retained on 90 micron sieve)	1.5	10.0 Max.
Soundness (Le-Chatlier expansion in mm)	1.0	10.0 Max.
Standard Consistency (%)	27.5	–
Setting Time (minutes)		
Initial Setting Time	165	30 Min.
Final Setting Time	237	600 Max.
Compressive Strength (MPa)		
3 days ± 1 h	26.25	23 Min.
7 days ± 2 h	36.88	33 Min.
28 days ± 4 h	48.42	43 Min.
Specific Gravity	3.14	–

4.2.2 Coarse Aggregate:

A combination of 20mm nominal size aggregate and 10mm nominal size aggregate is used as coarse aggregate concrete. Both types of coarse aggregate were locally procured and conformed to Indian Standard Specifications given in BIS 383:1970. Different Physical properties of both types of coarse aggregate are given in Table 4.2

TABLE 4.2: Physical Properties of Coarse Aggregate

Physical Property	**Test Result**	
	20mm Nominal Size Coarse Aggregate	**10mm Nominal Size Coarse Aggregate**
Specific Gravity	2.66	2.64
Water Absorption (%)	0.53	0.64
Bulk Density (kg/m^3)	1640	1590
Moisture Content	Nil	Nil

Sieve analysis results of 20mm nominal size coarse aggregate and 10mm nominal size coarse aggregate are given in Table 4.3 and Table 4.4, respectively.

TABLE 4.3: Sieve Analysis of 20mm Nominal Size Coarse Aggregate

Weight of Sample Taken = 10kg

Sieve Size (mm)	Weight Retained (gm)	% Retained	Cumulative % Retained	% Passing	Limits as per BIS 383:1970
40mm	0	0	0	100	100
20mm	208	2.08	2.08	97.92	85–100
10mm	8904	89.04	91.12	8.88	0–20
4.75mm	820	8.2	99.32	0.68	0–5

TABLE 4.4 : Sieve Analysis of 10mm Nominal Size Coarse Aggregate

Weight of Sample Taken = 5kg

Sieve Size (mm)	Weight Retained (gm)	% Retained	Cumulative % Retained	% Passing	Limits as per BIS 383:1970
12.5mm	0	0	0	100	100
10mm	264	5.28	5.28	94.72	85–100
4.75mm	3893	77.86	83.14	16.86	0–20
2.36mm	657	13.14	96.28	3.72	0–5

.

4.2.3 Fine Aggregate:

The natural sand used in the experimental program was locally procured and conformed to Indian Standard Specifications given in BIS 383:1970. Wood ash was collected form a local boiler plant situated in district Meerut, Uttar Pradesh. Different physical properties of natural sand and wood ash are given in Table 4.5. Sieve analysis of natural sand and wood ash is given in Table 4.6 and Table 4.7, respectively.

TABLE 4.5 : Physical Properties of Fine Aggregate

Physical Property	Test result	
	Natural Sand	**Wood Ash**
Specific Gravity	2.57	1.54
Water Absorption (%)	1.21	11.25
Bulk Density (kg/m^3)	1430	1178
Fineness Modulus	2.78	2.23
Grading Zone	Zone II	Zone II

TABLE 4.6 : Sieve Analysis of Natural Sand

Weight of Sample Taken = 1000g

Sieve Size (mm)	Weight Retained (gm)	% Retained	Cumulative % Retained	% Passing	Limits for Zone II as per BIS 383:1970
10mm	0	0	0	100	100
4.75mm	13	1.3	1.3	98.7	90–100
2.36mm	1	0.1	1.4	98.6	75–100
1.18mm	385	38.5	39.9	60.1	55–90
600 micron	169	16.9	56.8	43.2	35–59
300 micron	267	26.7	83.5	16.5	8–30
150 micron	120	12	95.5	4.5	0–10

TABLE 4.7 : Sieve Analysis of Wood Ash

Weight of Sample Taken = 1000g

Sieve Size (mm)	Weight Retained (gm)	% Retained	Cumulative % Retained	% Passing	Limits for Zone II as per BIS 383:1970
10mm	0	0	0	100	100
4.75mm	66	5.9	5.9	94.1	90–100
2.36mm	105	10.8	16.7	83.3	75–100
1.18mm	247	16.9	27.7	72.3	55–90
600 micron	118	19.6	53.6	63.5	35–59
300 micron	226	50.6	70.2	29.8	8–30
150 micron	101	31.3	81.9	18.1	0–20

Comparing the properties of wood ash with natural sand, it can be observed that although specific gravity of wood ash is lower than that of sand, but it has much higher micro-fine content and water absorption as compared to natural sand. Both, natural sand and wood ash confirm to Zone II specifications given in Indian Standard BIS 383:1970. Comparison between the particle size distribution of natural sand and wood ash is shown in Fig. 4.1.

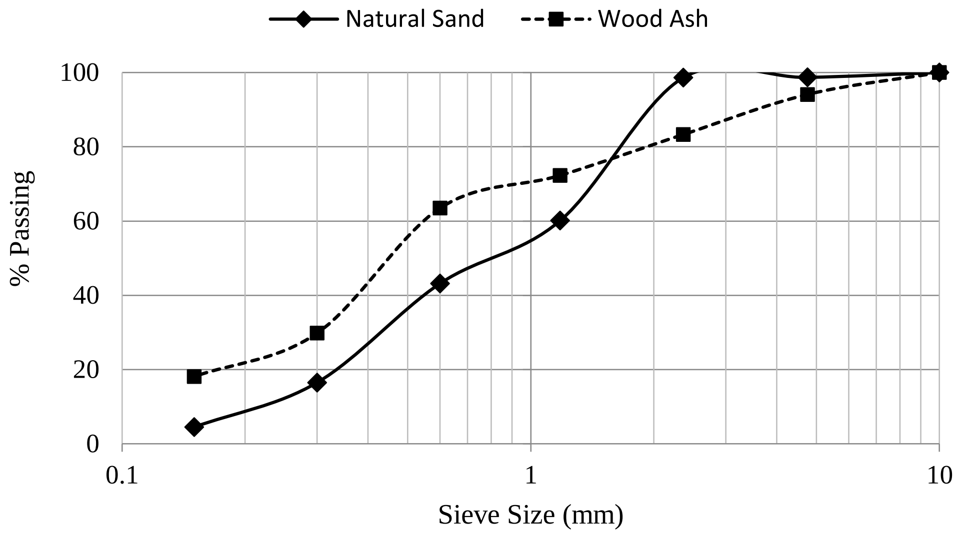


Fig. 4.1 : Comparison of Particle Size Distribution of Natural Sand and Wood Ash

X-ray diffraction (XRD) technique was used for the identification of various minerals present in wood ash. XRD pattern was recorded with X-ray diffractometer with CuKα radiation (λ=1.54 Å) at diffraction angle 2θ ranged between 10° to 80° in steps of 2θ=0.013°. X-ray diffraction pattern of wood ash is given in Fig. 4.2.

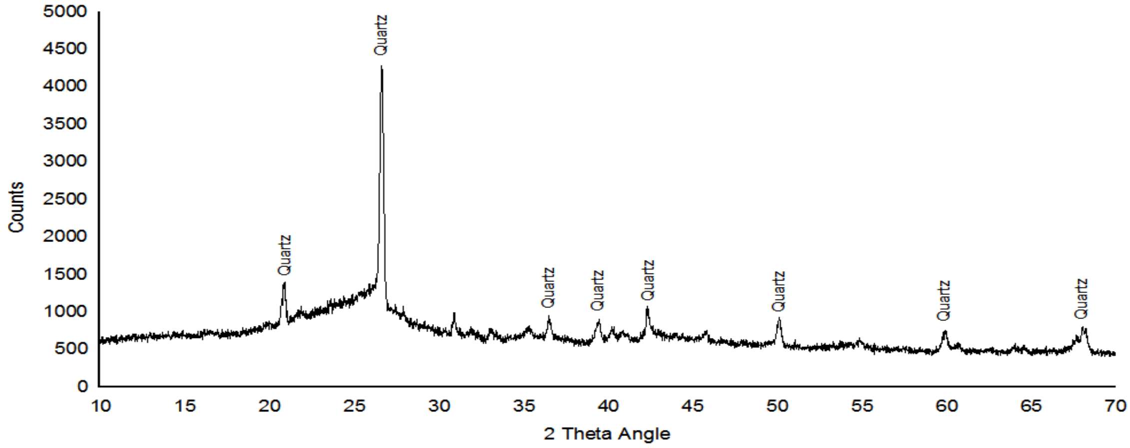


Fig. 4.2 : X-ray Diffraction Pattern of Wood Ash

Fig. 4.2 shows that wood ash mainly contains quartz. Bump around 2θ=27° indicate the presence of amorphous material. It can be concluded that as wood contains amorphous material along with crystalline materials, it is pozollanic in nature.

To know the particle shape and surface texture of wood ash particles, Scanning Electron Microscope (SEM) technique was used.

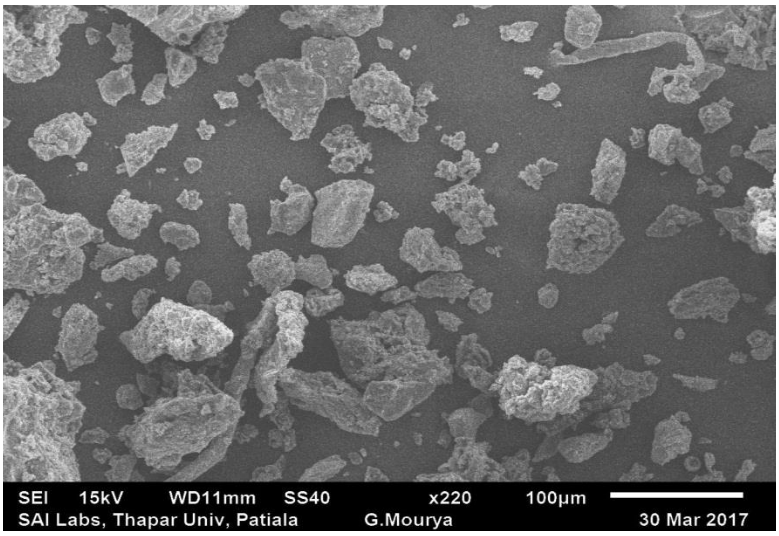


Fig. 4.3 : SEM Morphology of Wood Ash

SEM image of wood ash particles shows that wood ash particles have angular shape and rough surface texture. Table 4.8 gives the approximate chemical composition of wood ash.

TABLE 4.8 : Approximate Chemical Composition of Wood Ash

Compound	Composition (%)
SiO_2	65.00
Al_2O_3	17.68
Fe_2O_3	13.24
MgO	1.96
K_2O	2.12

4.3 Mix Proportioning of Concrete:

4.3.1 All-In Aggregate Grading:

Based on the individual sieve analysis of coarse aggregate and fine aggregate, all in aggregate grading was done as per the specifications of BIS 383:1970, so as to fix their proportions during the mix design of concrete. All-In aggregate grading, as per the proportions taken in mix design, is given in Table 4.9 and Fig. 4.4.

TABLE 4.9 : All-In Aggregate Grading

Sieve Size	Individual % Passing			Combined Aggregate % Passing			All-In Aggregate % Passing	Limits as per IS 383:1970
	20mm	10mm	Sand	20mm 39%	10mm 26%	Sand 35%		
40mm	100	100	100	39	26	35	100	100
20mm	97.92	100	100	38.19	26	35	99.19	95–100
4.75mm	0.68	16.86	98.7	0.27	4.38	34.55	39.20	30–50
600 micron	–	–	43.2	–	–	15.12	15.12	10–35
150 micron	–	–	4.5	–	–	1.58	1.58	0–6

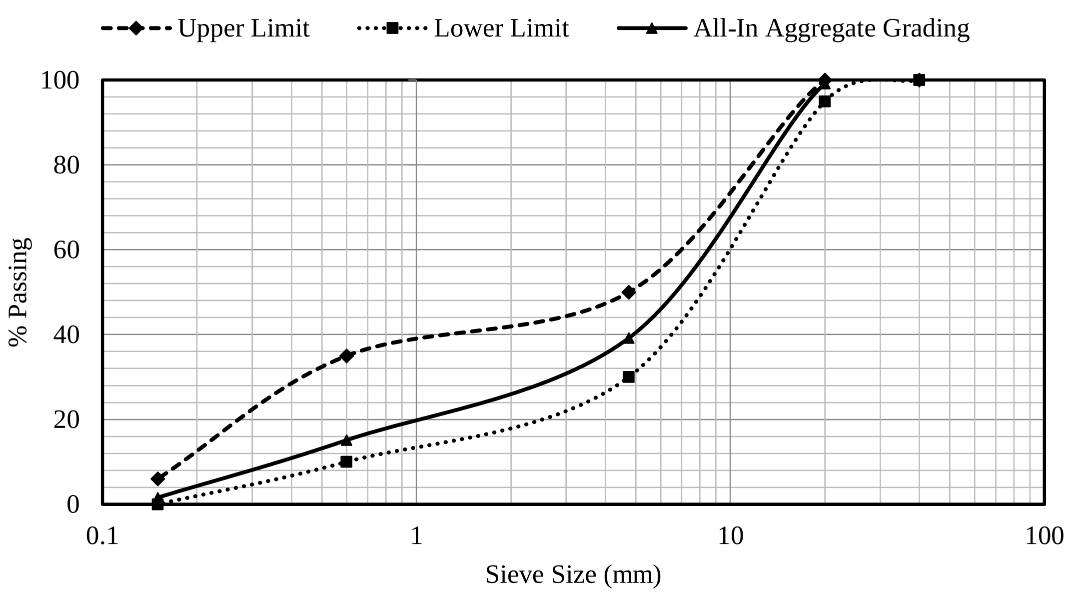


Fig. 4.4 : All-In Aggregate Grading for Concrete

Summary of the mix proportions of aggregate used in mix design of control concrete, as per the all-in aggregate grading is given in Fig. 4.5.

