USE OF WOOD ASH AS PARTIAL CEMENT REPLACEMENT IN CEMENT MORTAR

A Thesis Submitted in Fulfillment of the Requirements for The Award of Degree of

MASTER OF ENGINEERING

IN

STRUCTURAL ENGINEERING

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JULY, 2019

DECLARATION

I, **Pramod**, hereby declare that the work presented in this thesis entitled, **"USE OF WOOD ASH AS PARTIAL CEMENT REPLACEMENT IN CEMENT MORTAR"**, in fulfillment of the requirement for the award of degree of Master of Engineering in Structural engineering submitted at Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record work carried out under the supervision of **Dr. Maneek Kumar**, Professor and **Dr. Gurbir Kaur,** Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala from **Jan 2019 to July, 2019**. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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CERTIFICATE

It is certified that the above statement made by student is correct to the best of my knowledge and belief.

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ACKNOWLEDGMENT

It is a great pleasure for me to take this opportunity to express my profound sense of gratitude to all those who assisted me in the completion of this dissertation work. I gratefully acknowledge my supervisors **Dr. Maneek Kumar** and **Dr. Gurbir Kaur** for their knowledge, encouragement and personal attention that have provided good and smooth basis for my dissertation tenure. This work would not have been possible without their guidance, support and encouragement. Under their guidance, I successfully overcame many difficulties and learned a lot. I am also thankful to Dr. PremPal Bansal, Head of Civil Engineering Department for providing the facilities for the completion of my coursework.

I am also thankful to my batch mates, seniors, lab staff, fellow research scholars and Non-Teaching Staff who devoted their valuable time for the successful completion of dissertation. I extend my gratitude to the researchers and scholars whose hours of toil have produced the papers that I have used for my dissertation.

I would like to express my deepest gratitude to my parents and family, without whom I am nothing. To provide me with a great opportunity, everlasting support, big encouragement and lots of love.

Words are short to express my deep sense of gratitude towards my family members and friends for their encouragement, inspiration, emotional support, and love. Finally, I bow to the almighty who gave me the strength to carry out this work of dissertation with sincerity and dedication.

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ABSTRACT

Management of solid waste is the major concern globally due to increasing quantities of waste materials and by-products from industries. Lack of space availability for land filling and because of its increasing cost, utilization and recycling of industrial by-products and waste materials has the only option as it is economical and ecofriendly. There are several types of such materials, which can be recycled or reused in construction. The utilization of such materials in construction not only makes it economical, but also helps in reducing disposal problems.

One such material is wood ash (WA). Wood ash (WA) is the residue generated due to combustion or incineration of wood and wood products (chips, saw dust, bark, etc.).The XRD (X-RAY DIFFRACTION) test results, SEM (scanning electron microscope) analysis and chemical analysis of WA showed that it contains amorphous silica and thus can be used as cement replacing material.

Many researches had been carried out to incorporate wood waste ash as a cement replacement material in the production of greener construction material (concrete/mortar) and also as a sustainable means of disposal for wood waste ash. Results of these researches indicated that wood waste ash can be effectively used as a cement replacement material for the production of structural concrete/mortar of acceptable strength and durability parameters.

This report presents an overview of the work carried out with cement mortar in which cement is partially replaced by wood waste ash on several aspects such as the physical, chemical, strength and durability properties of mortar with wood waste ash. This report shows the effect of wood ash on the workability, porosity, water absorption, compressive strength, flexural strength, thermal cycling, salt crystallization and rapid chloride permeability test etc.

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LIST OF ABBREVATIONS

ASTM	American society for Testing and Materials
BS	British Standards
CH	Calcium Hydroxide
C-S-H GEL	Calcium-Silicate-Hydrate gel
CTM	Compression Testing Machine
ED-X	Energy Dispersive X-Ray
FA	Fly Ash
IS	Indian Standards
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
RCPT	Rapid Chloride Permeability Test
SEM	Scanning Electron Microscopy
SF	Silica Fume
SRPC	Sulphate Resistant Portland Cement
UTM	Universal Testing Machine
^0C	Degree Calcius
kg	kilogram
kg/m^3	Kilogram per cubic meter
mm	Millimeters
cm	Centimeters

N/mm^2	Newton per square millimeter
h	Hours
min	Minutes
sec	Seconds
MPa	Mega Pascal
µm	Micrometer

CHAPTER 1: INTRODUCTION

This chapter contains the introduction, wood ash origin, wood ash applications, factors that affect quantity and quality of wood ash and objectives of wood ash in cement industry. This chapter also deals with the problems that arise from combustion of wood, from cement industries and how we can handle wood ash economically as well as environment friendly.

1.1 GENERAL INTRODUCTION

Accumulation of industrial/domestic waste, mainly in developing countries, has resulted in a great environmental concern. In the last few years, growing awareness about global environment and increasing energy security has led to increasing demand for renewable energy resources and to explore some new methods of energy production. Since, due to increase in population, demand of building materials is also increasing that causes a shortage of building material, the civil engineers/researchers have to convert industrial and domestic wastes to useful building material substitute. Among the resources of energy production, biomass (forestry and agricultural wastes) is a promising source of renewable energy. In the current trends of energy production, power plants which run from biomass have low operational cost and have continuous supply of renewable fuel.

The thermal combustion/incineration reduces the mass and the volume of the waste up to a large extent, thus providing an environmentally safe and economically efficient way to manage the solid waste. Solid wood waste is commonly preferred as fuels over other light/herbaceous and agricultural waste as their combustion produces comparatively less fly ash and other residual material.

1.2 Origin of Wood Ash

The combustion/incineration of wood biomass produces wood ash as a by-product. A major problem arising from the usage of forest/agricultural waste product as fuel is related to the ash produced in significant amount after the combustion of such wastes. It is commonly observed that the hardwood produce more ash than softwood and the bark and leaves generally produce more ash as compared to the inner part of the trees.

1.3 Applications of Wood ash

Ash by-products obtained from combustion of wood biomass are generally used in land filling for embankments, road/highway construction. It can be used as soil supplementing material to reduce the alkalinity of soil in agricultural lands. And it can also be used as raw material in the manufacturing of cement in cement industries.

As par current situation, approximately 70% of wood ash produced is managed by land filling, 20% of total wood ash produced is used as a soil supplement material for agricultural activity and the remaining 10% is implemented for other/miscellaneous applications as metal recovery and pollution control.

Siddique R. (2012) gave a data that, on an average, 6 to 10% (by weight of wood) ash is produced by the burning of wood and its composition may differ according to wood type, geographical location and industrial process.

Godwin (2013) proved that rice husk ash can be used to make structural concrete by replacing cement by rise husk ash at suitable replacement levels.

Greene (1998) observed that wood ash produced from the combustion of wood waste biomass is widely used as raw material for cement production and also as filling material in the construction of road base in place of soil. Due to lack of space availability and strict environmental rule and regulations issued by environmental bodies, land filling of wood ash is becoming restrictive. Moreover, the use of wood ash as soil supplementary material is becoming limited due to significant heavy metal content in wood ash which may cause serious ground water pollution with uncontrolled applications on agricultural land. As wood ash primarily consists of fine particle matter which can easily dissolve in environment by winds, it is dangerous/hazardous as it may cause respiratory health problems to the workers, householders near the dump/ working site or can cause groundwater contamination by leaching toxic elements in the water. There are restrictions on land filling of wood ash and the use of wood ash as a soil supplementary material. In this regard, many attempts and research has been carried out to reuse of wood ash especially as a constituent in construction material to dispose the ash material.

1.4 Objectives of using Wood Ash in Cement

The production of cement needs a massive amount of raw material, and at the same time releases carbon dioxide into the atmosphere. Researchers showed that for every 600 kg of cement, approximately 400 kg of CO_2 is released into the atmosphere. The increasing demand of cement, as the population is increasing day by day, environmental pollution is also increasing and exploitation of natural resources for raw material is also increasing.

The availability of thermal power plants in a large number throughout the world will results in the generation of thousand tones of wood ash produced annually which require proper management and handling/monitoring so that it will not cause environmental pollution.

Researchers have conducted tests which showed effective results that wood ash can be suitably used to replace cement partially in concrete production. Hence, usage of wood ash as replacement for cement is beneficial for the environmental point of view as well as producing low cost construction entity thus leading to a sustainable relationship.

The main objective of this report is to find out

(a) optimum amount of wood ash in cement mortar

(b) effect of wood ash on mortar strength and durability properties.

1.5 Factors affecting the quantity and quality of wood waste ash

There are several factors which influence the qualitative and quantitative aspects of wood ash produced from its combustion, some are as follows:

1. Combustion temperature
2. Combustion technology, type of furnace used
3. Biomass characteristics (species of trees)

1. Combustion temperature: The combustion temperatures of the wood waste influence both the yield and chemical composition of the wood ash. Combustion of the wood waste at higher temperature leads to the production of lower amount of ash. It was observed that wood ash production reduced by 45% when the combustion temperature was raised from 538^0C to 1093^0C. Combustion at higher temperatures, above 1000^0C causes decomposition of carbonates and bicarbonates and thereby decreases the alkalinity of the ash due to their reduction in the ash, being chemical species contributing to the alkalinity of the wood ash. At an incineration/combustion temperature below 500^0C, carbonate and bicarbonate compounds, especially calcite ($CaCO_3$), are predominant in wood ash whereas at higher temperatures like 1000^0C, oxide compounds such as quick lime (CaO) are in majority, in the chemical phase of wood ash. Moreover, the presence of light metallic elements such as potassium, sodium and zinc decreases upon increasing the combustion temperature.

2. Combustion technology: Different types of combustion technologies affect the physical properties of ash and varying the thermal temperature causes corresponding variation in the chemical composition of wood ash. Generally, wood ash produced in a grate fired furnace has a tendency to be coarser in nature and settle inside the chamber as bottom ash whereas in more efficient fluidized bed furnaces, the ash produced is finer, with a very low fraction of coarse particles. Wood ash produced from open incineration/burning is also finer with a low fraction of coarser particles.

(a) (b)

Fig 1. 1:Wood Waste Ash Obtained from Open Burning

3. Biomass characteristics (species of trees): Some species of trees, from which wood waste is taken, has shown a dominant factor governing the chemical properties of wood ash produced. The chemical composition of wood ash which governs the suitability of wood ash as a cement replacement material is silica, alumina, iron oxide, quicklime which varies significantly according to different type of trees. Table 1.1 gives the variation in chemical composition of wood ash produced from different trees given by **Vassilev et al. (2010)** .

Table 1. 1:Variation in chemical composition of different species of trees (Vassilev et al., 2010)

Biomass	**SiO_2**	**CaO**	**K_2O**	**Al_2O_3**	**MgO**	**Fe_2O_3**	**SO_3**	**Na_2O**
Alder-fir sawdust	37.49	26.41	6.1	12.23	4.04	8.09	.83	1.81
Balsam bark	26.06	45.76	10.7	1.91	2.33	2.65	2.86	2.65
Beech bark	12.4	68.2	2.6	0.12	11.5	1.1	.8	.09
Birch bark	4.38	69.06	8.99	0.55	5.92	2.24	2.75	1.85
Christmas trees	39.91	9.75	8.06	15.12	2.59	9.54	11.66	0.54
Elm bark	4.48	83.46	5.47	0.12	2.49	0.37	1	0.87
Eucalyptus bark	10.04	57.74	9.29	3.1	10.91	1.12	3.47	1.86
Fir mill residue	19.26	15.1	8.89	5.02	5.83	8.36	3.72	29.2
Forest residue	20.65	47.55	10.23	2.99	17.2	1.42	2.91	1.6
Hemlock bark	2.34	59.62	5.12	2.34	14.57	1.45	2.11	1.22
Land clearing wood	65.82	5.79	2.19	14.85	1.81	1.81	0.36	2.7
Maple bark	8.95	67.36	7.03	3.98	6.59	1.43	1.99	1.76
Oak sawdust	29.93	15.56	31.99	4.27	5.92	4.2	3.84	2
Oak wood	48.95	17.48	9.49	9.49	1.1	8.49	2.6	0.5
Olive wood	10.24	41.47	25.16	2.02	3.03	.88	2.65	3.67
Pine bark	9.2	56.83	7.78	7.2	6.19	2.79	2.83	1.97
Pine chips	68.18	7.89	4.51	7.04	2.43	5.45	1.19	1.2
Pine pruning	7.76	44.1	22.32	2.75	11.33	1.25	4.18	0.42
Pine sawdust	9.71	48.88	14.38	2.34	13.8	2.1	2.22	0.35
Poplar	3.87	57.33	18.73	.68	13.11	1.16	3.77	0.22

Poplar bark	1.86	77.31	8.93	.62	2.36	.74	0.74	4.84
Sawdust	26.17	44.11	10.83	4.53	5.34	1.82	2.05	2.48
Spruce bark	6.13	72.39	7.22	.68	4.97	1.9	1.88	2.02
Spruce wood	49.3	17.2	9.6	9.4	1.1	8.3	2.6	0.5
Tamarack bark	7.77	53.5	5.64	8.94	9.04	3.83	2.77	3.4
Willow	6.1	46.09	23.4	1.96	4.03	.74	3	1.61
Wood	23.15	37.35	11.59	5.75	7.26	3.27	4.95	2.57
Wood residue	53.14	11.66	4.85	12.64	3.06	6.24	1.99	4.47
Mean	22.22	43.03	10.75	5.09	6.07	3.44	2.78	2.85

CHAPTER 2: LITERATURE REVIEW

This chapter contains the details of work done by researchers on mortar/concrete in with partial replacement of cement by wood waste ash. This chapter contains work of researchers on physical properties, hardened properties, durability and strength properties of mortar/concrete. By their work, they showed that wood ash may be used as a replacement material in mortar/concrete. Findings of some researchers are as follows:

2.1 PHYSICAL PROPERTIES

In this section, we study the findings, outcome and results of researchers on physical properties of mortar/concrete such as workability (slump), porosity, bulk density and water absorption by capillarity etc.

2.1.1 SLUMP:

Udoeyo et al. (2006) found the behavior of concrete containing wood ash at varying replacement percentages (0%, 5%, 10%, 15%, 20%, 25%, 30%). It was found out by experiments that concrete mix with WWA as a replacing material, decreases the workability of concrete. This was due to that wood ash particles are smaller than that of cement particles due to which, wood ash particles has more specific surface area. Hence these particles absorb more water and ultimately, workability decreased. Test results are shown in table 2.1.

Table 2. 1:Slump of concrete with replacement of WWA (Udoeyo et al., 2006)

Content of WWA (%)	0	5	10	15	20	25	30
Slump(mm)	62	8	5	2.5	0	0	0

Abdullahi (2006) observed the effect of wood ash on slump of concrete. He used cement mortar in which wood ash is partially replaced at levels of 0%, 10%, 20%, 30%, 40% by weight of cement in concrete mixture of proportion 1:2:4. Test results are shown in table 2.2. Test results showed that workability decreased with increase in percentage of wood ash that means more water is needed to get reasonable workability.

Table 2. 2:Slump test results (Abdullahi, 2006)

WWA content, %	0	10	20	30	40
W/C ratio	0.6	0.66	0.67	0.68	0.69
Slump (mm)	30	35	40	40	35

Elinwa and Mehmood (2002) found that when the cement is partially by wood waste ash obtained from open combustion/incineration of saw dust ash had the adverse effect on workability of grade 20 concrete. At constant w/c ratio of 0.565, when the percentage of replacement of cement is increased from 5% to 30% by weight of cement, slump value of concrete is decreased by 5-40mm with respect to control mix.

2.1.2 BULK DENSITY:

Ellinwa at al. (2005) found that when the cement was partially replaced by wood waste ash in concrete, bulk density decreased when we increased the replacement percentage. Grade 20 concrete mix bulk density was found out to be 2281 kg/m^3 at 40% replacement level while the bulk density of same mix was found out to be 2482 kg/m^3 at 0% wood ash level.

Farinha et al. (2018) found the bulk density of fresh mortar in which cement is replaced by forest biomass ash (FBA) at replacement percentages of 0,5,10,15%. They used prism size of 40mm*40mm*160mm as per BS EN 1015 Part-11. Their outcomes are shown in table 2.3.

Table 2. 3:Bulk Density of FBA mortar, Farinha et al. (2018)

FBA Content, %	**Bulk Density, kg/m^3**
0%	1975.2
5%	2058.6
10%	2061.6
15%	2044.7

2.1.3 WATER ABSORPTION CAPACITY:

Elinwa and Ejeh (2004) found that the water absorption capacity was reduced as compared to control mix at 15% replacement of cement by wood ash. Average water absorption capacity of 15% replacement of mortar containing wood ash was 0.8% of the total volume of specimen whereas water absorption capacity of control mix with no wood ash was found to be 1.25% of the total volume of specimen but these values are far below the accepted value of water absorption capacity which is 10%.

Udoeyo et al. (2006) investigated the water absorption capacity of concrete made by different replacement percentages of cement (5-30% replacement by weight of cement). It was observed that as we increased the percentage of wood ash, water absorption capacity increased as shown in fig 2.1. It was found that water absorption capacity at 5% WWA replacement was 0.4% of total volume of specimen and at 30% WWA replacement, water absorption capacity was 1.05%. These values were also less than 10% which is an acceptable limit.

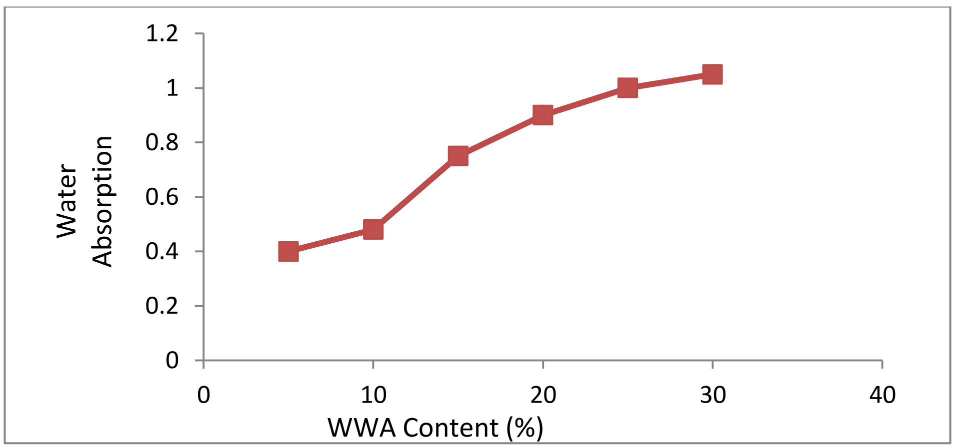

Fig 2. 1:Water absorption % versus WWA content (%), Udoeyo et al. (2006)

2.1.4 POROSITY:

Vishwakarma V. et al. (2015) studied the porosity results of concrete made by OPC with replacement of rice husk ash (RHA) and fly ash (FA) and some admixture (1.2% by weight of cement). They made cylinders of size 50mm*100mm and two types of mix, one with fly ash and the other with rice husk ash. The ratio of OPC/FA was 4:1 and the ratio of OPC/SF was 3.91:1. They observed that the porosity of RHAC was less than FAC as shown in fig 2.2 due to the presence of nanosilica which enhance the formation of more hydration products which fills the voids of concrete and hence decrease the porosity.

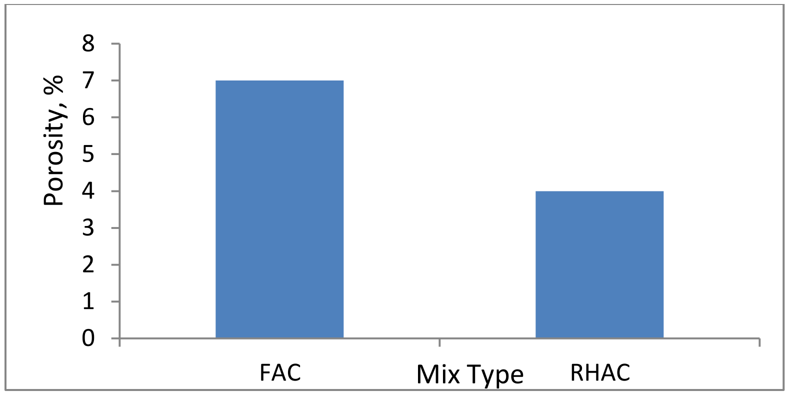

Fig 2. 2:Variation in Porosity of FAC and RHAC

2.2 STRENGTH PROPERTIES

In this section, researchers work on strength properties like compressive strength, flexural strength and split tensile properties and their outcomes are discussed.

2.2.1 COMPRESSIVE STRENGTH:

Ellinwa and Ejeh (2004) studied the effect of wood waste ash on compressive strength of mortar with different replacement percentages between 5% and 30%, at a rate of 5% increment in wood ash at each step. They observed that the mortar with 10% replacement level exhibits more compressive strength at all ages of curing upto 60 days. At 60 days of curing, mortar with partial replacement of wood ash at 10% has the equivalent strength as that of control mix.

Naik et al. (2002) studied the behavior of compressive strength of concrete containing wood waste ash as partial replacement for curing age upto 365 days. Wood ash replacement levels were 5%, 8% and 12%. From the compressive strength results, it is concluded that

(a) control mixture (only OPC as binder) gained a strength level of 34 MPa at curing of 28 days and 44 MPa at curing of 365 days.

(b) concrete containing wood ash as replacing material gained a strength level of range from 33MPa at 28 days and 42 to 46 MPa at 365 days of curing.

(c) the replacement of wood ash upto 12% had a significant contribution to strength development of concrete mix produced. There was continuous gain in strength of wood ash concrete mix upon long time curing durations. This was an indication of pozzolanic reaction between cement and wood waste ash.

Rajamma et al. (2009) showed the effect on compressive strength of cement mortar mixes when cement is replaced by wood ash at different replacement levels (0%, 10%, 20%, 30%). It was observed that when we increase the replacement level of wood waste ash, compressive strength of mortar decrease at 28 days in comparison to neat mortar (control mixture).

Udoeyo et al. (2006) worked out the compressive strength of concrete at varying percentages of wood ash as 5, 10, 15, 20, 25 and 30 by weigth. Test results are given in table 2.4. Results showed that there was increase in strength due to longer period of curing but decrease in strength as we increase the percentage level of wood ash.

Table 2. 4:Compressive strength of concrete at Different replacement level of WWA (Udoeyo et al., 2006)

WWA content (%)	**3 day strength (MPa)**	**7 day strength (MPa)**	**14 day strength (MPa)**	**28 day strength (MPa)**	**90 day strength (MPa)**
0	16.24±.10	16.85±.05	23.40±.46	28.35±2.64	31.48±.50
5	14.23±1.04	15.31±.87	18.32±.67	24.61±.51	28.66±.70
10	14.01±.86	15.31±.37	16.92±.75	21.86±1.11	27.54±.34
15	13.75±.62	14.18±.26	15.78±.68	21.73±.84	23.70±.81
20	13.25±.47	14.10±.39	15.78±.68	20.55±.79	22.68±.81
25	13.17±.36	14.05±.58	15.03±.88	20.35±1.16	19.62±.56
30	12.83±.30	13.88±.76	14.85±.25	19.52±.57	19.52±.57

2.2.2 FLEXURE STRENGTH:

Naik et al. (2002) worked out the effect of wood waste ash on the flexural strength of concrete. Replacement levels 5%, 8% and 12% of cement were used. Based on their experimental work they concluded that

(a) control mixture gained a strength of 4.1 MPa at 28 days and 4.4 MPa at 365 days.

(b) mixture with WWA achieved a strength between 3.9 to 4.4 MPa at 28 days and 4.3 to 5.3 MPa at 365 days.

(c) test results showed that flexural strength increase with percentage increase of wood waste ash due to pozzolanic contribution of wood ash.

Rajamma et al. (2006) studied the behavior of cement mortar at 28 days containing partial replacement of cement by wood ash from two different biomass power plant sources. Replacement percentages were 0% (control mix), 10%, 20%, 30%. Experimental results showed that there was a gradual decrease in flexural strength with increase in replacement levels. It was found out that mortar with 10% wood ash gave results of flexure strength in the range of 60.6-1%, 20% wood ash exhibited flexure strength in the range of 59.6-61.7%, 30% wood ash exhibited flexural strength in the range of 45-48.5% of control mix respectively. It was also concluded that

(1) for an acceptable strength, 20% replacement level is sufficient (optimum).

(2) above 20% replacement level, strength decreased rapidly.

Udoeyo et al. (2006) worked out the flexural strength test of concrete containing wood ash with replacement percentages as 5, 10, 15, 20, 25 and 30% by weight of cement. Results of their experimental work are shown in table 2.2. They showed that flexural strength is decreased with increase in percentage of wood ash as replacement of cement because decrease in the amount of binder but at a slower rate in comparison of compressive strength. The 28 days strength was 5.20 N/mm^2 at 5% replacement of wood ash and it decreased to 3.74 N/mm^2 at 30%of wood ash. The results of flexural strength were in the range of 67% to 93% of control mixture at different ages and at different replacement levels as shown in table 2.5.

Table 2. 5:Flexural strength of concrete with WWA (Udoeyo et al., 2006)

WWA content, %	Flexural stremgth (N/mm2)				
	3 days	7 days	14 days	21 days	28 days
0	4.45±0.04	4.93±0.15	5.44±0.42	5.46±0.03	5.57±0.05
5	4.34±0.02	4.67±0.27	5.04±0.20	5.18±0.01	5.20±0.01
10	3.81±0.02	3.92±0.07	3.99±0.03	4.08±0.09	4.28±0.09
15	3.75±0.06	3.91±0.03	3.97±0.04	4.01±0.15	4.04±0.04
20	3.64±0.04	3.76±0.04	3.79±0.05	3.80±0.05	3.85±0.08

25	3.51±0.02	3.53±0.07	3.55±0.04	3.57±0.03	3.73±0.03
30	3.65±0.06	3.66±0.02	3.69±0.03	3.71±0.05	3.74±0.03

2.3 DURABILITY PROPERTIES

In this section, we study the findings of researchers on durability properties of concrete/mortar such as thermal cycling, salt crystallization and rapid chloride permeability test etc.