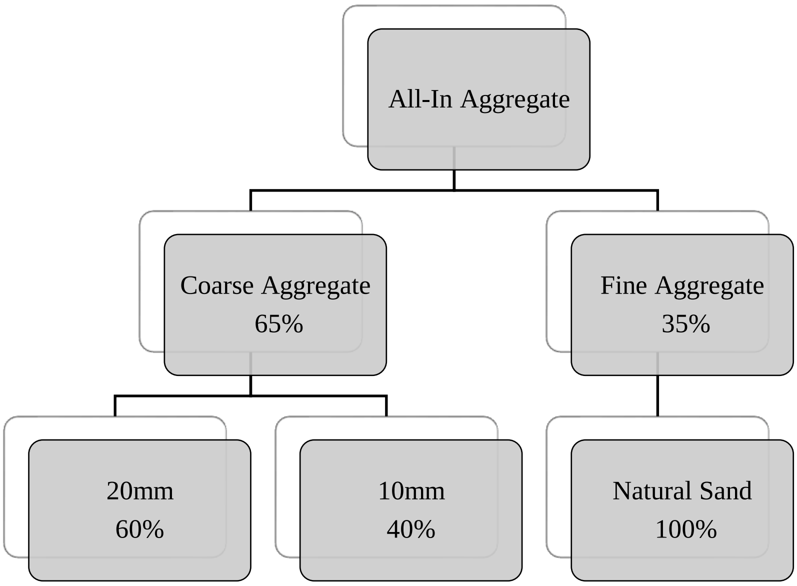


Fig. 4.5 : Mix Proportioning of Aggregate as per All-In Aggregate Grading

4.3.2 Mix Design of Concrete:

Mix design of concrete used in the experimental program was as per Indian Standard Specifications given in BIS 10262:2009. Grade of the concrete selected was M25. Exposure conditions were selected as per the specifications of BIS 456:2000.

Step-1: General stipulations for mix proportioning:

Grade of Concrete	:	M25
Type of Cement	:	OPC 43 grade conforming to IS 8112
Maximum Nominal Size of Aggregate	:	20mm
Exposure Conditions	:	Moderate (for RCC)
Target Slump	:	100mm

Step 2: Target Strength for Mix Proportioning:

Assume, Standard Deviation, s = 4 MPa

Target Average Compressive Strength at 28 days, $f_t = f_{ck} + 1.65 \times s$

$= 25 + 1.65 \times 4 = 31.6$ MPa

Step 3: Selection of water-cement ratio:

As per Table 5 of BIS 456:2000, maximum water-cement ratio for moderate exposure conditions in RCC = 0.5

For M25 grade of concrete, adopted water-cement ratio = 0.48

Step 4: Selection of Water Content:

As per Table 2 of BIS 10262:2009, maximum water content for concrete with 20mm nominal size aggregate with slump range of 25 to 50mm = 185 kg/m^3

Estimated water content for 100mm slump = 185 + (185×6)/100 = 196.1 kg.m^3

Step 5: Calculation of Cement Content:

Water-cement ratio = 0.48

Cement Content = 196.1/0.48 = 408.54 kg/m^3 ≈ 410 kg/m^3

As per Table 5 of BIS 456:2000, minimum cement content for moderate exposure conditions in RCC = 300 kg/m^3, Hence OK

Step 6: Proportions of volume of coarse aggregate and fine aggregate:

As per all-in aggregate grading:

Volume of Fine Aggregate = 35%

Volume of Coarse Aggregate = 65%

20mm : 10mm = 60 : 40

Thus, Volume of 20mm nominal size aggregate = 0.65×0.6 = 0.39

Volume of 10mm nominal size aggregate = 0.65×0.4 = 0.26

Step 7: Mix Calculations:

The mix calculations for unit volume of concrete are given below:

Volume of Cement = 410/(3.14×1000) = 0.1306 m^3

Volume of Cement = 196.1/(1×1000) = 0.1961 m^3

Volume of all-in aggregate = 1− (0.1306+0.1961) = 0.673 m^3

Mass of sand = 0.6733×0.35×2.57×1000 = 601.36 kg/m^3 ≈ 600 kg/m^3

Mass of 20mm aggregate = 0.673×0.39×2.66×1000 = 698.17 kg/m^3 ≈ 700 kg/m^3

Mass of 10mm aggregate = 0.673×0.26×2.64×1000 = 465.45 kg/m^3 ≈ 465 kg/m^3

Step 8: Mix Proportioning for Control Concrete:

Summary of mix proportioning of control concrete with all aggregate in SSD conditions is given below:

Cement = 410 kg/m^3

Water = 196.8 kg/m^3

Fine Aggregate = 600 kg/m^3

20mm nominal size Coarse Aggregate = 700 kg/m^3

10mm nominal size Coarse Aggregate = 465 kg/m^3

Water-cement ratio = 0.48

4.3.3 Mix Proportioning of Different Concrete Mixes:

Table 4.10 gives a summary of mix proportioning of different concrete mixes with all aggregate in SSD condition. Concrete mixes made with replacing natural sand with wood ash at a replacement level of 5, 10, 15 and 20% are denoted as CWA5, CWA10, CWA15 and CWA20 respectively.

TABLE 4.10 : Mix Proportioning of Concrete Mixes with Aggregate in SSD Condition

Mix Designation	Cement (kg/m^3)	w/c	Water Content (kg/m^3)	Natural Sand (kg/m^3)	Wood Ash (kg/m^3)	Coarse Aggregate (kg/m^3)	
						20mm	10mm
Control Concrete	410	0.48	196.8	600	0	700	465
CWA5	410	0.48	196.8	570	30	700	465
CWA10	410	0.48	196.8	540	60	700	465
CWA15	410	0.48	196.8	510	90	700	465
CWA20	410	0.48	196.8	480	120	700	465

4.3.4 Water Correction:

As the quantity of aggregate calculated in mix design of concrete was based upon the SSD condition of aggregate, so necessary water corrections must be applied, as all aggregate used were in dry conditions. Water corrections applied at the time of casting are given as follows:

Water correction for Sand = 600×1.21/100 = 7.26 kg/m^3

Water correction for 20mm nominal size aggregate = 700×0.53/100 = 3.71 kg/m^3

Water correction for 10mm nominal size aggregate = 465×0.64/100 = 2.97 kg/m^3

Water correction in water content = 7.26+3.71+2.97 = 13.94 kg/m^3

Summary of mix proportioning of control concrete with all aggregate in dry conditions is given below:

Water	=	196.8 + 13.94	=	210.74 kg/m^3
Fine Aggregate	=	600 − 7.26	=	592.74 kg/m^3
20mm nominal size Coarse Aggregate	=	700 − 3.71	=	696.29 kg/m^3
10mm nominal size Coarse Aggregate	=	465 − 2.97	=	462.03 kg/m^3

For concrete mixes containing wood ash, water correct for 20mm and 10mm nominal size aggregate will remain same. However, for natural sand and wood ash, it is different for different concrete mixes, according to the weight of natural sand and wood ash in that particular mix. For instance, water correction calculation for CWA10 is as follows:

Water correction for Sand = 540×1.21/100 = 6.53 kg/m^3

Water correction for 20mm nominal size aggregate = 700×0.53/100 = 3.71 kg/m^3

Water correction for 10mm nominal size aggregate = 465×0.64/100 = 2.97 kg/m^3

Water correction for wood ash= 60×11.25/100 = 6.75 kg/m^3

Water correction in water content = 6.53+3.71+2.97+6.75 = 19.96 kg/m^3

Summary of mix proportioning of CWA10 concrete mix with all aggregate in dry conditions is given below:

Water	=	196.8 + 19.96	=	216.76 kg/m^3
Fine Aggregate	=	540 − 6.53	=	533.47 kg/m^3
Wood Ash	=	60 − 6.75	=	53.25 kg/m^3
20mm nominal size Coarse Aggregate	=	700 − 3.71	=	696.29 kg/m^3
10mm nominal size Coarse Aggregate	=	465 − 2.97	=	462.03 kg/m^3

Similarly, mix proportioning of CWA5, CWA15 and CWA20 are also calculated with all aggregate in dry conditions. Table 4.11 gives a summary of mix proportioning of different concrete mixes with all aggregate in SSD condition.

TABLE 4.11 : Mix Proportioning of Concrete Mixes with Aggregate in Dry Condition

Mix Designation	Cement (kg/m^3)	w/c	Water Content (kg/m^3)	Natural Sand (kg/m^3)	Wood Ash (kg/m^3)	Coarse Aggregate (kg/m^3)	
						20mm	10mm
Control Concrete	410	0.48	210.74	592.74	0	696.29	462.03
CWA5	410	0.48	213.76	563.10	26.63	696.29	462.03
CWA10	410	0.48	216.77	533.47	53.25	696.29	462.03
CWA15	410	0.48	219.78	503.83	79.88	696.29	462.03
CWA20	410	0.48	222.79	474.19	106.50	696.29	462.03

4.4 Fresh Properties of Concrete:

4.4.1 Workability:

Workability of all concrete mixes was evaluated as slump in mm, to study the effect of replacement of natural sand with wood ash on workability of concrete and the observations are given in Table 4.12.

TABLE 4.12 : Slump Test Results of Fresh Concrete Mixes

Mix Designation	Slump (mm)
Control Concrete	90
CWA5	30
CWA10	15
CWA15	2
CWA20	0

Observations of workability of all concrete mixtures as slump in mm, are graphically represented in Fig. 4.6.

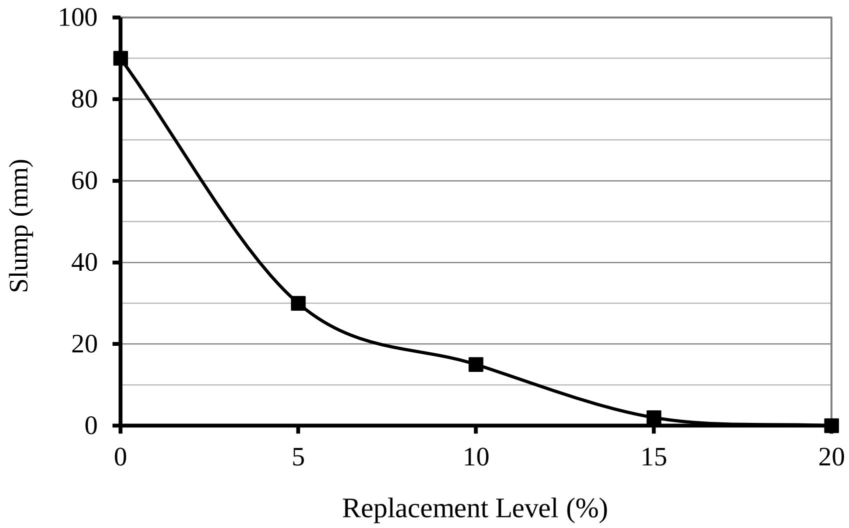


Fig. 4.6 : Effect of Replacement of Natural Sand with Wood Ash on Workability of Concrete

It can be observed that workability of all concrete mixes with wood ash was lower than that of control concrete. With the inclusion of wood ash as a replacement of natural sand, workability of concrete goes on decreasing and the decrease in workability is more profound at higher replacement levels of 15 and 20%. The slump of control mix was 90mm, whereas for concrete mix with 20% wood ash, slump dropped to 0 mm. Similar kind of decreasing trend of workability due to inclusion of wood ash as partial replacement of natural sand is also reported in previous researches by Rajamma et.al. (2009), Ramos et. al. (2013), Udoeyo et. al.(2006) , Udoeyo and Dashibil (2002).

The decrease in workability due to the inclusion of wood ash as partial replacement of sand can be attributed to the difference in shape and particle size distribution of natural sand and wood ash particles. Fig. 4.1 gives the difference between particle size distribution of natural sand and wood ash. Moreover, SEM images show that wood ash particle has angular shape with rough surface texture, whereas natural sand generally has round particles with smooth surface texture. Thus, when the natural sand was replaced with equal weight of wood ash, specific surface area was increased due to the presence of excessive micro-fines in wood ash as compared to natural sand. The angular shape of wood ash particles further increased the water demand of concrete, which leads to decrease in workability. Moreover, wood ash particles have rough surface texture, which tend to increase the friction between paste and coarse aggregate and may also be reason of decrease of workability of concrete.

Also, the wood ash has high percentage of loss of ignition (LOI) which may implicate the presence of high organic content which implies the high water absorption.

It can be concluded that inclusion of wood ash as a partial replacement of sand leads to increase in water demand of concrete, i.e., higher water content will be needed to produce concrete with same workability as that of control concrete. As increase in water content will have negative impact on compressive strength, so use of super-plasticizers may be one of the options, which can be used to counteract the negative influence of wood ash inclusion on workability of concrete.

4.5 Hardened Properties of Concrete:

4.5.1 Density of Concrete:

Density of concrete, based upon the 1-day weight of the cubes of 150mm×150mm×150mm at the time of de-moulding after 24 hours of casting, was calculated and observations of density of concrete with increase in replacement of natural sand with wood ash are given in Table 4.13.

TABLE 4.13 : 1-day Density of Concrete Mixes

Mix Designation	Cube Weight (gm)	Density (kg/m^3)	Average Density (kg/m^3)
Control Concrete	8241	2441.8	2435.06
	8196	2428.4	
	8218	2435	
CWA5	8221	2435.9	2433.5
	8193	2427.6	
	8225	2437.0	
CWA10	8194	2427.9	2421.8
	8173	2421.6	
	8154	2416.0	
CWA15	8132	2409.5	2410.7
	8113	2403.9	
	8163	2418.7	
CWA20	8105	2401.5	2402.9
	8137	2411.0	
	8087	2396.1	

Graphical representation of average 1-day density of different concrete mixes at various sand replacement levels is given in Fig. 4.7

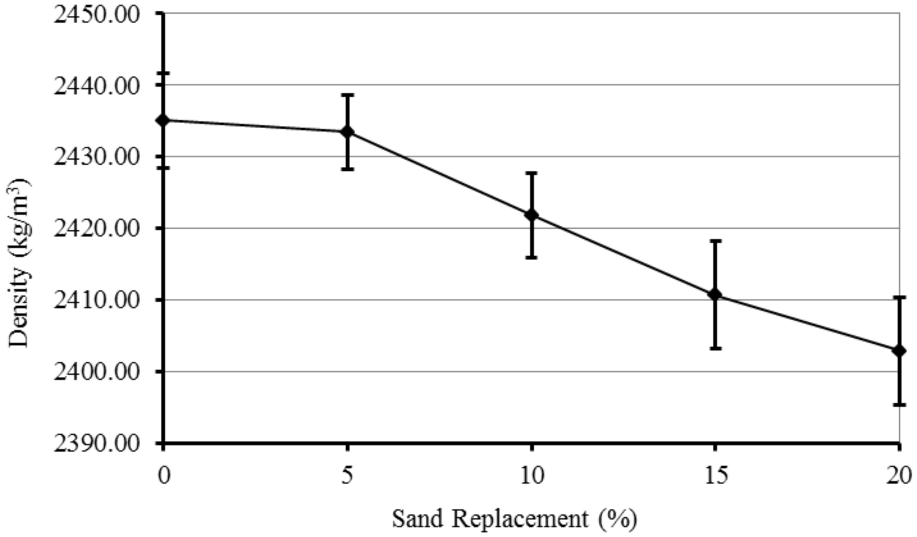


Fig. 4.7 : Effect of Replacement of Sand with Wood Ash on 1-day Density of Concrete

It can be observed that with the inclusion of waste wood ash as a replacement of natural sand, density of the concrete is decreasing. Control concrete mix has maximum density among all concrete mixes. Control concrete has a density of 2435.06 kg/m^3, whereas for concrete mix with 15% sand replacement, it has been decrease to 2410.7 kg/m^3, which is a decreased of only 1% ,whereas for concrete mix with 20% sand replacement, it has been decreased to 2402.9 kg/m^3, which is a decrease of 1.3%. Interestingly, density of concrete with 5% and 10% sand replacement shows a slight decrease in density, as compared to that of concrete with 0% sand replacement level with decrease of only 0.06% and 0.5% respectively.

The slight decrease in density of concrete with 5% replacement of natural sand with wood ash is mainly attributed to the filling effect of micro-fines present in the wood ash, which tend to fill up the voids present in concrete and makes the microstructure of concrete more dense. However, as specific gravity of wood ash is lesser than that of natural sand, so at higher wood ash content of 10% and above, we are replacing natural sand with comparatively lighter particles, which may be the reason behind the decrease in density of concrete.

4.5.2 Compressive Strength:

Compressive strength of different concrete mixes was evaluated at age of 7, 28 and 90 days to study the effect of replacement of natural sand with wood ash and observations are given in Table 4.14.

TABLE 4.14 : Compressive Strength Test Results of Concrete Mixes

Mix Designation	Compressive Strength (MPa)					
	7 days		28 days		90 days	
	Individual	**Average**	**Individual**	**Average**	**Individual**	**Average**
Control Concrete	25.09	26.29	30.89	32.13	34.08	34.89
	28.49		33.28		34.67	
	25.29		32.23		35.92	
CWA5	28.35	27.66	32.79	34.17	36.72	37.78
	26.69		35.13		39.08	
	27.93		34.60		37.55	
CWA10	24.46	23.81	28.61	29.86	33.36	34.14
	22.48		30.78		33.80	
	24.49		30.20		35.25	
CWA15	19.28	20.54	25.44	25.83	29.59	30.77
	21.73		26.98		30.81	
	20.60		25.06		31.91	
CWA20	18.76	17.72	22.81	23.21	27.96	28.48
	17.65		24.17		27.85	
	16.75		22.66		29.64	

It can be observed that inclusion of wood ash as replacement of natural sand leads to slight increase in compressive strength of concrete as compared to control mix at 5% sand replacement. At 7 days, compressive strength of control mix was 26.29 MPa, whereas compressive strength of CWA5, CWA10, CWA15 and CWA20 concrete mixes was 27.66, 23.81, 20.54 and 17.72 MPa, respectively. Similarly, at 28 days, compressive strength of control mix was 32.13 MPa, whereas compressive strength of CWA5, CWA10, CWA15 and CWA20 concrete mixes was 34.17, 29.86, 25.83 and 23.21 MPa, respectively. At 90 days, compressive strength of control mix was 34.89 MPa, whereas compressive strength CWA5, CWA10, CWA15 and CWA20 concrete mixes was 37.78, 34.14, 30.77 and 28.48 MPa, respectively. It means that compressive strength of concrete goes on increasing with increase in sand replacement level first and attains a maximum value at sand replacement level of 5% and then starts decreasing gradually. Concrete mixes show similar trend at all ages of testing. Similar trend in compressive strength was also observed in previous researches by Udoeyo et. al. (2006)

Graphical representation of compressive strength results of all concrete mixes at different ages is given in Fig. 4.8.

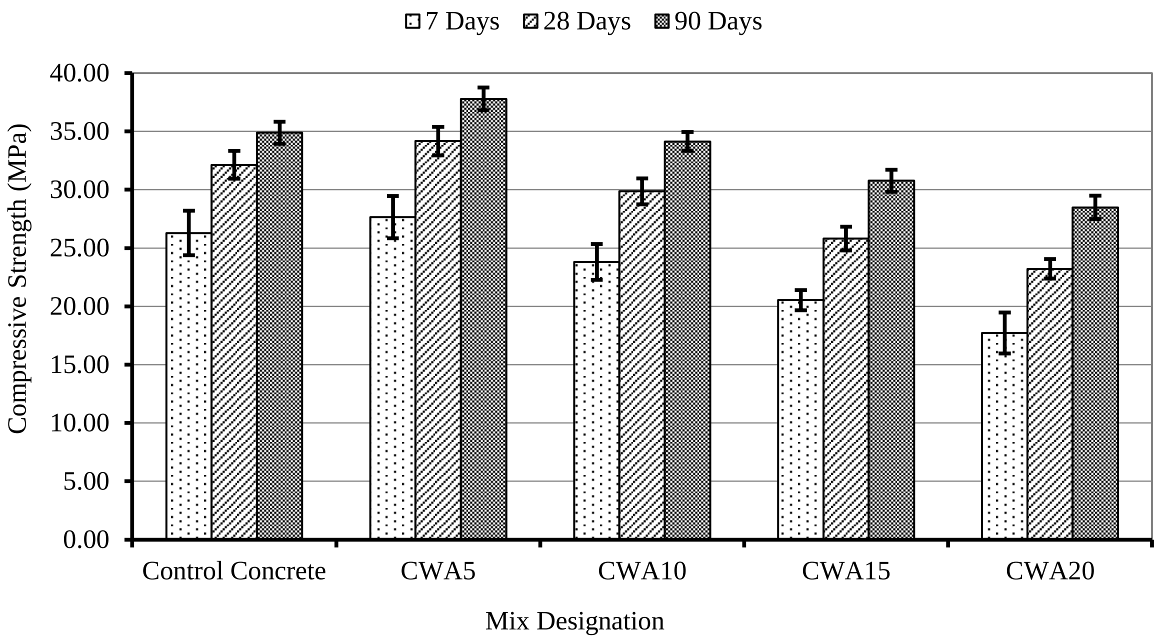


Fig. 4.8 : Effect of replacement of natural sand with wood ash on Compressive Strength of concrete

Graphical representation of change in compressive strength results as compared to control mix at different ages is given in Fig. 4.9.

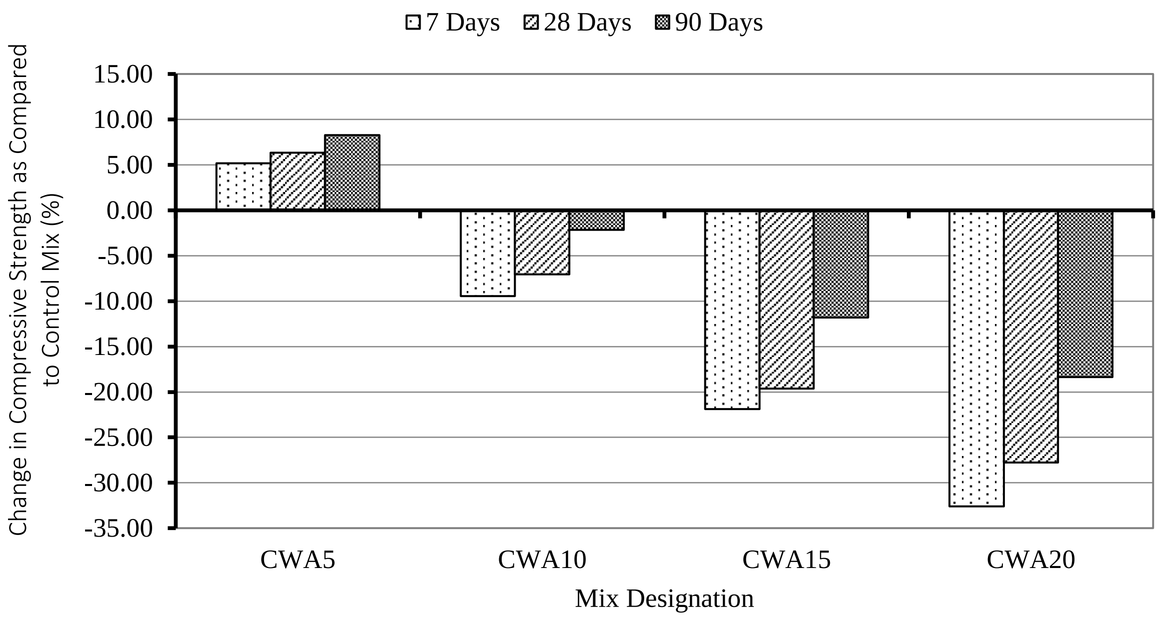


Fig. 4.9 : Effect of Change in Compressive Strength of Concrete at Different Replacement Level w.r.t. Control Mix

At age of 28 days, change in compressive strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 6.35%, -7.06%, -19.63% and -27.76%, respectively. However, at age of 7 days, change in compressive strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 5.2%, -9.43%, -21.88% and -32.6%, respectively. At age of 90 days, change in compressive strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 8.29%, -2.16%, -11.8% and -18.37% respectively.

One of the important observations from Table 4.14 and Fig. 4.9 was that compressive strength of concrete is maximum for concrete with 5% sand replacement level and for further replacement of sand by 10%, the compressive strength starts decreasing. This decrease can be explained on the basis of two facts. First, wood ash has much lower specific gravity as compared to natural sand. Thus, when we are replacing sand with equal weight of wood ash, we are actually replacing a strong material with weaker one, as intrinsic strength of wood ash particle will be much lower as compared to natural sand. Thus, inclusion of wood ash as partial replacement of natural sand causes decrease in compressive strength. The increase in compressive strength of CWA5 mix may be due to the filling effect of wood ash micro-fines, which tend to decrease the voids present in concrete. Observations of density also show that density of CWA5 mix is almost equal to control mix. Secondly, the workability of the concrete goes on decreasing with increase in sand replacement level and for concrete mix with 10% sand replacement, slump is low, i.e., 15mm, as compared to other mixes. This decrease in workability may have a negative influence on compressive strength of concrete leading to improper compaction [Chowduary et. al. (2015)].

It has also been observed that rate of increase in compressive strength as compared to control mix is more at 28 days and 90 days, as compared to that of at 7 days. For instance, in WA5 concrete mix, rate of increase in compressive strength as compared to control mix at 28 days and 90 days was 6.35% and 8.29%, respectively. However, rate of increase in compressive strength for the same concrete mix at 7 days was 5.20%. Such trend is more profound in concrete mixes with higher replacement levels of 10, 15 and 20%. Higher rate of increase in compressive strength at 90 days may be due to pozollanic activity of wood ash.