2.3.1 THERMAL CYCLING:

W. Yao et al. (2017) studied the effect of heating at elevated temperatures on mortar/concrete. They studied that heating during a fire and the subsequent cooling after fire generates thermal gradient which cause anisotropic or uneven thermal expansion in concrete/mortar which cause cracks. They also concluded that rise in temperature cause following chemical changes:

(1) at around 150^0C temperature - dehydration of calcium silicate hydrate (C-S-H) gel

(2) at around 450^0C temperature – dehydroxylation of calcium hydroxide (CH)

(3) at around 574^0C temperature – transition in quartz

(4) at around 700^0C temperature – decarbonation of calcium carbonate ($CaCO_3$)

Mobili et al. (2016) studied the effect of higher temperature on cement mortar as per BS EN 1015:2007 Part-11 on prisms of 40mm*40mm*160mm sizes. They used white cement as binder and alternative binders for substitution of cement, namely coal fly ash (FAF), biomass fly ash (FAB), ceramic fired bricks (CP) and metakaolin (MK). They observed the residual compressive strength when samples are exposed to heigher temperatures such as 500, 700 and 1000^0C. They showed that after exposure to 500^0C, there was a decrease of 15% in compressive strength in control mortar and in 60C+40 FAF mortar, whereas in 60C+40CP and in 40C+40FAB, there was 20% decrease in compressive strength as compare to the samples which were tested at room temperature. It was also observed that there was not any change in 60C+40MK due to unavailability of portlandite [$Ca(OH)_2$] which decomposes at 420^0C by reaction with metakaolin.

2.3.2 SALT CRYSTALLIZATION:

Nehdi and Hayek (2008) studied the effect of sulphate attack on normal portland cement (NPC) and sulphate-resistant portland cement (SRPC) mortars. Mortars were prepared by replacing cement as partial replacement by 25% fly ash (FA), 8% silica fume (SF) and 8 % diatomaceous earth (DE). Cement and sand ratio was taken as 1:2 and 5cm cubes were made. Curing was done for 28 days. The performance of mortar is monitored for 24 weeks. The performance was noted in the form of weight loss in the sample day by day after immersion in 5% solution of Na_2SO_4 and in the solution of 5% $MgSO_4$ and in the form of reduction of compressive strength in comparison to mixture which was not immersed in the sulphate solution. Loss in compressive strength is shown in fig 2.3.

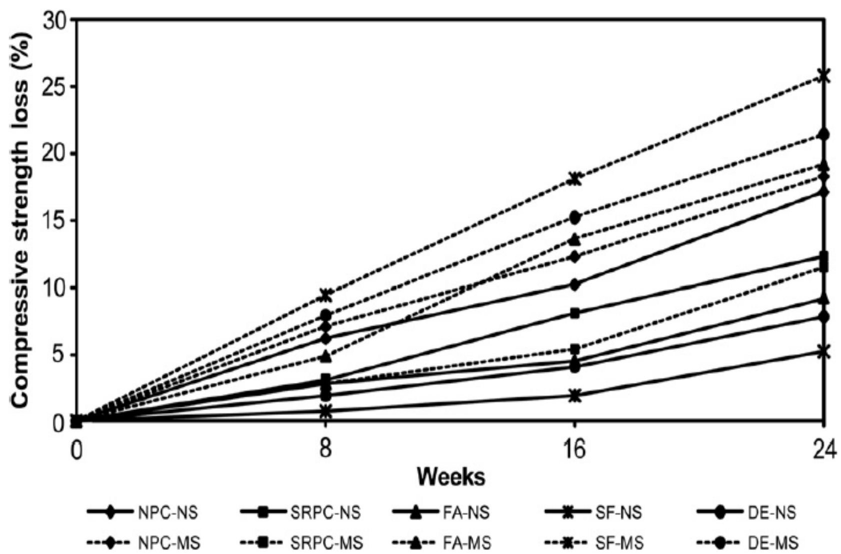

Fig 2. 3:Loss of Compressive Strength by Salt Attack, Nehdi and Hayek (2008)

Higher reduction in compressive strength in NPC mortar was noted followed by SRPS and FA after 24 weeks. It is clear from the fig that strength is lower in blended mortars as compared to neat mortar. This is because of reduction in the quantity of calcium hydroxide (CH) and tricalcium aluminate (C_3A). CH is the most vulnerable substance which is affected by Na_2SO_4 to a most.

Haynes et al. (2008) studied the effect of 10% Na_2SO_4 with temperature and humidity cycles on concrete mix made with Portland cement. They concluded that concrete scaling occurs at the surfaces when sample is immersed in solution of sulphate and it is significant when repeative cycles are applied.

2.3.3 RAPID CHLORIDE PERMEABILITY:

Horsakulthai et al. (2011) studied the effect of finely ground ash obtained from combustion of wood, rice husk ash, sugarcane bagasse waste (BRWA) as partial replacement of cement on chloride permeability of concrete. They used replacement percentages as 0%, 10%, 20%, 30% and 40% of total cement content by weight. It was concluded that incorporation of wood ash enhanced the chloride permeability.

Wang et al. (2008) studied the chloride permeability on concrete mixture with partial replacement of wood/coal ash, wood fly ash. Level of cement replacement kept constant at 25%. Various types of ash was used like ash from combustion of wood, fly ash of class C type and class F type and coal ash is also blended with these. They performed the rapid chloride permeability test after 56 days of curing. Test was performed in accordance with ASTM C 1202-1991. Based on their experimental work, they concluded that

(a) level of 25% replacement level did not result in considerable effect on chloride permeability property of concrete.

(b) they also concluded that there was a decrease in chloride permeability when cement is replaced by different wood ashes as compared to pure OPC mixture.

Kok Seng Chia and Min-Hong Zhang (2001) performed the rapid chloride permeability test as per ASTM C 1202, on normal weight aggregate (NWA) concrete and light weight aggregate (LWA) concrete with or without silica fume (SF). Their findins with different mixes are shown in table 2.6.

Table 2. 6:Outcomes of Rapid Chloride Ion Permeability, Kok Seng Chia andMin-Hong Zhang (2001)

Series	Mix no.	Aggregate Type	W/(C+SF)	SF %	Charge Passed (Coulombs)	Chloride Permeability
1.	1.	NWA	0.55	0	5445	High
	2.	LWA	0.55	0	5095	High
2.	3.	NWA	0.35	0	2290	Moderate

	4.	LWA	0.35	0	2843	Moderate
3.	5.	NWA	0.35	10	421	Very low
	6.	LWA	0.35	10	316	Very low

CHAPTER 3: EXPERIMENTAL WORK

This chapter contains the details of experimental work done to check the performance and behavior of cement mortar in which cement is partially replaced by wood waste ash. In this chapter, details of materials used at the time of experiments, equipment used, code used, how we performed the test etc., are given.

3.1 MATERIALS

In this section, details about materials used at the time of experimental work, is given in detail. We used cement, sand, wood waste ash and water.

3.1.1 CEMENT:

Ordinary Portland cement of grade 43 confirming to **IS 8112:2013** was used physical properties of which are shown in table 3.1 and Table 3.2 depicts the chemical properties of OPC 43 grade.

Table 3. 1:Physical properties of cement

S. No.	Property	Value
1.	Fineness (by Blaine's method)	225 m^2/kg
2.	Specific gravity	3.15
3.	Loss on ignition (percentage by mss)	Less than 5%
4.	Initial setting time	30 minutes
5.	Final setting time	10 hours

Table 3. 2:Chemical composition of cement

S. No.	Composition	Percentage	Average percentage
1.	Lime (CaO)	62 to 67%	62
2.	Silica (SiO_2)	17 to 25%	22
3.	Alumina (Al_2O_3)	3 to 8%	5
4.	Calcium sulphate ($CaSO_4$)	3 to 4%	4

5.	Iron oxide (Fe_2O_3)	3 to 4%	3
6.	Magnesia (MgO)	0.1 to 3%	2
7.	Sulphur	1 to 3%	1
8.	Soda and potash (Na_2O+K_2O)	0.5 to 1.3%	1

3.1.2 SAND:

Standard sand confirming to **IS 2116:1980** was used. Standard sand should pass from 2 mm IS sieve and should retain on 90 µm IS sieve.

3.1.3 WATER:

Water, fit for drinking purpose, is used for making mortar or for completing hydration reaction of cement.

3.1.4 WOOD WASTE ASH:

Fig 3.1 shows the physical appearance of wood ash obtained from open burning.

(a) (b)

Fig 3. 1:Wood Waste Ash Obtained from Open Burning

Wood waste ash is taken from open burning/incineration of woods and wood waste at an uncontrolled temperature. An adequate particle size of wood ash was obtained by "Los Angeles abrasion machine" in which grinding is done by steel balls and rotating drum. Some SEM (scanning electron microscope) images are shown in fig 3.2 and ED-X (energy dispersive X-ray spectroscopy) spectrum image is shown in fig 3.3.

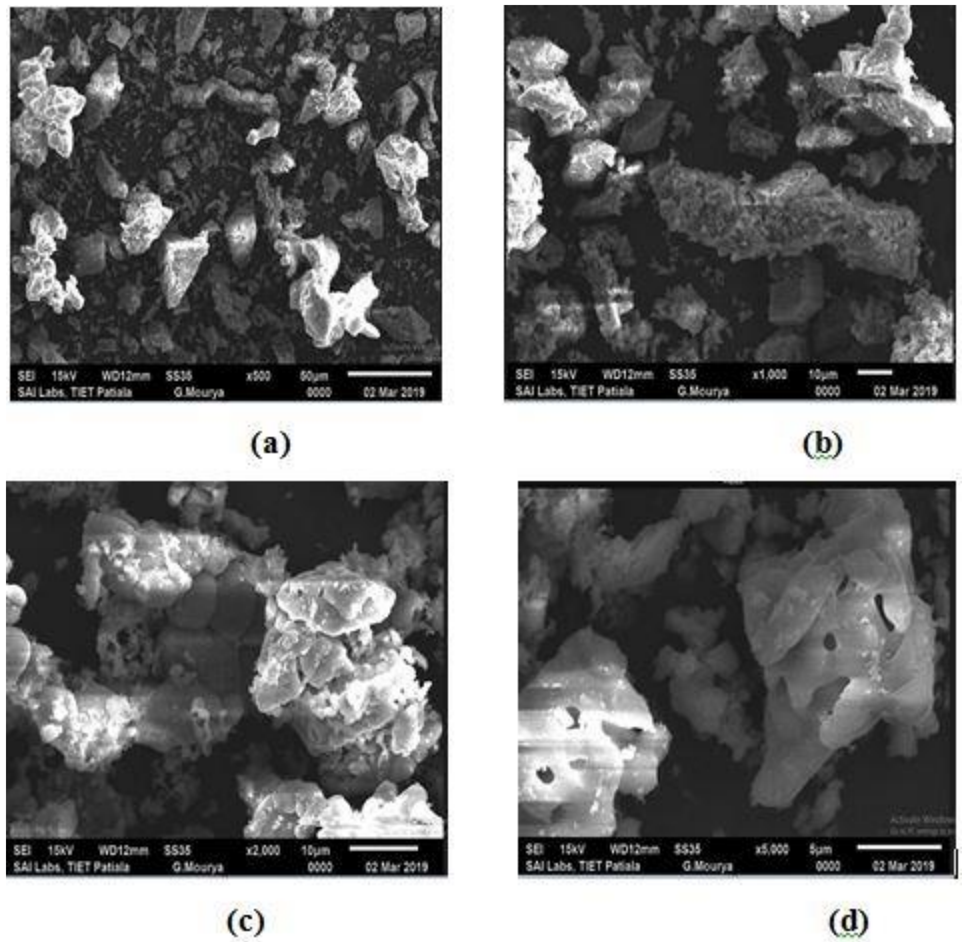

Fig 3. 2:SEM Images of WWA (a) 500 times enlarged, (b) 1000 times enlarged, (c) 2000 times enlarged, (d) 5000 times enlarged

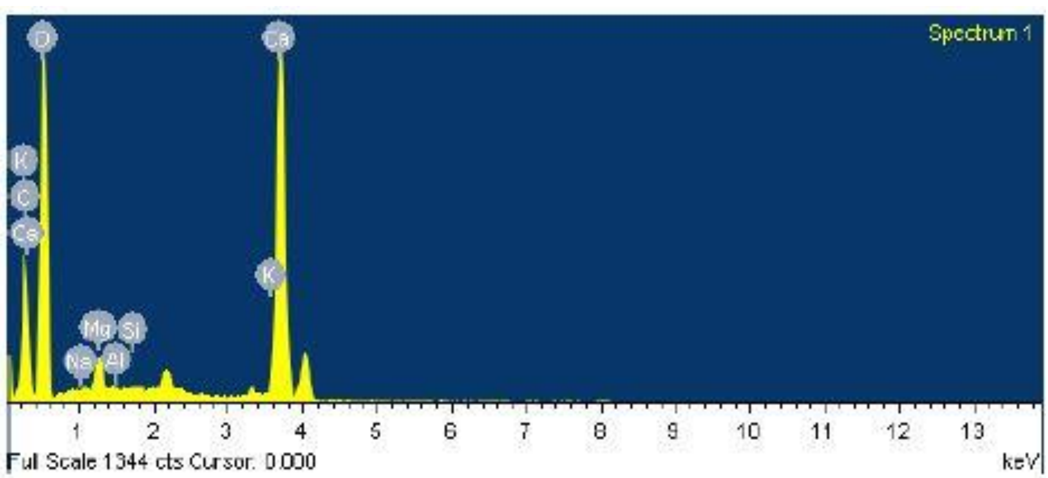

Fig 3. 3:Energy Dispersive X-Ray (EDX) Spectrum of WWA

Chemical composition of wood waste ash based on SEM (scanning electron microscope) analysis is shown in table 3.3.