Development of compressive strength at different ages in various concrete mixtures is given in Fig. 4.10.

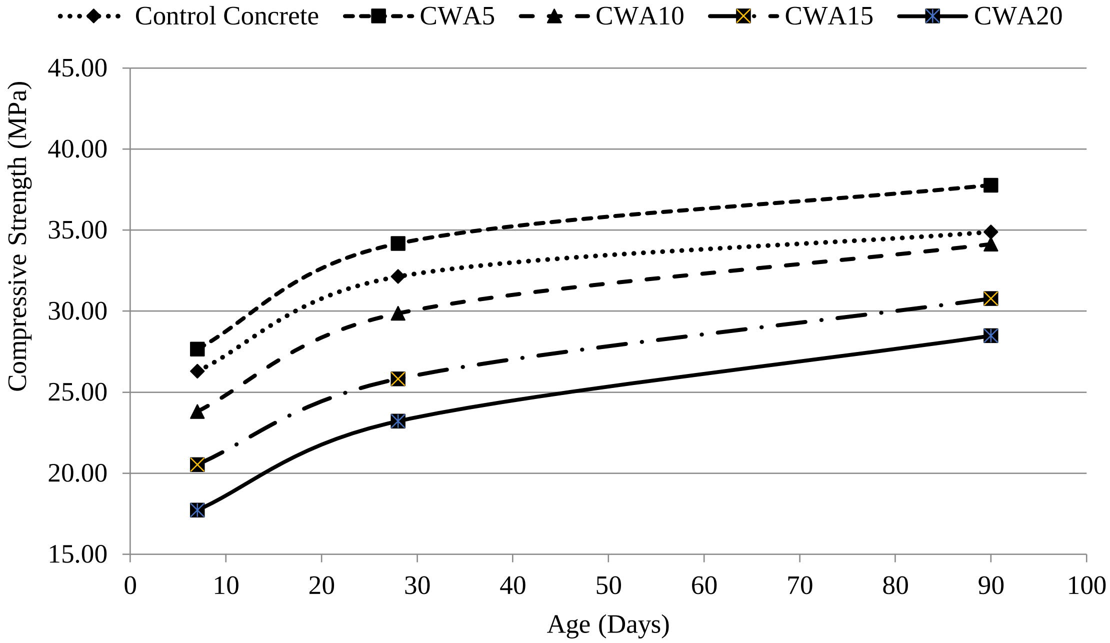


Fig. 4.10 : Development of Compressive Strength in Various Concrete Mixes

It can be concluded that concrete mix with 5% sand replacement has maximum compressive strength at all ages. So mix of 5% wood ash and 95% natural sand can be regarded as optimum combination to achieve maximum compressive strength.

4.5.3 Splitting Tensile Strength:

Splitting tensile strength of different concrete mixes was evaluated at age of 7, 28 and 90 days to study the effect of replacement of natural sand with wood ash and observations are given in Table 4.15.

It can be observed that inclusion of wood ash as replacement of natural sand leads to significant increase in splitting tensile strength of concrete as compared to control mix for only 5% replacement level, however at higher replacement level the splitting tensile strength decreases as compared to control mix at all curing ages. At 7 days, splitting tensile strength of control mix was 2.10 MPa, whereas splitting tensile strength of CWA5, CWA10, CWA15 and CWA20 concrete mixes was 2.16, 1.89, 1.66 and 1.42 MPa, respectively. Similarly, at 28 days, splitting tensile of control mix was 2.46 MPa, whereas splitting tensile strength of CWA5, CWA10, CWA15 and CWA20 concrete mixes was 2.57, 2.33, 2.02 and 1.79 MPa, respectively. At 90 days, splitting tensile strength of control mix was 2.68 MPa, whereas splitting tensile strength of CWA5, CWA10, CWA15 and CWA20 concrete mixes was 2.88, 2.65, 2.41 and 2.17 MPa, respectively. It means that splitting tensile strength of concrete goes on increasing with increase in sand replacement level and attains a maximum value at sand replacement level of 5% and then starts decreasing with increase in sand replacement level. Concrete mixes show similar trend at all ages of testing. Similar trend in splitting tensile strength was also observed by Elinwa et. al. (2005) and Rajamma et. al. (2009) 10% replacement level.

TABLE 4.15 : Splitting Tensile Strength Test Results of Concrete Mixtures

Mix Designation	Splitting Tensile Strength (MPa)					
	7 days		28 days		90 days	
	Individual	Average	Individual	Average	Individual	Average
Control Concrete	2.12	2.10	2.31	2.46	2.65	2.68
	1.98		2.51		2.59	
	2.20		2.55		2.81	
CWA5	2.31	2.16	2.67	2.57	3.02	2.88
	2.00		2.58		2.83	
	2.16		2.47		2.78	
CWA10	1.84	1.89	2.41	2.33	2.70	2.65
	2.02		2.22		2.69	
	1.82		2.37		2.55	
CWA15	1.65	1.66	1.94	2.02	2.34	2.41
	1.72		2.09		2.53	
	1.62		2.02		2.37	
CWA20	1.36	1.42	1.93	1.79	2.23	2.17
	1.39		1.69		2.11	
	1.52		1.76		2.17	

At age of 28 days, change in splitting tensile strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 4.72, -5.14, -18.03 and -27%, respectively. However, at age of 7 days, change in splitting tensile strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 2.78, -9.96, -20.83 and -32.23%, respectively. At age of 90 days, change in splitting tensile strength of concrete for CWA5, CWA10, CWA15 and CWA20 concrete mixes as compared to control concrete was 7.27, -1.37, -10.08 and 19.13%, respectively.

Graphical representation of splitting tensile strength results of all concrete mixes at different ages is given in Fig. 4.11.

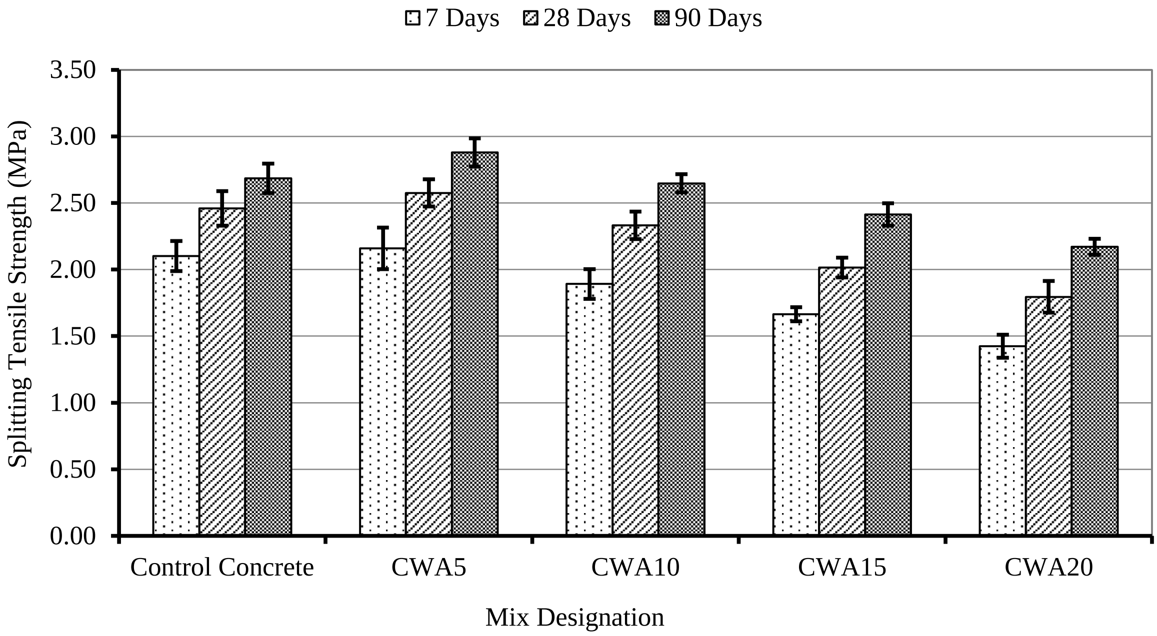


Fig. 4.11 : Effect of Replacement of Natural Sand with Wood Ash on Splitting Tensile Strength of Concrete

One of the important observations from Table 4.15 and Fig. 4.11 was that splitting tensile strength of concrete is maximum for concrete with 5% sand replacement level and for further replacement of sand by 10%, the splitting tensile strength starts decreasing, at all ages of testing. This variation is same as that was in case of compressive strength. Similar arguments can be made to explain this behaviour as in case of compressive strength.

It has also been observed that rate of increase in splitting tensile strength as compared to control mix is more at 28 days and 90 days, as compared to that of at 7 days. For instance, in WA5 concrete mix, rate of increase in splitting tensile strength as compared to control mix at 28 days and 90 days was 4.72 and 7.27%, respectively. However, rate of increase in splitting tensile strength for the same concrete mix at 7 days was 2.78%. Such trend is more profound in concrete mixes with higher replacement levels of 10, 15 and 20%. This trend is same as observed in the case of compressive strength of concrete mixes. Similar arguments can be made in this case also, as that of in compressive strength.

Graphical representation of change in compressive strength results as compared to control mix at different ages is given in Fig. 4.12.

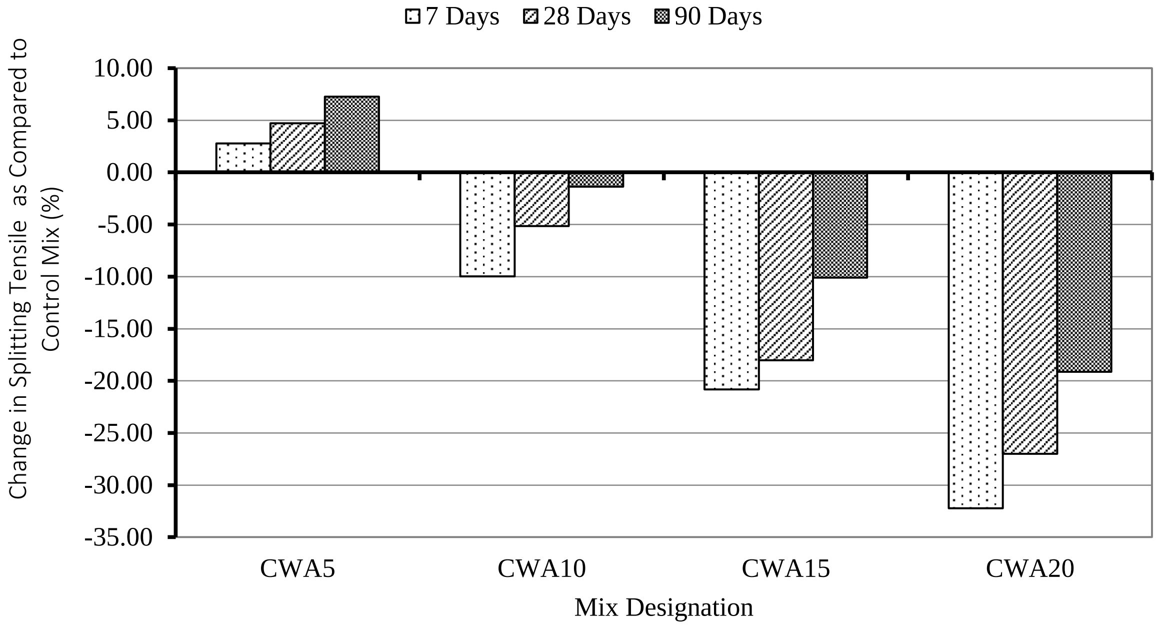


Fig. 4.12 : Effect of Change in Splitting Tensile Strength of Concrete at Different Replacement Level w.r.t. Control Mix

It should also be noted that % increase in splitting tensile strength of concrete is much higher as compared to % increase in compressive strength for only at CWA10, CWA15 and CWA20 whereas for WA5 the % increase in splitting tensile strength of concrete is much lesser as compared to % increase in compressive strength. For optimum sand replacement of 5%, increase in compressive strength at 7, 28 and 90 days was 5.2, 6.38 and 8.29%, respectively, whereas increase in splitting tensile strength at 7, 28 and 90 days was 2.78, 4.72 and 7.27%, respectively, whereas for sand replacement of 20%, increase in compressive strength at 7, 28 and 90 days was -32.60, -27.76 and -18.37%, respectively, whereas increase in splitting tensile strength at 7, 28 and 90 days was -32.23, -27 and -19.13%, respectively Thus effect of replacement of natural sand by wood ash is more significant for splitting tensile strength as the splitting tensile strength is increasing for CWA5.

It can be concluded that concrete mix with 5% sand replacement has maximum splitting tensile strength at all ages. So mix of 5% wood ash and 95% natural sand can be regarded as optimum combination to achieve maximum splitting tensile strength.

Development of compressive strength at different ages in various concrete mixtures is given in Fig. 4.13.

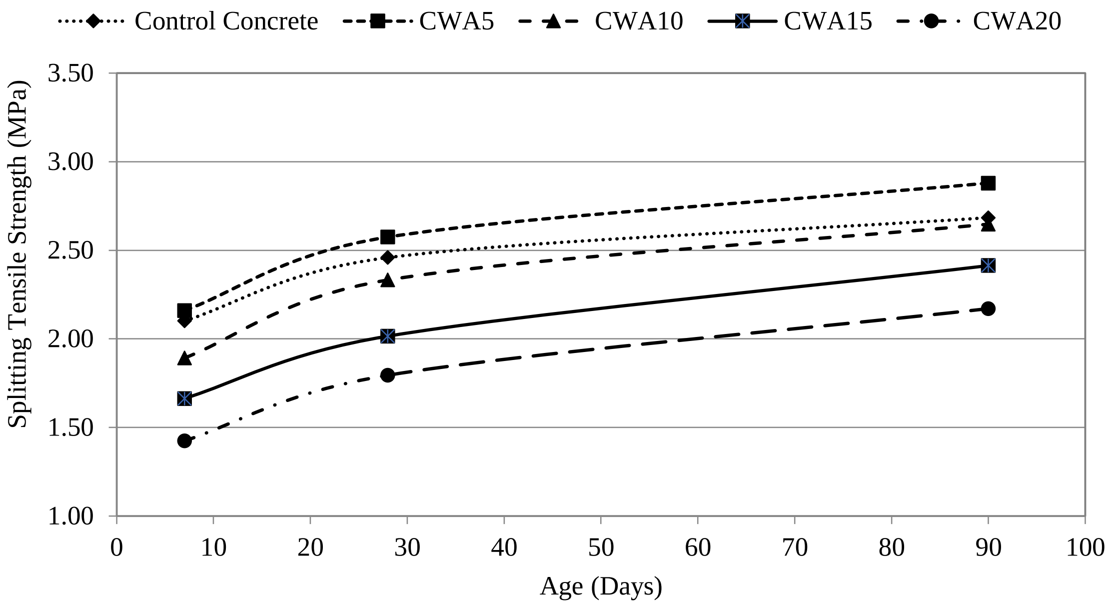


Fig. 4.13 : Development of Splitting Tensile Strength in Various Concrete Mixes

4.5.4 Relationship between Compressive Strength and Splitting Tensile Strength:

Ratios of splitting tensile strength to compressive strength of concrete as % are given in Table 4.16.

TABLE 4.16 : Splitting Tensile Strength and Compressive Strength Ratios at Different Ages

Mix Designation	Splitting Tensile Strength and Compressive Strength Ratio (%)		
	7 Days	**28 Days**	**90 Days**
Control Concrete	7.98	7.66	7.68
CWA5	7.81	7.52	7.62
CWA10	7.94	7.80	7.76
CWA15	8.08	7.82	7.83
CWA20	8.01	7.71	7.62

Careful observation of Table 4.16 shows that there is no definite relationship between the strength ratios and sand replacement level. Average ratio of splitting tensile strength and compressive strength of concrete comes out to be 7.97, 7.70 and 7.70 at 7, 28 and 90 days, respectively. Thus, with age, ratio between splitting tensile strength and compressive strength is decreasing. However, it is same for 28 and 90 days.

4.6 Durability Properties of Concrete:

4.6.1 Water Absorption:

Water absorption of different concrete mixes was evaluated at age of 35 and 56 days, i.e., 7 days and 28 days after initial curing of 28 days, to study the effect of replacement of natural sand with wood ash and observations are given in Table 4.17.

TABLE 4.17 : Water Absorption of Concrete Mixes at Different Ages

Mix Designation	Water Absorption (%)			
	35 Days		56 Days	
	Individual	Average	Individual	Average
Control Concrete	3.01	3.01	2.54	2.64
	2.93		2.72	
	3.10		2.66	
CWA5	2.68	2.78	2.24	2.33
	2.78		2.45	
	2.89		2.31	
CWA10	3.10	3.18	2.88	2.76
	3.08		2.80	
	3.37		2.60	
CWA15	3.76	3.68	3.25	3.22
	3.77		3.04	
	3.52		3.35	
CWA20	4.25	4.28	3.64	3.75
	4.39		3.82	
	4.21		3.80	

It can be observed that at 35 days, water absorption of control concrete was 3.01%, whereas water absorption of concrete mixes with 5, 10, 15 and 20% sand replacement was 2.78, 3.18, 3.68 and 4.28%, respectively. Whereas at 56 days, water absorption of control concrete was 2.64%, whereas water absorption of concrete mixes with 5, 10, 15 and 20% sand replacement was 2.33, 2.76, 3.22 and 3.75%, respectively. It can be observed that replacement of natural sand with wood ash has very significant effect on water absorption of concrete at all ages. Water absorption of all concrete mixtures at 56 days is less than the respective water absorption of concrete mixtures at 35 days. Moreover, water absorption of concrete mixtures at 5% replacement level is less than as compare with control concrete mix, but after that as the sand replacement level increase the water absorption also increase as compare with the water absorption at control mix concrete. So, it can be concluded that concrete absorb more water when the replacement level is goes beyond 5% as compare with control mix. Ban and Ramli (2011) and Udoeyo et. al. (2006) also reported increase in water absorption of concrete with increase in sand replacement with wood ash.

From the above results it can also be concluded that, the wood ash concrete can be used where ground water level is high as the wood ash concrete absorb less water the optimum value which is 10% for the all construction materials. [Ban and Ramli (2011), Elinwa and Ejeh (2004) and Udoeyo et. al. (2006)].

The decrease in water absorption of concrete with age can be explained on the fact that hydration of cement and formation of hydration products continues with age as long as sufficient curing is done. Thus, compressive strength of concrete goes on increasing with age and hence, water absorption of concrete goes on decreasing with age. At lower replacement level of 5%, wood ash act as a filler and it reduces the voids present in concrete, as discussed earlier. Thus, for CWA5 concrete mix, there is a decrease in water absorption as compared to control mix. However, at sand replacement level of 10% and above, wood ash content is comparatively high. As wood ash has much higher water absorption as compared to natural sand, thus it tends to absorb more water, causing an increase in water abortion. That's why, water absorption of concrete mixes above 5% sand replacement level goes on increasing with increase in wood ash content.

Graphical representation of the water absorption results of concrete mixtures at different ages if given in Fig. 4.14

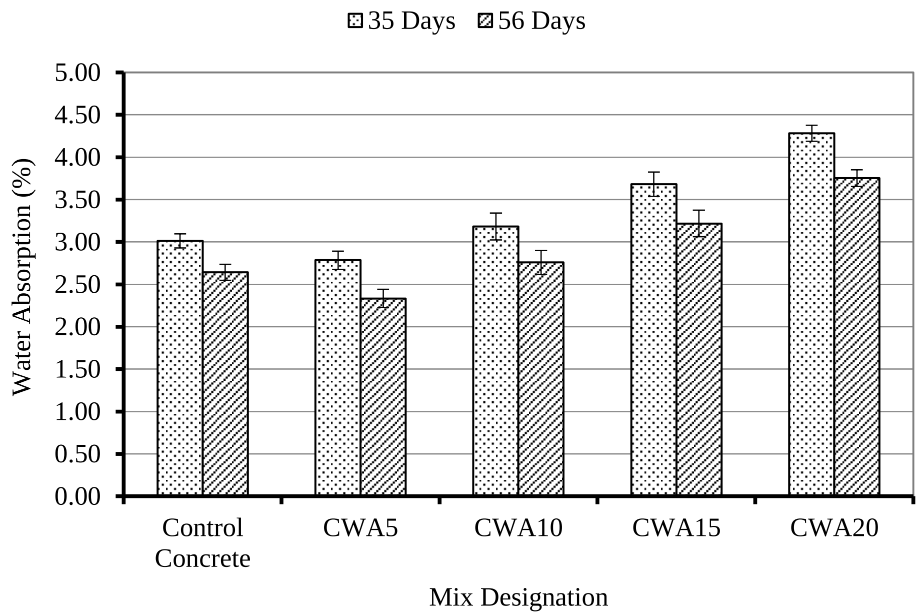


Fig. 4.14 : Effect of Replacement of Natural Sand with Wood Ash on Water Absorption of Concrete

4.6.2 Sorptivity:

Sorptivity of different concrete mixes was evaluated at age of 35 and 56 days, i.e., 7 days and 28 days, after initial curing of 28 days, to study the effect of replacement of natural sand with wood ash and observations are given in Table 4.18.

TABLE 4.18 : Sorptivity of Concrete Mixes at Different Ages

Mix Designation	Sorptivity ($mm^3/mm^2/min^{0.5}$)			
	35 Days		56 Days	
	Individual	Average	Individual	Average
Control Concrete	0.1775	0.1767	0.1644	0.1657
	0.1759		0.1669	
CWA5	0.1606	0.1613	0.1510	0.1517
	0.1620		0.1524	
CWA10	0.1878	0.1886	0.1703	0.1698
	0.1894		0.1692	
CWA15	0.2120	0.2110	0.1978	0.1975
	0.2099		0.1971	
CWA20	0.2506	0.2516	0.2324	0.2349
	0.2525		0.2374	

From Table 4.18, it can be observed that at 35 days, sorptivity of control concrete (in $mm^3/mm^2/min^{0.5}$) was 0.1767, whereas sorptivity of concrete mixes (in $mm^3/mm^2/min^{0.5}$) with 5, 10, 15 and 20% sand replacement was 0.1613, 0.1886, 0.2110 and 0.2516, respectively. whereas at, 56 days, sorptivity of control concrete (in $mm^3/mm^2/min^{0.5}$) was 0.1657, whereas sorptivity of concrete mixes (in $mm^3/mm^2/min^{0.5}$) with 5, 10, 15 and 20% sand replacement was 0.1517, 0.1698, 0.1975 and 0.2349, respectively. It can be observed that replacement of natural sand with wood ash has very significant effect on sorptivity of concrete at all ages. Sorptivity of all concrete mixtures at 56 is less than the respective sorptivity of concrete mixtures at 35 days. Moreover, at 5% replacement level of sand with wood ash sorptivity of CWA5 concrete mixtures is less than the sorptivity at control concrete mix, But after the 5% replacement level sorptivity of concrete mixtures goes on increasing with increase in sand replacement level. This observation is exactly same as that of in case of water absorption.

Graphical representation of the sorptivity results of concrete mixtures at different ages is given in Fig. 4.15.

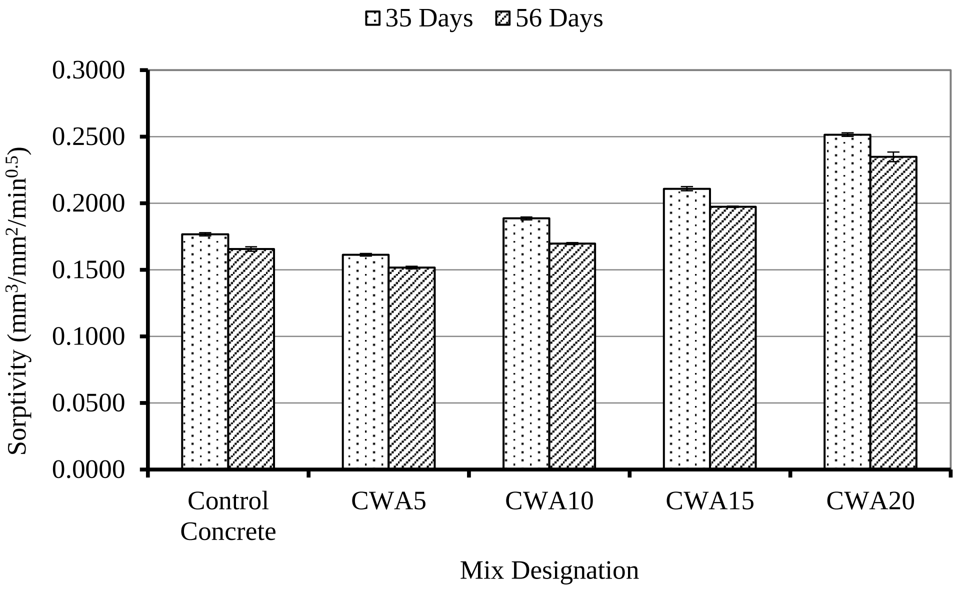


Fig. 4.15 : Effect of Replacement of Natural Sand with Wood Ash on Sorptivity of Concrete

The decrease in sorptivity of concrete with ages can be explained on the fact that hydration of cement and formation of hydration products continues with age as long as sufficient curing is done. Thus, compressive strength of concrete goes on increasing with age and hence, sorptivity of concrete goes on decreasing with age. At lower replacement level of 5%, wood ash act as a filler and it reduces the voids present in concrete, as discussed earlier, blocking interconnected capillary pores. Thus, for CWA5 concrete mix, there is a decrease in sorptivity as compared to control mix. However, at sand replacement level of 10% and above, wood ash content is comparatively high. As wood ash has much higher water absorption as compared to natural sand, thus it tends to absorb more water, causing an increase in sorptivity. That's why, sorptivity of concrete mixes above 5% sand replacement level goes on increasing with increase in wood ash content.

4.6.3 Rapid Chloride-ion Permeability:

Rapid chloride-ion permeability test was conducted and charge passed in coulombs was recorded for different concrete mixes at age of 28 days to study the effect of replacement of natural sand with wood ash and observations are given in Table 4.19.

TABLE 4.19 : Rapid Chloride-Ion Permeability Test Results

Mix Designation	Total Charge Passed at 28 days (Coulombs)	Average Charge Passed (Coulombs)	Chloride-Ion Permeability as per ASTM C-1202
Control Concrete	2052	2153	Moderate
	2254		
CWA5	1710	1807	Low
	1904		
CWA10	2167	2315	Moderate
	2463		
CWA15	2514	2646	Moderate
	2779		
CWA20	2843	3014	Moderate
	3186		

Graphical representation of rapid chloride-ion permeability test results for different concrete mixtures is given in Fig. 4.16.