Table 3. 3:Chemical composition of WWA

S. No.	Composition	Percentage by weight
1.	CO_2	10.24
2.	Na_2O	0.21
3.	MgO	1.70
4.	Al_2O_3	0.10
5.	SiO_2	0.09
6.	K_2O (feldspar)	0.64
7.	CaO	41.61
8.	Oxides	45.41
9.	Total	100

3.2 MIXING AND PROPORTIONING

The cement and sand ratio is 1:3 and water/cement ratio is 0.50. Quantity of cement was taken as 513 kg/m^3 and quantity of sand was 1539 kg/m^3 and quantity of water was 256.5 kg/m^3. Cement is partially replaced by wood waste ash as 0%, 5%, 7.5%, 10%. Each batch of mortar is mixed homogeneously by hand mixing or by using epicyclic type mechanical mixture as shown in fig 3.4. Table 3.4 depicts quantity of material in design mix with different replacement percentages.

Table 3. 4:Mix Design of Mortar with WWA for per cubic meter (1m3)

S. No.	Materials (in kg)	WWA 0%	WWA 5%	WWA 7.5%	WWA 10%
1.	Cement	513	487.35	474.52	461.7
2.	Sand	1539	1539	1539	1539
3.	Water	256.5	256.5	256.5	256.5
4.	Wood Ash	0	25.65	38.48	51.3

(a) (b)

Fig 3. 4:(a) Hand mixing with trowel and (b) Mixing with Mechanical Mixture

3.3 CODES USED

Codes used in the experimental work are described in table 3.5.

Table 3. 5:Codes Used in Experimental Work

S. No.	Codes	Description of Codes
1.	IS 8112:2013	For ordinary Portland cement of grade 43 specifications.
2.	IS 4031:1998	Part-7: Methods of physical tests for hydraulic cement
3.	IS 5512:1983	For specifications of flow table for use in tests of hydraulic cement and pozzolanic materials.
4.	BS EN 1015:1999	Part-11: For determination of flexural and compressive strength of hardened mortar. Part-18: For determination of water absorption coefficient due to capillary action of hardened mortar.
5.	ASTM C 1202	For standard test method of electrical indication for ability of concrete to resist chloride ion penetration
6.	RILEM	(a) RILEM 1980 for durability of mortars under thermal cycling and salt attack. (b) RILEM 1980 for the determination of porosity accessible to water and bulk density of hardened mortar.

3.4 PHYSICAL PROPERTIES OF MORTAR

In this section, we will describe the experimental procedure of physical properties such as workability, porosity, water absorption and bulk density of mortar.

3.4.1 WORKABILITY:

The ease with which we can work with or handle, place or transport the concrete/mortar is called workability. Workability depends upon many factors but mainly upon w/c ratio. Higher the w/c ratio, higher is the workability and vice-versa but at the same time when workability is high, strength may be lower because of the presence of excess water. So, water quantity in mortar/concrete should be optimum.

Preparation:

This test is performed as per **IS 4031:1998** in which make mortar of cement and sand in proportion 1:3 and w/c ratio is kept 0.5 and also make mortars with different replacement percentages of wood ash.

Testing:

Put the uniformly mixed mortar in mould in two layers of 25mm each and temped by temping rod for 20 times. Mould has 70mm diameter at top, 80mm diameter at bottom and 50mm height. Temping pressure should be sufficient to ensure uniform filling of mould without any space. Wipe of the excess mortar and turn on the flow table after one minute. Give 25 blows in 15 seconds. After every blow, mortar spreads as shown in fig, note down the base diameter of spread mortar after 25 blows. Fig 3.5 shows the arrangement of flow table and spread in mortar after 25 blows.

Fig 3. 5:Flow Table and Flow (Spread) in Mortar on Flow Table

Measure the base diameter at approximately four equidistant intervals and flow is the average of these four flow values expressed as increase in percentage with respect to original base diameter.

3.4.2 POROSITY:

Porosity is defined as the ratio of volume of voids present in any mortar specimen to the total volume of that specimen expressed as a percentage. Porosity is simply a ratio of volume of voids accessible to water, to the bulk volume of specimen.

Porosity is a fundamental property of mortar/concrete/stone which influence the durability properties. Fig 3.6 shows the pores present in hardened mortar.

Fig 3. 6:Voids Present in Mortar Sample

Preparation:

To perform this test, we made prisms of size **40mm*40mm*160mm** as per **RILEM 1980** three for each replacement percentage (0, 5, 7.5, 10%). Take material in already given proportion as the cement and sand ratio is 1:3 and water/cement ratio is 0.50 and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 28 days.

Testing:

The prisms were dried at a temperature of 60 ± 5^{0}C till constant mass is attained. The constant mass is reached when the difference between two consecutive weighing is very very negligible. Drying was done at lower temperature instead of higher temperature so that organic matter in mortar, if present, should not be decomposed and so that structural water should not be destroyed.

After drying to constant mass (M1), samples were put into evacuation vessel for 24 hours in order to eliminate the air present in voids of the sample. Fig 3.7 shows evacuation vessel or called as vacuum desiccator.

Fig 3. 7:Evacuation Vessel

Now, samples were put into water for another 24 hours at atmospheric pressure. Then, these samples weighed separately in water (M2). This is called hydrostatic weighing as shown in fig 3.8.

Fig 3. 8:Hydrostatic Weighing

Now, took the samples out of water and wiped with a cotton cloth to wipe extra water drops and saturated weight was taken of samples (M3).

Calculation:

Porosity, accessible to water, is expressed as a percentage and is calculated by the following formula:

$$\textbf{Porosity (\%)} = ((M3-M1)/(M3-M2))*100$$

where,

M1 = constant mass of sample, in grams

M2 = hydrostatic weighing (weighing in water), in grams

M3 = weight of saturated sample, in grams

3.4.3 BULK DENSITY:

Bulk density or apparent density is defined as the ratio of mass of the sample to the total volume of the sample. It is expressed in kg/m^3.

Preparation:

To perform this test, we made prisms of size **40mm*40mm*160mm** as per **RILEM 1980** three for each replacement percentage (0, 5, 7.5, 10%). Take material in already given proportion as the cement and sand ratio is 1:3 and water/cement ratio is 0.50 and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 28 days.

Testing:

The prisms were dried at a temperature of 60 ± 5^0C till constant mass is attained. The constant mass is reached when the difference between two consecutive weighing is very negligible. Drying was done at lower temperature instead of higher temperature so that organic matter in mortar, if present, should not be decomposed and so that structural water should not be destroyed.

After drying to constant mass (M1), samples were put into evacuation vessel for 24 hours in order to eliminate the air present in voids of the sample. Fig 3.9 shows evacuation vessel or called as vacuum desiccator.

Fig 3. 9:Evacuation Vessel

Now, samples were put into water for another 24 hours at atmospheric pressure. Then, these samples weighed separately in water (M2). This is called hydrostatic weighing. Now, took the samples out of water and wiped with a cotton cloth to wipe extra water drops and saturated weight was taken of samples (M3).

Calculations:

Bulk density is the ratio of mass of dry sample to the bulk volume of sample, which is calculated by the following formula:

$$\textbf{Bulk Density (kg/m}^3\textbf{) = (M1/(M3-M2))*1000}$$

where,

M1 = constant mass of sample, in grams

M2 = hydrostatic weighing (weighing in water), in grams

M3 = weight of saturated sample, in grams

3.4.4 WATER ABSORPTION CAPACITY:

Water is absorbed by the hardened mortar by the capillary action when hardened mortar is placed in any water body or near any water body. Water absorption is due to pores present in it which act as a capillary tube. Water rises in the tube (pores connected to each other) due to capillarity.

Preparation:

To perform this test, we made prisms of size **40mm*40mm*160mm** as per **BS EN 1015:1999 Part-18,** three for each replacement percentage (0, 5, 7.5, 10%). Take material in already given proportion as the cement and sand ratio is 1:3 and water/cement ratio is 0.50 and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 28 days.

Testing:

The prisms were dried at a temperature of 60 ± 5^{0}C till constant mass is attained. The constant mass is reached when the difference between two consecutive weighing is very very negligible. Drying was done at lower temperature instead of higher temperature so that organic matter in mortar, if present, should not be decomposed and so that structural water should not be destroyed.

After drying to constant mass, samples are coated with wax/epoxy on all four faces lengthwise as shown in fig 3.10 so that epavoration from sides does not take place.

Fig 3. 10:Prisms with Epoxy Coating

Now, cut these samples into two halves (i.e., 80mm) and place the samples into tray as shown in fig 3.11 with cutting edge downwards in water. Put water upto 5 to 10mm depth into the tray to allow capillarity in samples.

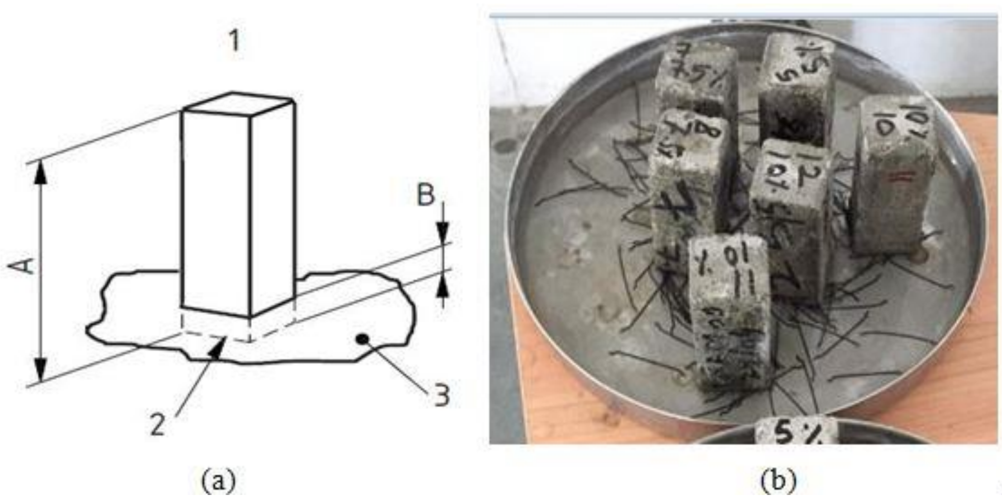

Fig 3. 11:Immersion of Samples into Water Tray

Remove the samples after 10 minutes to get readings. Weigh individually the specimen and note down as M1. Now, take the readings after 90 minutes and note these as M2.

3.5 STRENGTH PROPERTIES OF MORTAR CONTAINING WOOD ASH

In this section, we deal with the strength properties (compressive and flexural properties) of mortar after 7 days and 28 days of curing.

3.5.1 COMPRESSIVE STRENGTH:

Compressive strength is defined as the resistance of mortar breaking under compressive load. It is the capacity of mortar to withstand under compressive load which break the specimen or fracture occurs in specimen. Here, compressive load is applied by Universal Testing Machine or by Compression Testing Machine.

Preparation:

To perform compressive strength test, we used two broken pieces (two halves) of flexural strength test (as mentioned in **BS EN 1015-11:1999**). When load was applied on prisms in flexure test, these prisms broke into two halves. These two halves were used for compression test. Two bearing plates of steel of size **40mm*40mm*10mm** are used to apply load on broken pieces.

Testing:

Test the samples at 7 days and 28 days after regular curing**. Universal Testing Machine (UTM)/ Compression Testing Machine (CTM)** of capacity 3000kN are used to test the compressive strength. Prisms, to be tested, were placed on UTM/CTM as shown in fig 3.12. Bearing plates were applied, one above the prism and the other one below the prism, to uniformly distribute the load and to apply load on specified area (40mm*40mm). Fig 3.12 shows the different arrangements of placing the sample between plates.

(a) (b)

Fig 3. 12:Different Arrangements of Bearing Plates on UTM

The loading rate should be uniform (without shock) at a rate of **10N/sec to 50N/sec** so that failure can occur within a period of 30 sec to 90 sec.

Calculate the compressive strength as the maximum/peak load carried by the specimen divided by its cross-sectional area (area of bearing plates). Record the strength of each specimen individually.

Calculations:

UTM/CTM gives us peak load (in kN) value. We have to find out compressive strength/compressive stress (in N/mm^2). To get compressive strength of broken halves (obtained from flexural strength test), we use following formula:

Compressive Strength = Peak load/ area of bearing plates

where,

Area of bearing plates = 40mm*40mm = 1600mm^2

To get compressive strength of cubes, we use following formula:

Compressive Strength = Peak load/ area of cube

where,

Area of cube = 50mm*50mm = 2500mm^2

3.5.2 FLEXURAL STRENGTH:

Flexural strength, also known as bending strength, is a property of a material, which is defined as the stress experienced by a material just before it yields in flexure.

Preparation:

To perform this test, we made prisms of size **40mm*40mm*160mm** as per **BS EN 1015:1999 Part-11** three for each replacement percentage (0, 5, 7.5, 10%). Mould of prisms is shown in fig 3.13. Take material in already given proportion (the cement and sand ratio is 1:3 and water/cement ratio is 0.50) and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 7 days and at 28 days.

Fig 3. 13:Moulds for Prisms of Size 40mm*40mm*160mm.

Curing is done for 7 days and for 28 days in curing tank to complete hydration reaction of cement. Samples in curing tank are shown in fig 3.14.

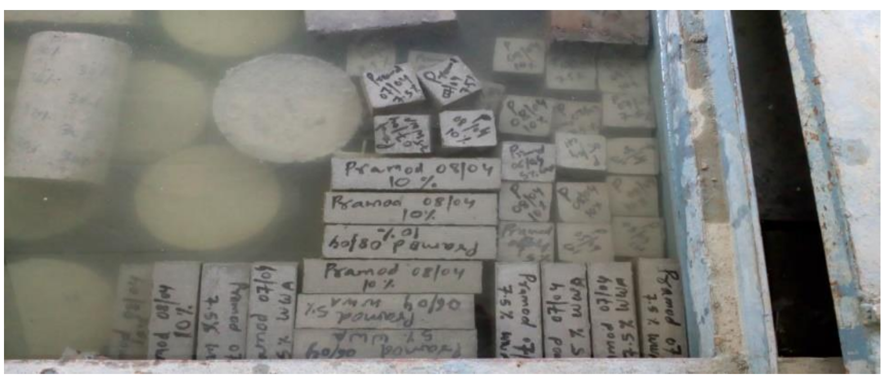

Fig 3. 14:Curing of Prisms

Testing:

Universal Testing Machine (UTM) is used to test the flexural strength. As per codal provisions, prisms, to be tested, were placed on mould as shown in fig 3.15.and as in actual condition, prisms, to be tested, were placed on mould as shown in fig 3.16.

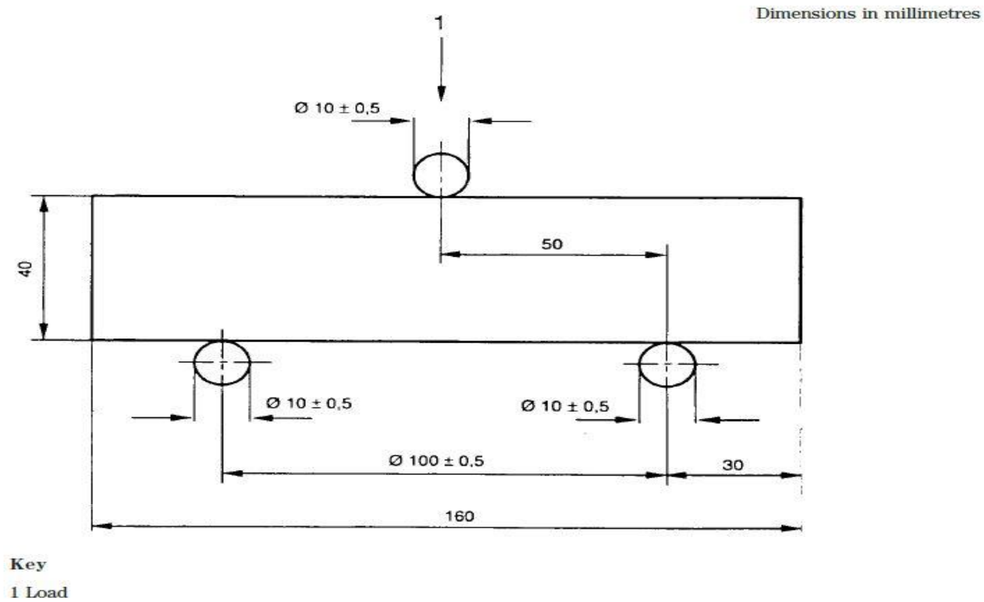

Fig 3. 15:Flexural Strength Test Arrangement (acc. to BS EN 1015-11)

Fig 3. 16:Flexural Strength Test Arrangement (actual)

Three point loading is applied to the prisms. The loading rate should be uniform (without shock) at a rate of **0.05mm/min (displacement control)**. In actual, overhang portion is of 20mm on both sides and distance between two supports is 120mm. Load is applied from middle of the beam (80mm from either side). A **Dial Gauge** or **LVDT** (linear variable differential transformer) was used to measure linear displacement or deflection of beam at the bottom of the beam in middle portion. With the help of this deflection, we made load versus deflection graphs. Fig 3.17 shows the arrangement of dial gauge and failure of beam on application of load.

(a) (b)

Fig 3. 17: (a) Loading Arrangement of Flexure Test with Dial Gauge (b) Flexure Failure in Beam

UTM automatically record the maximum load (in kN) at which beam fails or cracks occur.

3.6 DURABILITY PROPERTIES OF MORTAR CONTAINING WOOD ASH

In this section, we deal with the experimental procedure of durability properties such as thermal cycling, salt crystallization, rapid chloride permeability test etc, of mortar at different replacement of cement by wood ash after 28 days of curing.

3.6.1 THERMAL CYCLING:

This test is performed to analyze the impact of heat/sunlight on mortar. By this test, we analyze the performance of mortar when exposed to weathering induced by wet, followed by dry cycle brought by environmental exposure. This test is also done to check the performance of mortar when exposed to fire.

A mortar must withstand disintegration by thermal expansion. Therefore, it is necessary to conduct durability testing that will give an indication of mortar resilience under thermal cycling mechanism.

Preparation:

To perform this test, we made cubes of size **50mm*50mm*50mm** as per **RILEM 1980,** three of each replacement percentage (0, 5, 7.5, 10%). Fig 3.18 shows the mould of 50mm cube.

Fig 3. 18:Moulds of Cubes of Size 50mm*50mm*50mm

Take material in already given proportion (the cement and sand ratio is 1:3 and water/cement ratio is 0.50) and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 28 days. Fig 3.19 shows the casted cubes of 50mm size for thermal cycling.

Fig 3. 19:Cubes Casted for Thermal Cycling Test

Testing:

After curing of 28 days, we immersed mortar specimens into water at a constant temperature 20±0.5^{0}C for a period of 16 hours. The specimens were removed from water and placed in a pre-heated oven at a temperature of **105^{0}C** to dry for 6 hours as shown in figure.

After drying in oven, samples are allowed to cool at room temperature for 2 hours. Fig 3.20 shows the cubes placed in oven and cubes in polybag to protect cubes from moisture when cooling at room temperature.

(a) (b)

Fig 3. 20:(a) Hot Air Oven and (b) Cubes Protected from Humid Atmosphere

When samples are allowed to cool at room temperature, samples were protected from atmosphere so that humidity cannot alter the weight of samples. When samples cooled down, their individual weight was measured accurately with an accuracy of ±0.5 grams. After each cycle, condition of the samples was recorded and results were taken in the form of weight loss (expressed as a percentage of initial dry weight of sample).

The samples were subjected to **20 such cycles**. Repeat the same procedure after every cycle and record the weight loss of the sample. Table shows the chemical composition of mortar containing 10% WWA after 20 cycles of thermal cycling process, obtained from SEM (scanning electron microscopy).

Table 3.6 shows the chemical composition of mortar obtained from SEM (scanning electron microscope) at 10% replacement of wood waste ash after 20 cycles of thermal cycling. Fig 3.21 shows the energy dispersive X-Ray analysis of cement mortar containing wood ash at 10% replacement level treated by thermal cycling.

Table 3. 6:Chemical Composition of Mortar containing 10% WWA Treated with Thermal Cycling

S. No.	Composition	Percentage by weight
1.	CaO	29.18
2.	SiO_2	8.64
3.	Al_2O_3	2.61
4.	Fe_2O_3	1.40
5.	Oxides	50.86
6.	Na_2O	3.20
7.	K_2O (feldspar)	0.46
8.	$CaCO_3$	3.48
9.	Total	100

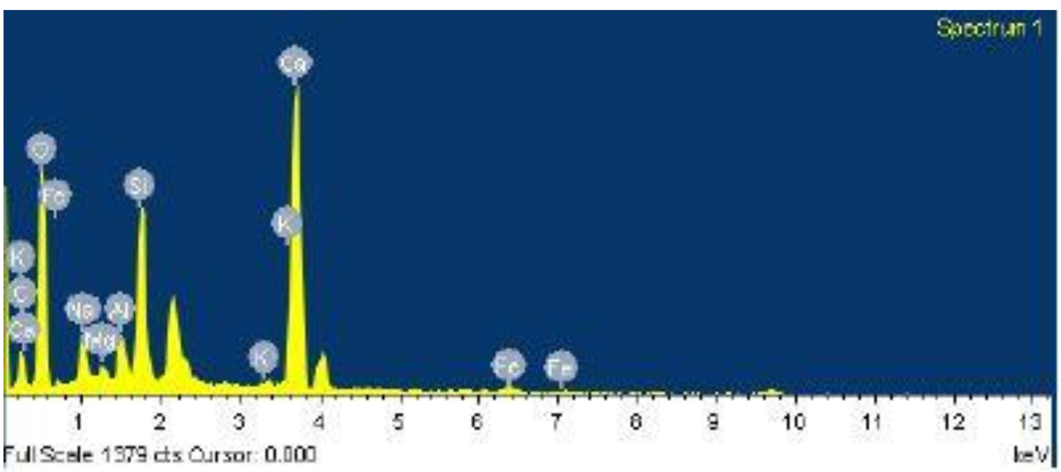

Fig 3. 21:EDX Analysis of Mortar containing 10% WWA Treated by Thermal Cycling.

Fig 3.22 shows the images of scanning electron microscope analysis of mortar containing 10% WWA which is thermally treated.

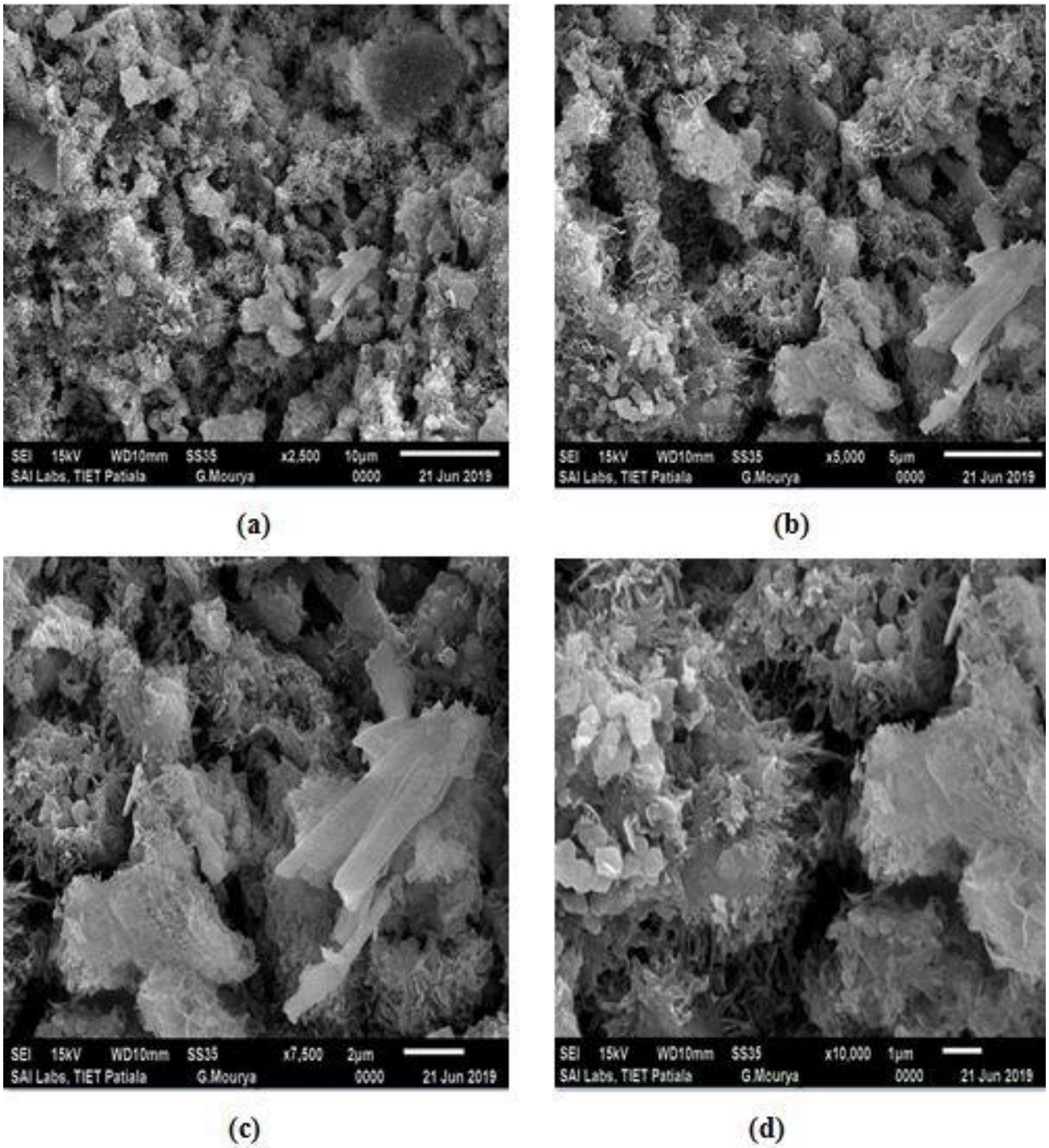

Fig 3. 22:SEM Images of Thermally Treated Mortar containing 10% WWA (a) 2500 times enlarged, (b) 5000 times enlarged, (c) 7500 times enlarged, (d) 10000 times enlarged

3.6.2 SALT CRYSTALLIZATION:

Salt crystallization test is used to determine the resistance of mortar against salt attack. A mortar must withstand disintegration by salt attack. Therefore, it is necessary to conduct durability testing that will give an indication of mortar resilience under salt crystallization mechanism.