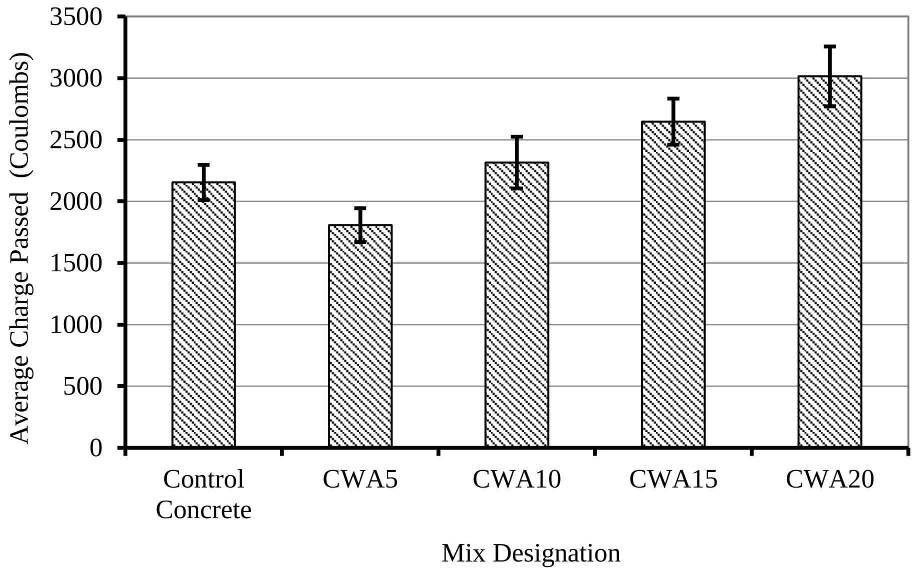


Fig. 4.16 : Rapid Chloride-ion Permeability Test Results for Different Concrete Mixtures at 28 Days

From Fig. 4.16, it can be observed that with increase in sand replacement level upto replacement level 5% after that it starts decreasing; there is a very significant influence in chloride-ion permeability of concrete mixes. For control concrete, average charge passed after 6 hours was 2153 coulombs, which is moderate as per ASTM C-1202. For concrete mixtures with sand replacement level of 5, 10, 15 and 20%, average charge passed was recorded as 1807, 2315, 2646 and 3014 coulombs, respectively, i.e., the mix of 5% replacement level of natural sand with wood ash have chloride-ion permeability in low range as per ASTM C-1202. So, up to 5% sand replacement level, total charge passed is decreasing with increase in sand replacement level, i.e, chloride-ion permeability is decreasing with increase in replacement of sand replacement with wood ash. However, there is a sudden increase in total charge passed at sand replacement level of 10, 15 and 20%, thus, concrete mix with 5% sand replacement level has maximum resistance to chloride-ion penetration.

At lower replacement level of 5%, wood ash act as filler and it reduces the voids present in concrete, as discussed earlier, causing an increase in compressive strength. Thus, there is a decrease in total charge passed in CWA5 mix as compared to control concrete. However, at sand replacement level of 10% and above, the addition of wood ash as partial replacement of natural sand starts causing decrease in compressive strength of concrete, as discussed earlier. Thus, the chloride-ion penetration resistance starts decreasing, which goes on decreasing with increase in sand replacement with wood ash.

4.7 Mineralogical Characteristics and Microstructural Analysis:

4.7.1 X-ray diffraction analysis

X-ray diffraction analysis was done to identify various cement phases in concrete and also to identify any qualitative changes occurred in cement phases due to the partial replacement of natural sand with wood ash so as to find out the influence of addition of wood ash as a partial replacement of natural sand on hydration process of cement. X-ray diffraction analysis was performed on all concrete mixes at age of 28 and 90 days. X-ray diffraction pattern was recorded with X-ray diffractometer with CuKα radiation (λ=1.54 Å) at diffraction angle 2θ ranged between 10° to 80° in steps of 2θ=0.013°. X-ray diffractogram of control mix at 28 days is given in Fig. 4.17, at diffraction angle 2θ ranged between 10° to 70°.

From Fig. 4.17, it can be observed that at age of 28 days, various phases present in control concrete are quartz, portlandite, calcium silicate hydrate, calcium silicate, calcium aluminium silicate hydrate and calcite.

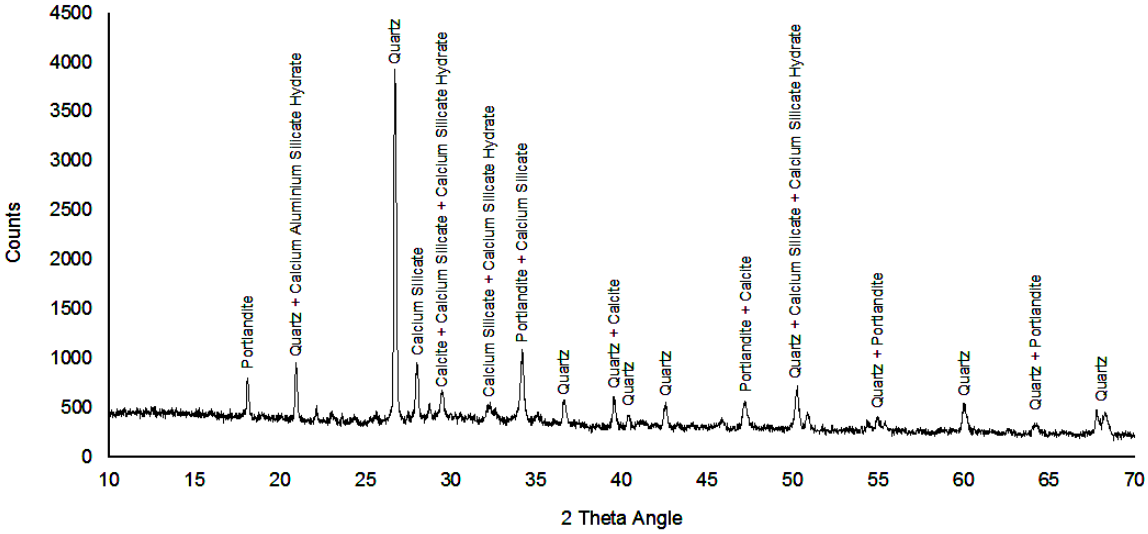


Fig. 4.17 : X-ray Diffractogram of Control Concrete at 28 Days

X-ray diffractograms of concrete mixes with 5, 10, 15 and 20% wood ash are given in Fig. 4.18, 4.19, 4.20 and 4.21, respectively, at diffraction angle 2θ ranged between 10° to 70°.

From Fig. 4.18, it can be observed that at age of 28 days, various phases present in concrete mixes containing 5% wood ash as the replacement of natural sand are Margarite, Calcium Magnisium Aluminium Oxide Silicate, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

From Fig. 4.19, it can be observed that at age of 28 days, various phases present in concrete mixes containing 10% wood ash as the replacement of natural sand are Margarite, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

From Fig. 4.20, it can be observed that at age of 28 days, various phases present in concrete mixes containing 15% wood ash as the replacement of natural sand are Tobermorite, Margarite, Calcium Magnisium Aluminium Oxide Silicate, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

From Fig. 4.21, it can be observed that at age of 28 days, various phases present in concrete mixes containing 20% wood ash as the replacement of natural sand are Margarite, Calcium Magnisium Aluminium Oxide Silicate, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

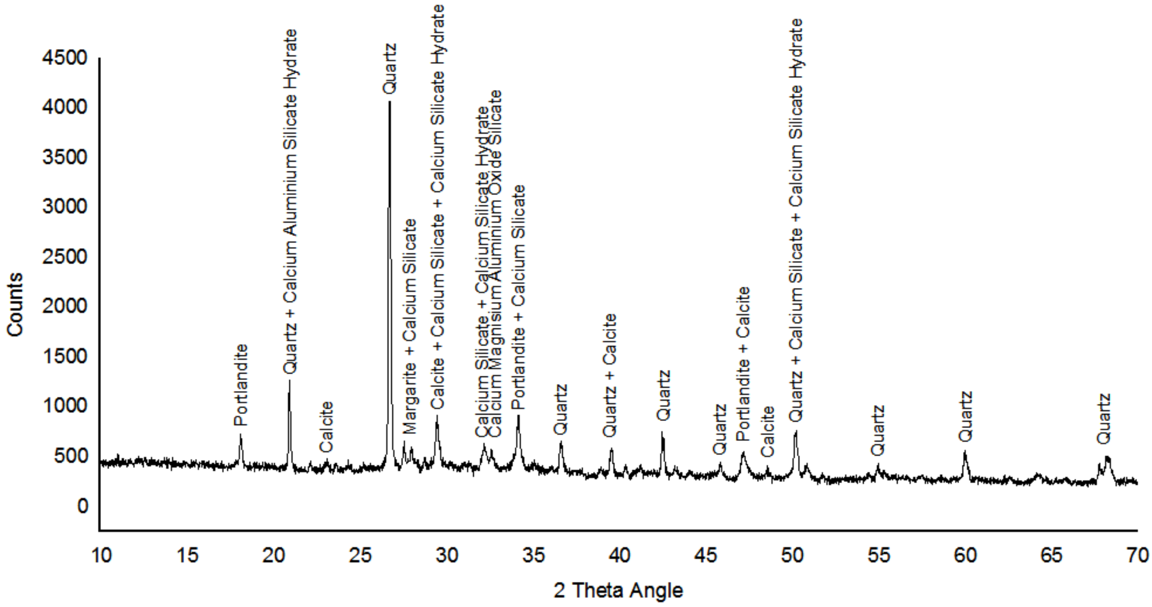


Fig. 4.18 : X-ray Diffractogram of Concrete Mix Containing 5% Wood Ash at 28 Days

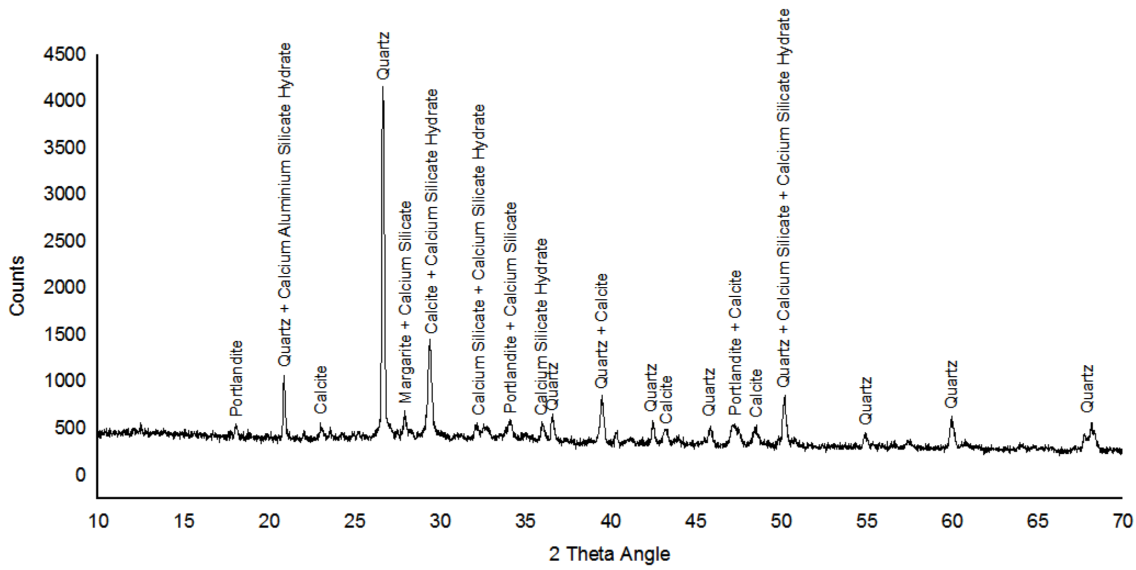


Fig. 4.19 : X-ray Diffractogram of Concrete Mix Containing 10% Wood Ash at 28 Days

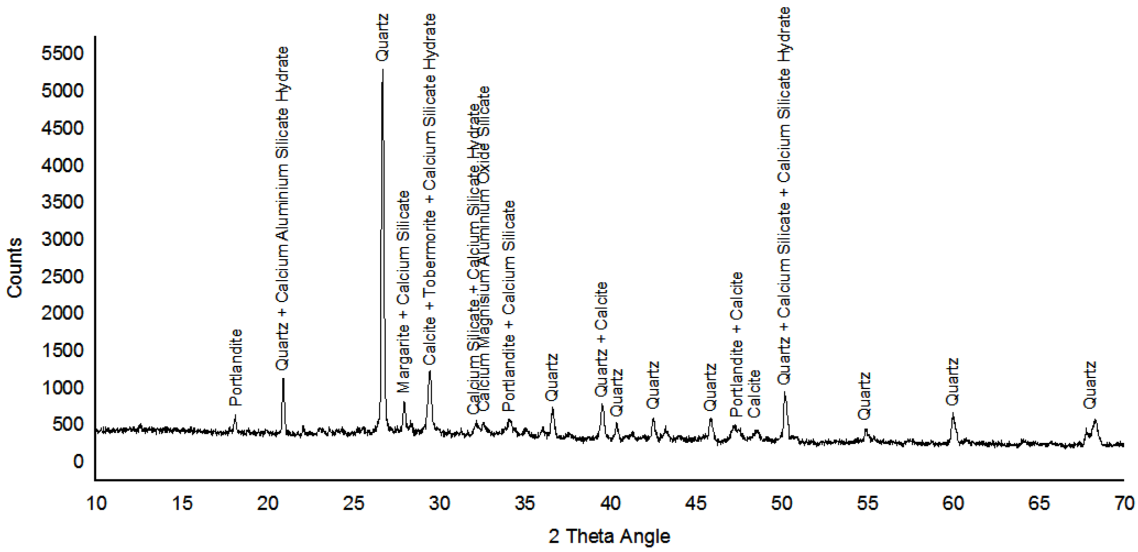


Fig. 4.20 : X-ray Diffractogram of Concrete Mix Containing 15% Wood Ash at 28 Days