Preparation:

To perform this test, we made cubes of size **50mm*50mm*50mm** as per **RILEM 1980,** three of each replacement percentage (0, 5, 7.5, 10%). Fig 3.23 shows the mould of 50mm cube.

Fig 3. 23:Moulds of Cubes of Size 50mm*50mm*50mm

Take material in already given proportion (the cement and sand ratio is 1:3 and water/cement ratio is 0.50) and mixed it by hand or by epicyclic mixture. Prepare three specimens for each replacement percentage for testing at an age of 28 days.

Testing:

After curing of 28 days, samples were put into pre-heated oven at a temperature of **105^0C** to dry for a period of 16 hours and after this, these samples were allowed to cool at room temperature for 5 hours. Temperature should not be greater than **105^0C** because high temperature destroy the structural water.

Fig 3.20 shows the cubes placed in oven and cubes in polybag to protect cubes from moisture when cooling at room temperature. When samples are allowed to cool at room temperature, samples were protected from atmosphere so that humidity cannot alter the weight of samples. When samples cooled down, their individual weight was measured accurately with an accuracy of ±0.5 grams before soaking samples into salt solution.

Now, the samples were immersed in **14% solution of sodium sulphate decahydrate ($Na_2SO_4.10H_2O$)** for a period of 4 hours as shown in fig 3.25.

(a) (b)

Fig 3. 24: (a) Hot Air Oven and (b) Cubes Protected from Humid Atmosphere

Fig 3. 25:Immersion of Samples in 14% Solution of Sodium Sulphate Decahydrate

After each cycle, condition of the samples was recorded and results were taken in the form of weight loss (expressed as a percentage of initial dry weight of sample). The samples were subjected to **20 such cycles**. Repeat the same procedure after every cycle and record the weight loss of the sample.

Preparation of Solution:

In actual, we had a container of 500 grams of sodium sulphate anhydrous (**Na_2SO_4)** instead of sodium sulphate decahydrate as shown in figure 3.26. So, we had to convert sodium sulphate anhydrous into sodium sulphate decahydrate.

As we know, 1000 grams of $Na_2SO_4.10H_2O$ is equivalent to 441 grams of Na_2SO_4. And **14% solution means 14% of $Na_2SO_4.10H_2O$ and 86% of water** in that solution.

So, after calculating, we required 6.965 kg of water and 500 grams of Na_2SO_4 to prepare a 14% solution of $Na_2SO_4.10H_2O$.

Fig 3. 26:Sodium Sulphate (Anhydrous)

Table 3.7 shows the chemical composition of mortar containing 10% WWA after 20 cycles of salt crystallization process obtained from SEM (scanning electron microscopy).

Table 3. 7:Chemical Composition of Mortar containing 10% WWA Treated with Sodium Sulphate

S. No.	Composition	Percentage by weight
1.	CaO	29.18
2.	SiO_2	8.64
3.	Al_2O_3	2.61
4.	Fe_2O_3	1.40
5.	Oxides	50.86
6.	Na_2O	3.20
7.	K_2O (feldspar)	0.46
8.	$CaCO_3$	3.48
9.	Total	100

Fig 3.27 shows the images of scanning electron microscope analysis of mortar containing 10% WWA which is treated by salt solution. Fig 3.28 shows the energy dispersive X-Ray analysis of cement mortar containing wood ash at 10% replacement level treated by salt solution.

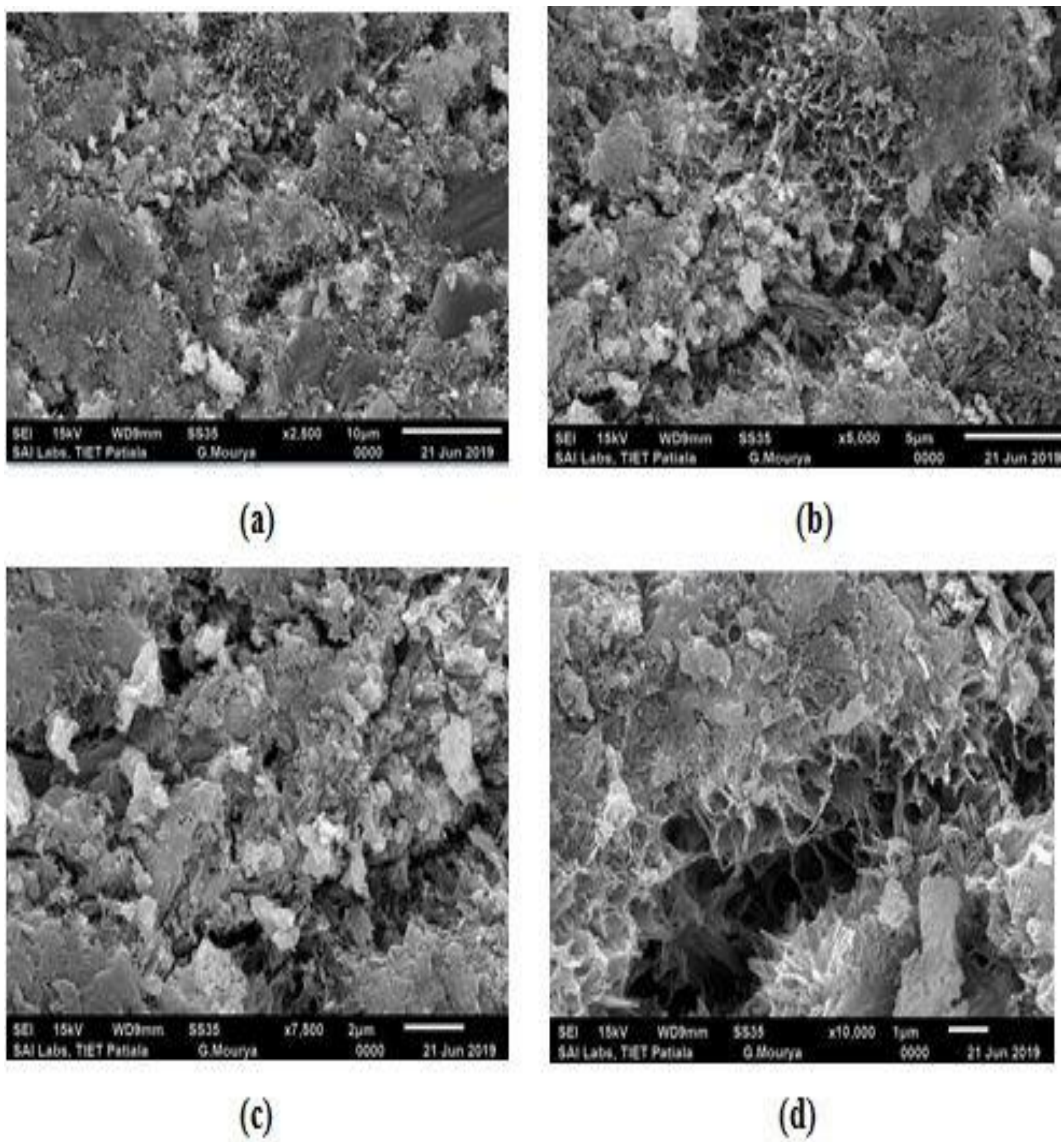

Fig 3. 27:SEM Images of Mortar containing 10% WWA Treated by Sodium Sulphate (a) 2500 times enlarged, (b) 5000 times enlarged, (c) 7500 times enlarged, (d) 10000 times enlarge

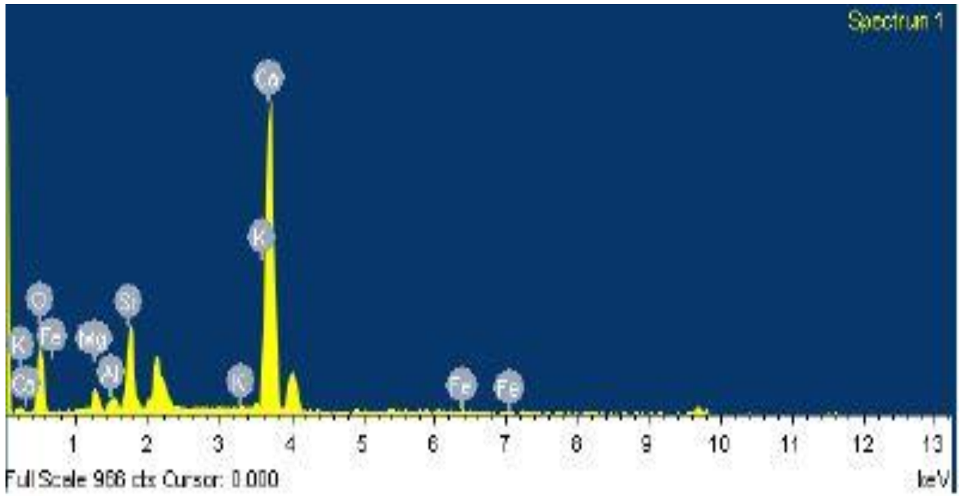

Fig 3. 28:EDX Analysis of Mortar containing 10% WWA Treated by Salt Solution

Fig 3.29 shows the physical appearance of samples treated with salt at different replacements by wood waste ash.

Fig 3. 29:Physical Appearance of Mortar Treated with Sodium Sulphate solution

3.6.3 RAPID CHLORIDE PERMIABILITY TEST:

This test determines the electrical conductance of mortar to provide a rapid indication of its resistance to penetration of chloride ions. Less the ion penetration, less is the permeability, less is the electrical conductance. This test consists of monitoring the amount of electrical current passed through 50mm thick and 100mm in diameter slices of cylinders during a 6h period and a potential difference of 60V is maintained across the ends of specimen, one of which is immersed in sodium hydroxide solution and other is immersed in sodium chloride solution.

Preparation:

To perform this test, we made cylinders of 100mm diameter and 200mm in length as per **ASTM C 1202** for each replacement percentage (0%, 5%, 7.5%, 10%) and cured for 28 days. Cut these cylinders into slices of 100mm diameter and 50mm height. Moulds of cylinder are shown in fig 3.30 and fig 3.31 shows the cut slices of cylinder for use in RCPT test.

Fig 3. 30:Moulds of Cylinder of 100mm dia. and 200mm height

Fig 3. 31:Cylindrical Slices (100mm diameter and 50mm height)

Place these slices in vacuum desiccator for 3 hours as shown in fig 3.32, to evacuate air from very tiny voids. Now, soak these slices in water for 18±2 h. Remove specimen from water and wipe out excess water from surface and place the specimens in **PROOVE'it** cell after applying sealent and rubber gaskets.

(a) (b)

Fig 3. 32:(a) Vacuum Desiccator, (b) Cylinders in Vacuum Desiccator

Fill the **PROOVE'it** cell with solutions as mentioned earlier. Make electrical connections and read out data from monitor attached to setup.

Testing:

The **PROOVE'it** equipment shown in fig 3.33, is designed to perform rapid chloride permeability of mortar ability to resist chlorides ion penetration according to **ASTM C1202-97** or **AASHTO T 277-831**. The **PROOVE'it** software is installed in IBM-compatible PC and test runs after adding required parameters. The specimen is positioned in **PROOVE'it** cell which has small reservoirs for containing solution at each face. One reservoir contains sodium chloride (3.0% NaCl) solution and the other contains solution of sodium hydroxide (0.3% NaOH). Reservoir containing NaCl is connected to negative terminal and reservoir containing NaOH is connected to positive terminal of **PROOVE'it** Microprocessor power supply unit as shown in fig 3.34.

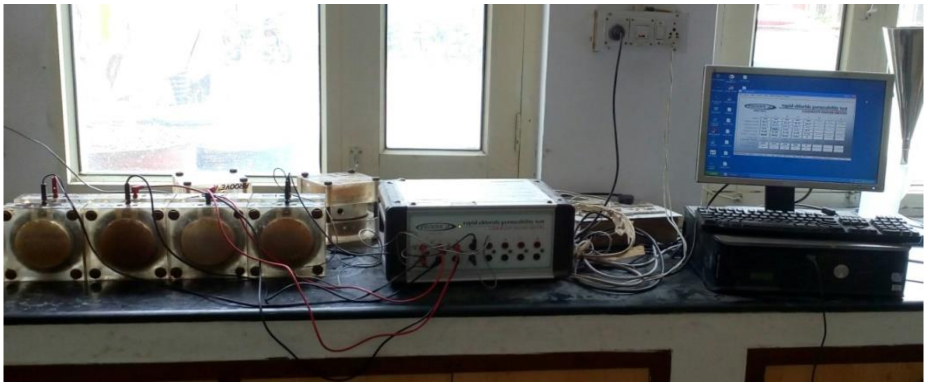

Fig 3. 33:Complete setup of Rapid Chloride Permeability Test

(a) (b)

Fig 3. 34: (a) PROOVE'it Microprocessor Power Supply Unit and (b) PROOVE'it Cell

Factors that affect chloride ion permeability include W/C ratio, type and quantity of cement and replacing material in mortar mixture, specimen age etc.

Total charge passed, in coulombs, is related to resistance of specimen to chloride ion penetration. Indication of ion penetrability based on outcomes is provided in table 3.8.

Table 3. 8:Chloride Ion Penetrability

Charge Passed (coulombs)	**Chloride Ion Penetrability**
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter contains the outcomes of our experimental work. In this chapter, results of all the experiments are mentioned with their explanations and reasons behind the outcomes. This chapter gives the details of variation in results, graphical and tabulated representation of results.

4.1 WORKABILITY

Workability of mortar is directly related to flow table value or simply flow value. To get workability, we note down the spread base diameter of mortar and more the spread mortar more is the workability. Table 4.1 depicts the results of flow value obtained from flow table.

Table 4. 1:Flow Values of Workability

WWA Content (%)	Base Diameter (mm)	Spread Diameter (mm)	Increase in Diameter (%)
0%	80	92	15%
5%	80	88	10%
7.5%	80	86	7.5%
10%	80	85	6.25%

As we increase the percentage of wood ash in mortar, workability decrease because particles of wood ash are finer than cement particles. Therefore, specific surface area of wood ash particles is more than cement particles due to which wood ash absorb more water than cement. To get desired workability for wood ash mortar, we have to add more water in comparison to cement mortar.

4.2 POROSITY TEST

Table 4.2 shows the variation in porosity on varying the content of wood ash in mortar. It is clear from the table that, on increasing replacement level of wood ash, porosity decreases accordingly.

Table 4. 2:Porosity at Different WWA Content

WWA Content	Dry Weight (gm), M1	Submerged Weight (gm), M2	Saturated Weight (gm), M3	Porosity (%)
0%	529.33	321.17	586.67	21.6%
5%	535	312.33	579.67	16.71%
7.5%	547	317.67	586.67	15.69%
10%	560	325.33	602.67	17.28%

Fig 4.1 shows the percentage decrease in porosity with increase in wood ash content.

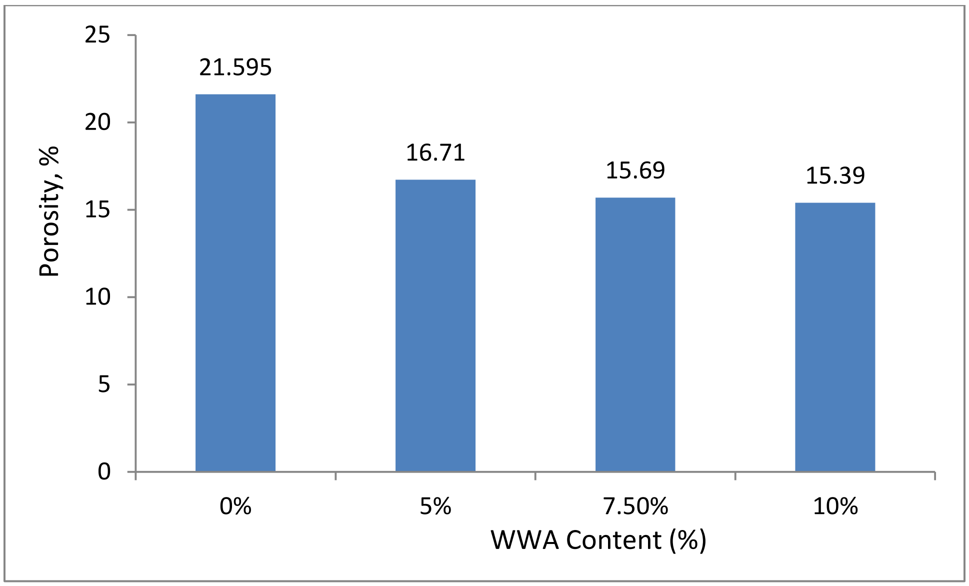

Fig 4. 1:Variation in Porosity with Variation in WWA Content

As we can see from graph and tabulated results, porosity of mortar decreases with increase in percentage of wood ash. The reason behind this is that the particles of wood waste ash are smaller than particles of cement which also acts like a filler material in hardened state. As these particles are smaller than cement particles, they fill the void space between cement and sand particles. As we increase the percentage of wood ash, we get compacted matrix, hence reduction in porosity.

4.3 BULK DENSITY TEST

Bulk density is the weight of hardened mortar in one cubic meter of volume. Table 4.3 depicts the variation in bulk density on varying wood ash content in cement mortar. It is clear from table 4.3 that as we increase percentage of wood ash, bulk density increase. Fig 4.2 shows the trend that how bulk density is increasing on increasing in percentage of wood ash in cement mortar.

Table 4. 3:Bulk Density at Different WWA Content

WWA Content	Dry Weight (gm), M1	Submerged Weight (gm), M2	Saturated Weight (gm), M3	Bulk Density (kg/m^3)
0%	529.33	321.17	586.67	1993.73
5%	535	312.33	579.67	2001.25
7.5%	547	317.67	586.67	2011.03
10%	560	325.33	602.67	2019.23

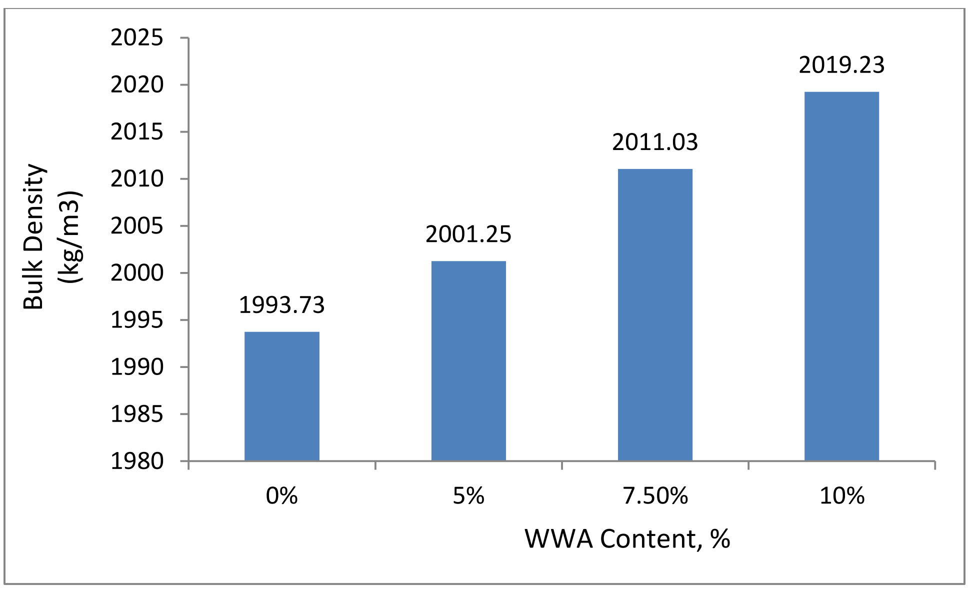

Fig 4. 2:Variation in Bulk Density with Variation in WWA Content

Bulk density is inversely proportional to porosity. When porosity decreases, bulk density increases. As we can see from graph and tabulated results, bulk density of mortar increases with increase in percentage of wood ash. The reason behind this is that the particles of wood waste ash are finer than particles of cement which also acts like a filler material in hardened state. As these particles are smaller than cement particles, they fill the void space between cement and sand particles. As we increase the percentage of wood ash, we get compacted matrix of higher density.

4.4 WATER ABSORPTION CAPACITY

Water absorption capacity is measured by calculating water absorption coefficient and for all replacement levels, water absorption coefficient is depicted in table 4.4.

Table 4. 4:Water Absorption Coefficient of Cement Mortar Containing WWA

WWA Content (%)	Water Absorption Coefficient, C_M [kg/(m^2*min$^{0.5}$)]	Mean of C_M
0%	0.197	0.196
	0.184	
	0.209	
5%	0.172	0.164
	0.160	
	0.162	
7.5%	0.159	0.148
	0.145	
	0.140	
10%	0.147	0.140
	0.139	
	0.135	

Variation in water absorption coefficient, when replacement level of wood ash in cement is increased, is shown in fig 4.3.

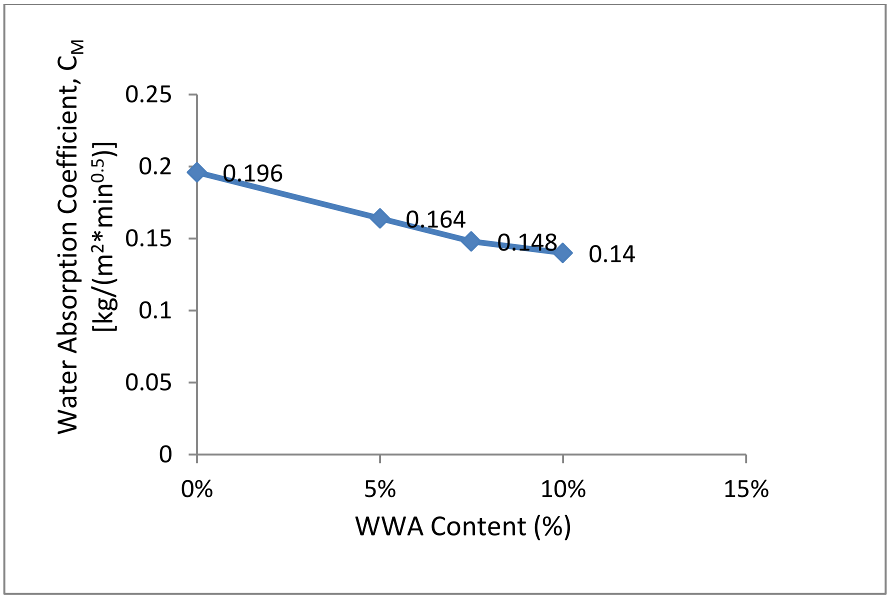

Fig 4. 3:Variation in Water Absorption Coefficient with Different WWA% Levels

Water absorption capacity is inversely proportional to porosity and directly proportional to bulk density. Water absorption capacity of mortar decreases with increase in percentage of wood ash. The reason behind this is that the particles of wood waste ash are finer than particles of cement which also acts like a filler material in hardened state. As these particles are smaller than cement particles, they fill the void space between cement and sand particles. As we increase the percentage of wood ash, we get compacted matrix which reduce water absorption capacity of hardened mortar.

4.5 COMPRESSION TEST

Variation in compressive strength of broken pieces obtained from flexural test, for 7 days and 28 of curing, is shown in table 4.5. UTM gives load value, we have to convert these load values in stress values by dividing load value from area of samples.

Table 4. 5:Compressive Strength of Mortar with WWA (Broken Halves)

WWA Content (%)	7 days strength (N/mm^2)	28 days strength (N/mm^2)
0%	24.07	28.13
5%	20.81	24.23
7.5%	18.63	22.37
10%	17.28	20.67

Fig 4.4 shows how the strength values differ with each other at 7 days curing period and at 28 days curing period at different replacement levels.

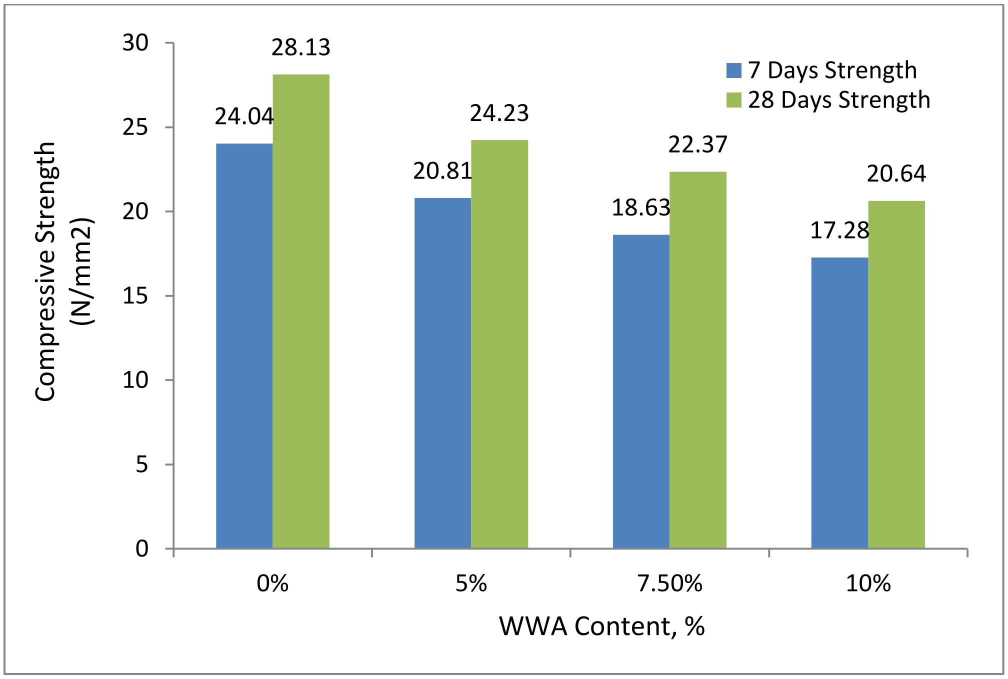

Fig 4. 4:Variation in Compressive Strength with Variation in WWA Content at 7 Days and at 28 Days (Broken Halves)

Table 4.6 shows the compressive strength of cubes of 50mm size with different replacement levels of wood ash in cement mortar.

Table 4. 6:Compressive Strength of Mortar with WWA (Cubes)

WWA Content (%)	28 days strength (N/mm^2)
0%	19.9
5%	18.1
7.5%	17.56
10%	16

The graph of decrease in compressive strength with increase in percentage of wood ash in mortar is shown in fig 4.5.