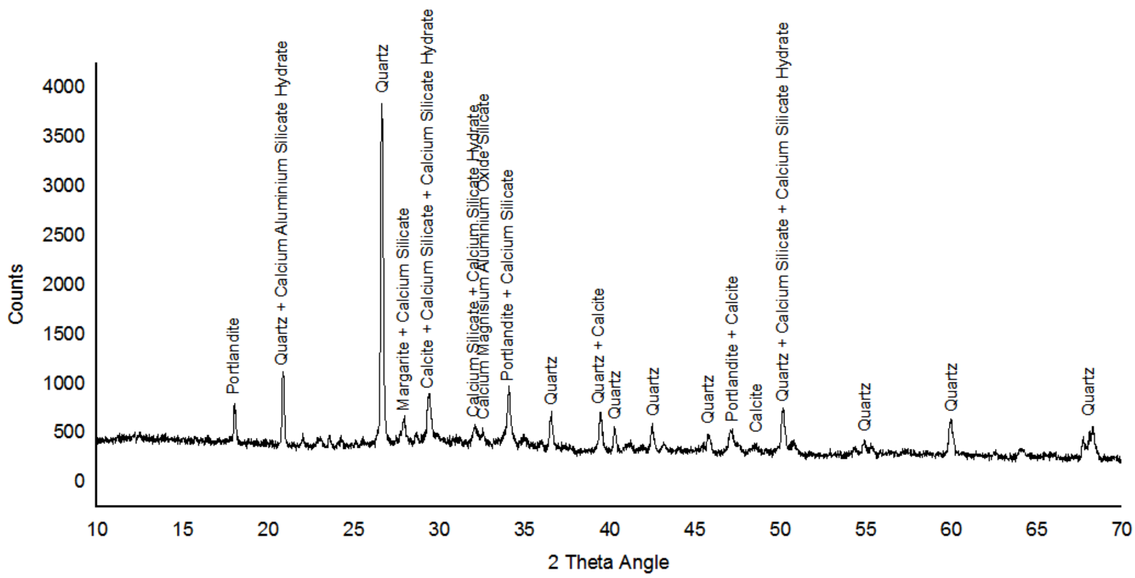


Fig. 4.21 : X-ray Diffractogram of Concrete Mix Containing 20% Wood Ash at 28 Days

To see the changes in cement phases at later ages, X-ray diffraction was also performed at 90 days. Fig. 4.22 shows X-ray diffractogram of control mix at 90 days at diffraction angle 2θ ranged between 10° to 70°.

From Fig. 4.22, it can be observed that at age of 90 days, various phases present in control concrete are quartz, portlandite, calcium silicate hydrate, calcium silicate, calcium aluminium silicate hydrate and calcite.

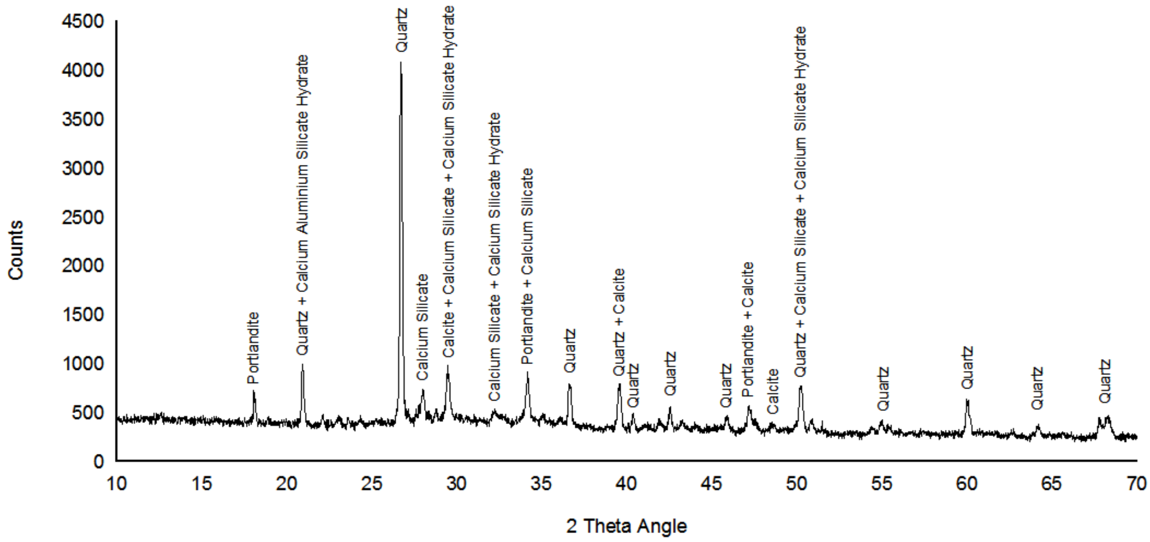


Fig. 4.22 : X-ray Diffractogram of Control Concrete at 90 Days

Similarly, X-ray diffractograms of concrete mixes with 5, 10, 15 and 20% wood ash at age of 90 days are given in Fig. 4.23, 4.24, 4.25 and 4.26, respectively, at diffraction angle 2θ ranged between 10° to 70°.

From Fig. 4.23, it can be observed that at age of 90 days, various phases present in concrete mixes containing 5% wood ash as the replacement of natural sand are Margarite, Tobermorite, Plorgeyite, Calcium Magnesium Aluminium Oxide Silicate, Calcium Iron Oxide, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

Whereas from Fig. 4.24, it can be observed that at age of 90 days, various phases present in concrete mixes containing 10% wood ash as the replacement of natural sand are Misenite, Sodium Aluminium Silicate Hydrate, Margarite, Plorgeyite, Calcium Magnesium Aluminium Oxide Silicate, Calcium Iron Oxide, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

Whereas from Fig. 4.25 it can be observed that at age of 90 days, various phases present in concrete mixes containing 15% wood ash as the replacement of natural sand are Sodium Aluminium Silicate Hydrate, Margarite, Tobermorite, Plorgeyite, Calcium Magnesium Aluminium Oxide Silicate, Calcium Iron Oxide, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

Whereas from Fig. 4.26 it can be observed that at age of 90 days, various phases present in concrete mixes containing 20% wood ash as the replacement of natural sand are Boggsite, Lazurite, Sodium Aluminium Silicate Hydrate, Margarite, Plorgeyite, Calcium

Magnesium Aluminium Oxide Silicate, Calcium Iron Oxide, Quartz, Portlandite, Calcium Silicate Hydrate, Calcium Silicate, Calcium Aluminium Silicate Hydrate and Calcite.

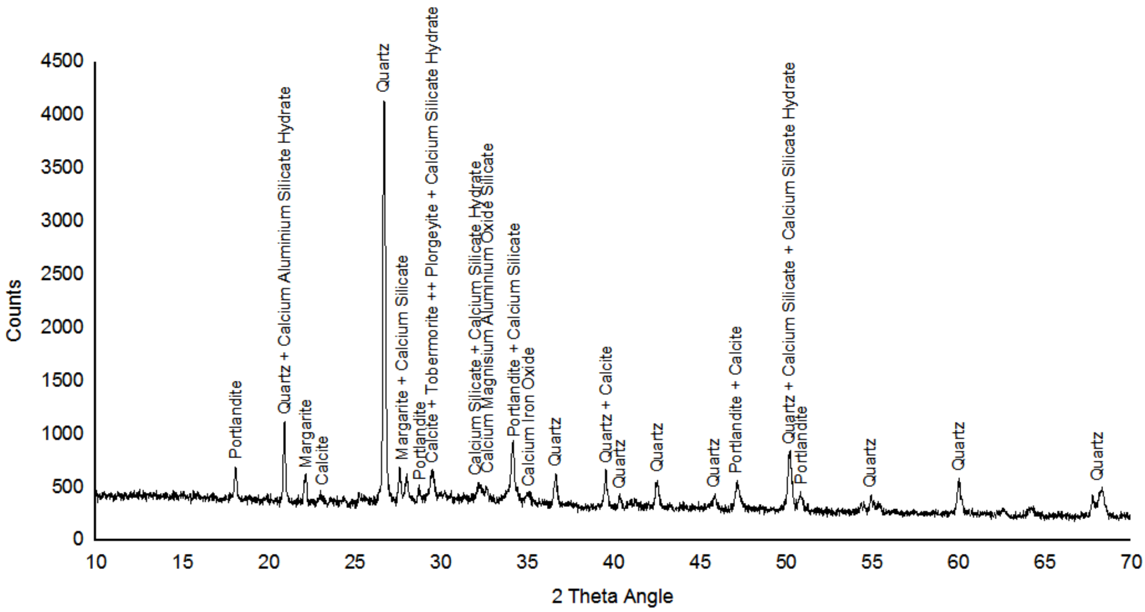


Fig. 4.23 : X-ray Diffractogram of Concrete Mix Containing 5% Wood Ash at 90 Days

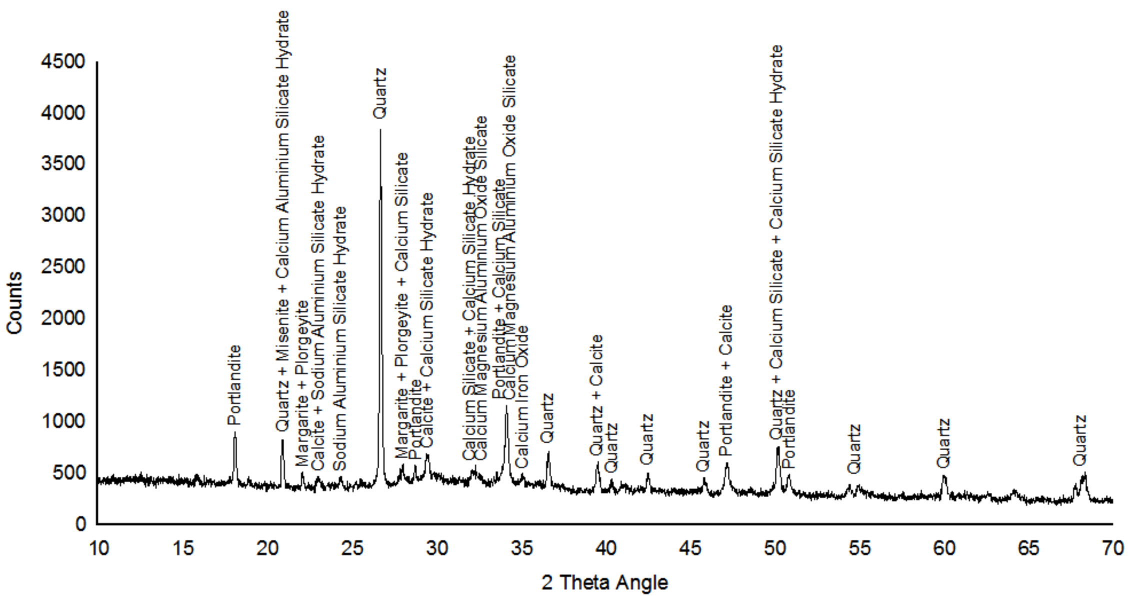


Fig. 4.24 : X-ray Diffractogram of Concrete Mix Containing 10% Wood Ash at 90 Days

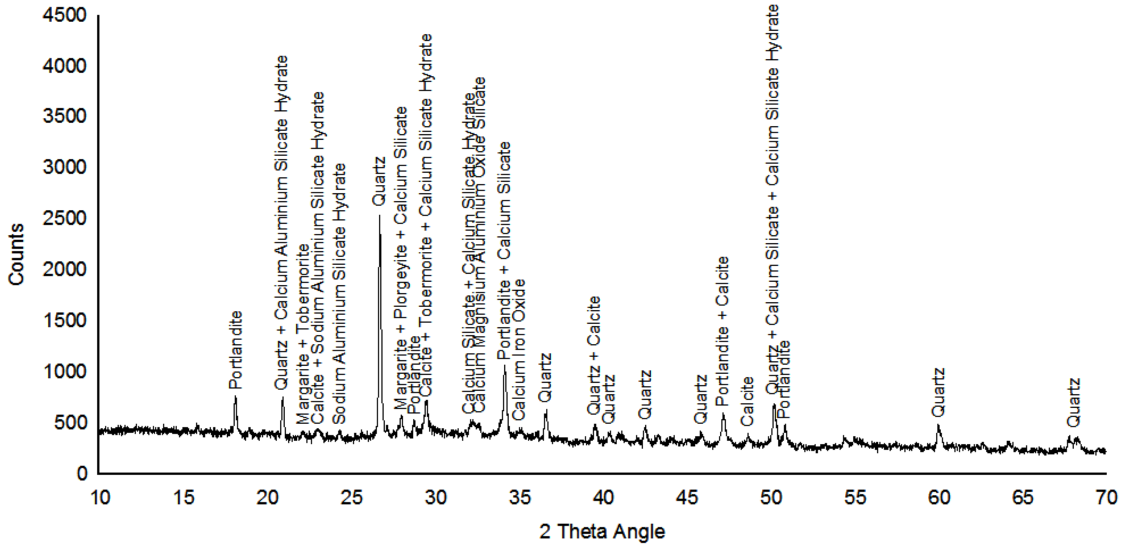


Fig. 4.25 : X-ray Diffractogram of Concrete Mix Containing 15% Wood Ash at 90 Days

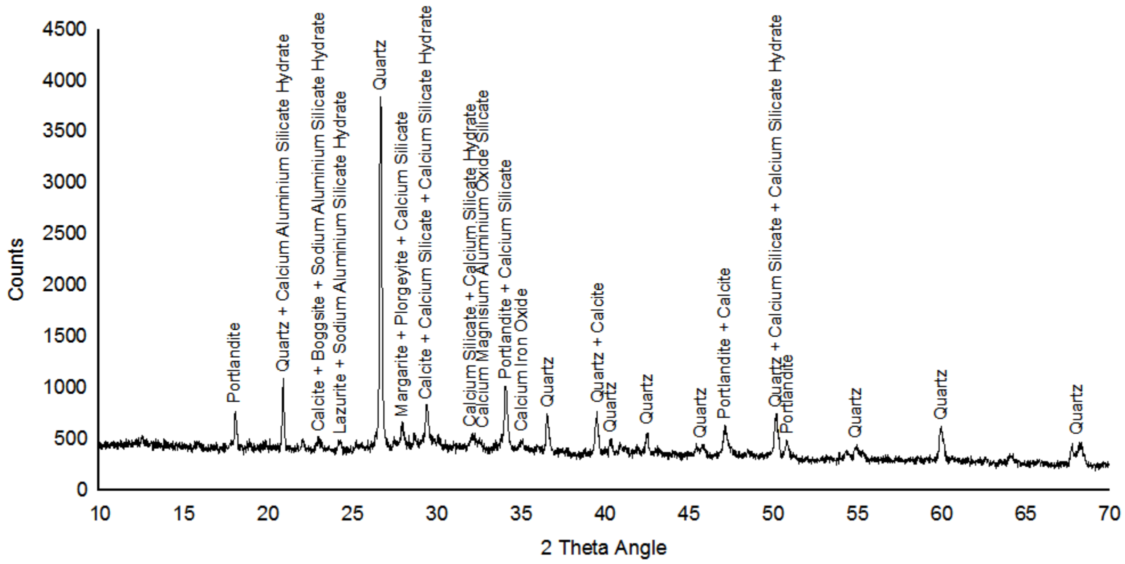


Fig. 4.26 : X-ray Diffractogram of Concrete Mix Containing 20% Wood Ash at 90 Days

Comparing the X-ray diffraction pattern of control concrete and all the concrete mixes containing wood ash, it can be said that new hydration products have formed in concrete mixes containing wood ash as a partial replacement of natural sand. Thus, there is qualitative change in various phases with the addition of wood ash as a partial replacement of natural sand in concrete.

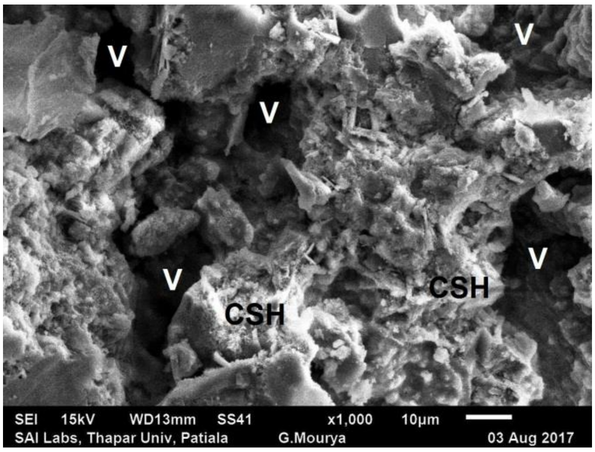
Comparing the X-ray diffraction patterns of corresponding wood ash concrete mixtures at 28 days and 90 days, we can say that few new hydration products have formed at later ages. Thus, there is qualitative change in various phases with age by the addition of wood ash as a partial replacement of natural sand in concrete.

So it can be concluded that wood ash is a pozollanic material, which has direct involvement in the hydration process of the cement.

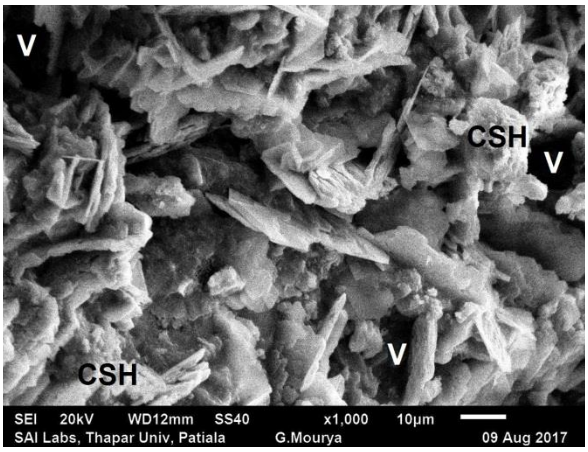
4.7.2 Scanning Electron Microscope (SEM) Analysis:

To study the various changes in the microstructure of concrete with addition of wood ash as a partial substitute of natural sand, scanning electron microscope (SEM) analysis was performed. Concrete samples collected from all concrete mixes at age of 28 days were analysed to study the microstructure of each concrete mix.

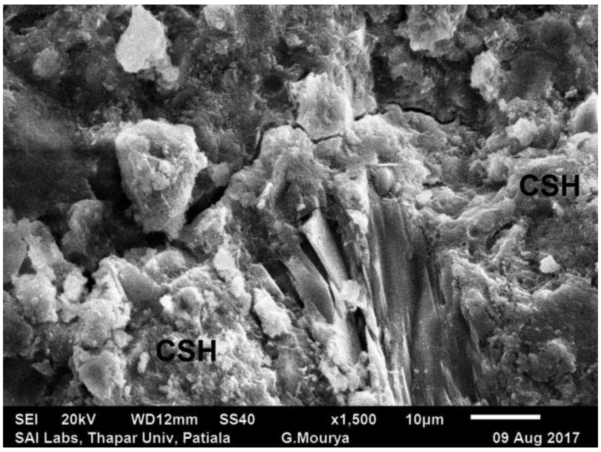
Fig. 4.27 shows the SEM morphology of different concrete mixes at age 28 day. It can be observed that inclusion of wood ash has a very profound effect on microstructure of concrete. Control concrete has maximum voids among all concrete mixes. As the substitution rate of natural sand with wood ash is increasing, voids goes on reducing. This proves the filling effect of wood ash micro-fines.



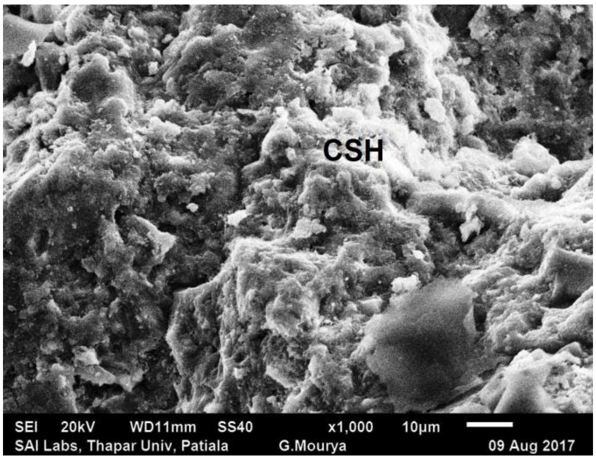
Control Concrete



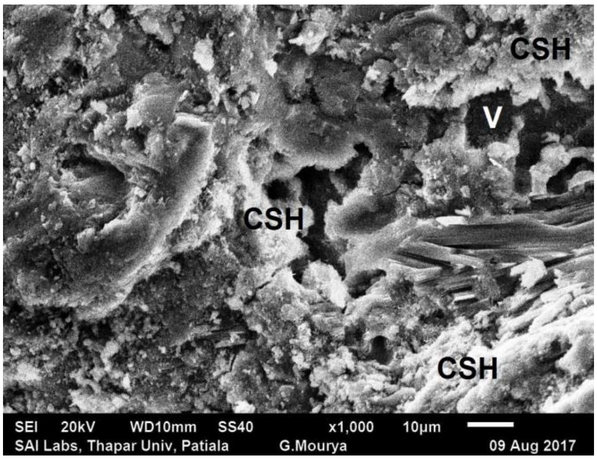
CWA5 : 5% Sand Replacement



CWA10 : 10% Sand Replacement



CWA15 : 15% Sand Replacement



CWA20 : 20% Sand Replacement

Fig. 4.27 : SEM Morphology of Concrete Containing Wood Ash as Partial Replacement of Natural Sand at Age of 28 Days

CHAPTER 5
CONCLUSIONS

5.1 General

The present experimental investigation was conducted to study the suitability of wood ash as a partial replacement of natural sand in concrete. Workability, compressive strength, splitting tensile strength, water absorption, sorptivity and rapid chloride-ion permeability of concrete were tested by replacing natural sand with wood ash at different varying percentages in concrete. XRD and SEM analysis was also done on all concrete mixes to study changes in cement phases as well as microstructure of concrete with the inclusion of wood ash as partial replacement of natural sand. Test results indicate that wood ash, an industrial by-product, is a suitable substitute of natural sand in concrete.

5.2 Conclusions:

1) Workability of concrete was decreased as the percentage replacement of natural sand with wood ash was increased. The angular shape of wood ash particles increased the water demand of concrete, as the wood ash have high water absorption capacity thus, consequently resulted in decrease in workability. However, workability of concrete mixes at 15% and 20% sand replacement was zero thus does not suitable in structural uses.
2) Density of concrete was decreased with increase in replacement of natural sand with waste wood ash. Density of concrete mix with 5% sand replacement level was 2433.5kg/m^3, which recorded only 0.06% lesser as compared to control mix and the maximum decrease in density of concrete was with 20% sand replacement which recorded only 1.3% lesser as compared to control mix. Filling effect of wood ash micro-fines to produce a dense microstructure and the lesser specific gravity of wood ash as compared to natural sand was the reason behind the lesser decrease in density of concrete.
3) Compressive strength of concrete was increased first but later on it was decreased with inclusion of wood ash as partial replacement of natural sand. Concrete mix with 5% sand replacement level had maximum compressive strength at all ages. Better conditions for hydration of cement in the presence of wood ash micro-fines as seen in XRD and SEM.

4) Splitting tensile strength of concrete was increased first but later it was decreased with inclusion of wood ash as partial replacement of natural sand. Concrete mix with 5% sand replacement level had maximum splitting tensile strength at all ages. Better conditions for hydration of cement in the presence of wood ash micro-fines, same as in case of compressive strength.
5) Water absorption of concrete was decreased first but later starts increased with increase in replacement of natural sand with wood ash at all ages. Concrete mix with 5% sand replacement level had lowest water absorption among all mixes. The filling effect of wood ash micro-fines reduced voids, which decreased water absorption of concrete in earlier replacement level. But as the replacement level increases due to the wood ash has absorb more water as compare to natural sand, so as the wood ash particles in the concrete increases the water absorption of concrete increases.
6) Sorptivity of concrete was decreased first but later it was increased with increase in replacement of natural sand with wood ash at all ages. Concrete mix with 5% sand replacement level had lowest sorptivity among all mixes. The reason behind the decrease in sorptivity was that the filling effect of wood ash micro-fines not only reduced the size of the voids, but also modified the internal pore structure of concrete by blocking interconnecting capillary pores.
7) Chloride-ion penetration resistance was increased first but later it decreased with inclusion of wood ash as partial replacement of natural sand. Concrete mix with 5% sand replacement level had minimum charge passed among all concrete mixes. The increase in chloride-ion penetration resistance can be mainly attributed to filling effect of micro-fines particles of wood ash.
8) X-ray diffraction analysis showed that there is qualitative change in various phases of cement in concrete mixes containing wood ash as partial replacement of natural sand as compared to control concrete. Various phases present in all concrete mixes were identified as quartz, portlandite, calcium silicate hydrate, calcium silicate, calcium aluminium silicate hydrate and calcite. Many new phases were present at 28 days and 90 days sample. Thus, wood ash can be considered as a pozollanic material.
9) SEM analysis of concrete mixes clearly demonstrated the filling effect of wood ash micro-fines in concrete. Control mix had maximum voids at all ages, which decreased continuously as the replacement of natural sand with wood ash was increased. Concrete mixes with 15% and 20% sand replacement seemed to have minimum voids and most dense microstructure among all mixes.

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