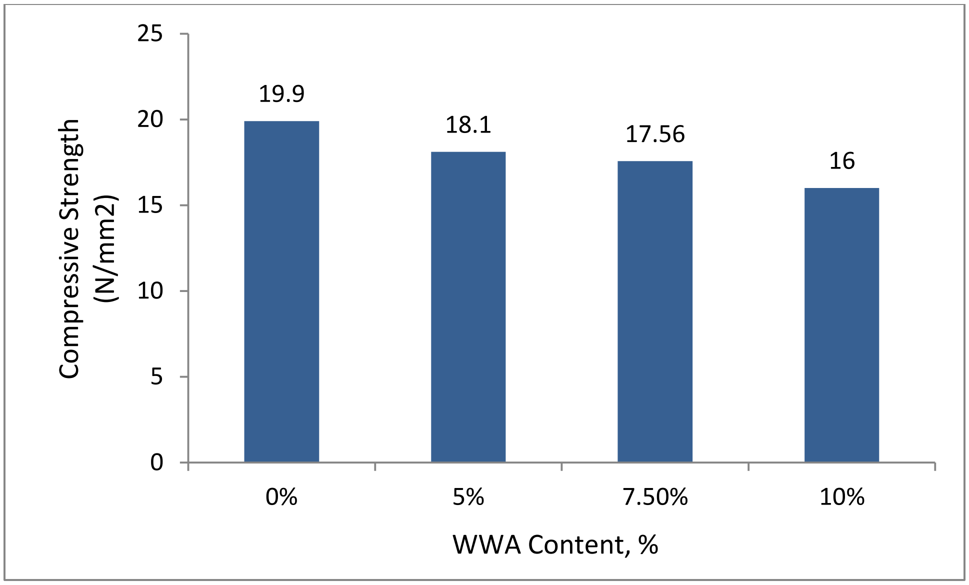

Fig 4. 5:Variation in Compressive Strength of Cubes with Variation in WWA Content at 28 Days

Main components of cement are C_3S, C_2S, C_3A and C_4AF. During hydration process, C_3S and C_2S react with water to form calcium silicate hydrate (C-S-H) gel. C-S-H gel is important for good binding properties in mortar/concrete. If silica content is more, more is the formation of C-S-H gel and more is the strength. But, from chemical composition of wood ash, silica is present in negligible amount which reduce the formation of C-S-H gel, hence reduction in compressive strength.

4.6 FLEXURAL TEST

Flexural strength of mortar with different replacements of wood ash at 7 days and at 28 days are shown in table 4.7.

Table 4. 7:Flexural Strength of Mortar with WWA

WWA Content (%)	7 days strength (N/mm^2)	28 days strength (N/mm^2)
0%	6.6	7.097
5%	6.26	6.61
7.5%	6.07	6.2
10%	5.09	5.82

Difference in values of flexural strength at 7 days and 28 days of testing with different wood ash content in mortar is shown in fig4.6.

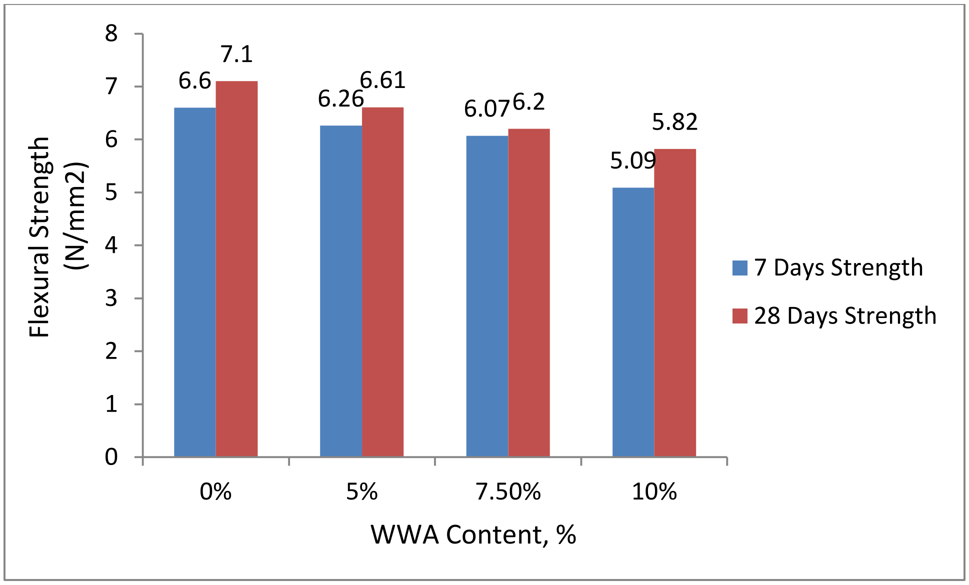

Fig 4. 6:Variation in Flexural Strength with Variation in WWA at 7 and 28 Days

Fig 4.7 shows the load versus deflection graph at different wood ash content. Load readings are taken from UTM and deflection readings are taken from dial gauge.

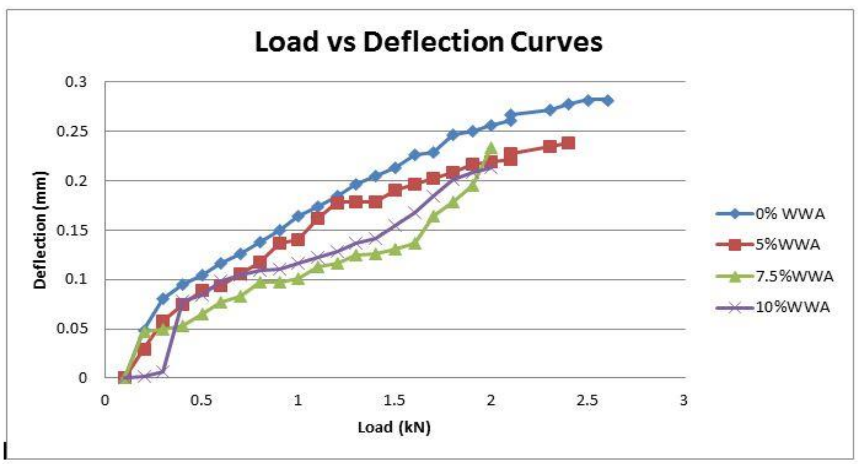

Fig 4. 7:Load versus Deflection Curves with Different WWA Content

Main components of cement are C_3S, C_2S, C_3A and C_4AF. During hydration process, C_3S and C_2S react with water to form calcium silicate hydrate (C-S-H) gel. C-S-H gel is important for good binding properties in mortar/concrete. If silica content is more, more is the formation of C-S-H gel and more is the strength. But, in case of wood ash, silica is present in negligible amount which reduce the formation of C-S-H gel, hence reduction in flexural strength.

4.7 <u>THERMAL CYCLING TEST</u>

Results are taken in the form of weight loss after every cycle expressed as a percentage of initial dry weight of specimens and results are also taken in the form of residual compressive strength of specimen as compared to those specimens which are not exposed to thermal cycling. Table shows the residual compressive stress in samples which are exposed to thermal cycling. Comparison in compressive strength values before and after thermal cycling is shown in fig 4.8.

Table 4. 8:Residual Compressive Strength in Samples exposed to Thermal Cycling

WWA Content, %	Residual Compressive Strength (N/mm^2)		Reduction (in comparison to normal sample)
	Normal Samples	Exposed to Thermal Cycling	
0%	19.9	18.80	5.53%
5%	18.1	17.34	4.19%
7.5%	17.56	17.29	1.54%
10%	16	15.78	1.38%

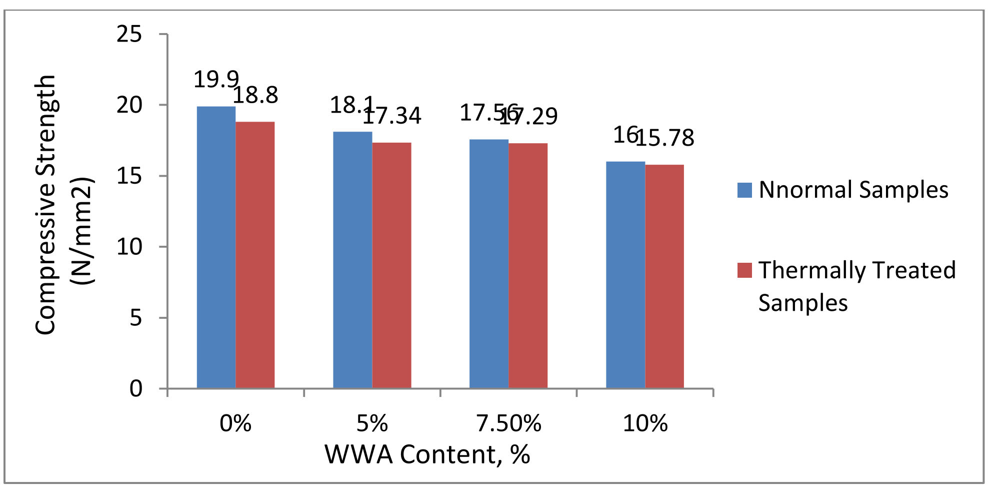

Fig 4. 8:Compressive Strength values before and after Thermal Cycling

Loss in weight of samples (expressed as a percentage with respect to initial dry weight) after 20 thermal cycles is shown in table 4.9.

Table 4. 9:Reduction in Weight after Thermal Cycles

WWA Content, %	Dry Weight (in gm)		Percentage Reduction in Weight
	Initial	After 20 Cycles	
0%	290.67	281.33	3.21%
5%	294.67	287	2.603%
7.5%	298	292.67	1.8%
10%	304.33	299.67	1.53%

As we increase the temperature upto 150^{o}C, dehydration of C-S-H gel is started which results in the decrease of strength properties of mortar as well as concrete. During hydration process, C_3S and C_2S react with water to form calcium silicate hydrate (C-S-H) gel. C-S-H gel is important for good binding properties in mortar/concrete. If silica content is more, more is the formation of C-S-H gel and more is the strength. But, in case of wood ash, silica is present in negligible amount which reduce the formation of C-S-H gel. And as we increase the temperature, water present in the pores of mortar starts evaporating, cause shrinkage cracks in samples. After every cycle, we allow to cool down the samples at room temperature, due to sudden change in temperature, expansion cracks occur in the samples. Due to these alternating cycles, scaling of specimen occurs which cause loss in weight.

4.8 SALT CRYTALLIZATION TEST

Results are taken in the form of weight loss after every cycle expressed as a percentage of initial dry weight of specimens and results are also taken in the form of residual compressive strength of specimen as compared to those specimens which are not exposed to salt attack or salt crystallization. Table 4.10 shows the residual compressive stress in samples which are exposed to salt attack. Reduction in compressive strength of samples (treated with sodium sulphate solution), in comparison of samples which are not treated by solution, is shown in fig 4.9.

Table 4. 10: Residual Compressive Strength in Samples exposed to Salt Attack

WWA Content, %	Compressive Strength (N/mm^2)		Reduction (in comparison to normal sample)
	Normal Samples	Exposed to Salt Attack	
0%	19.9	18.2	8.54%
5%	18.1	16.5	8.90%
7.5%	17.56	15.89	9.51%
10%	16	14.33	10.44%

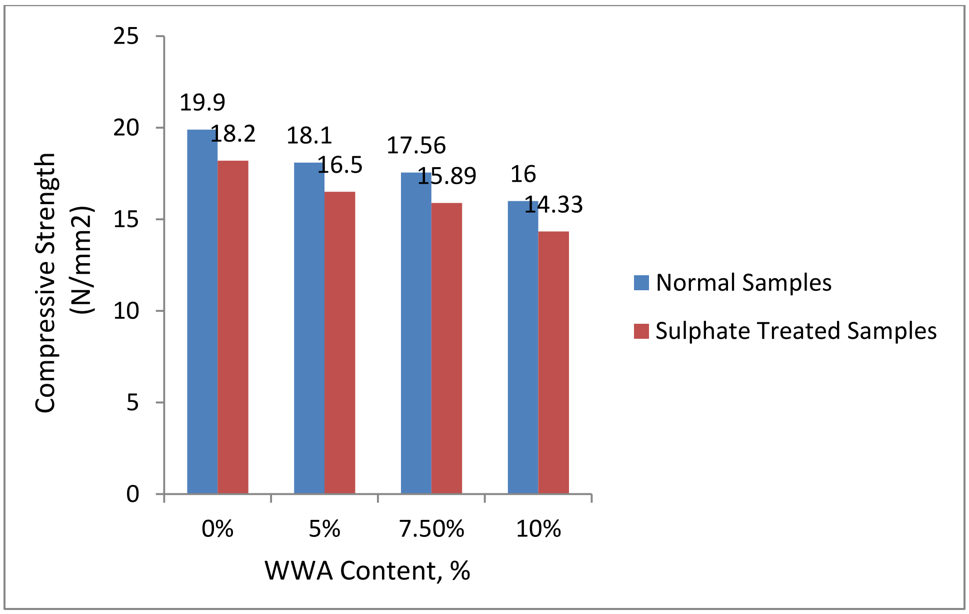

Fig 4. 9:Variation in Compressive Strength of normal samples and Sulphate Treated Samples

Loss in weight of samples (expressed as a percentage with respect to initial dry weight) after 20 salt crystallization cycles is shown in table 4.11.

Table 4. 11:Reduction in Weight after Salt Crystallization Cycles

WWA Content, %	Dry Weight (in gm.)		Percentage Reduction in Weight
	Initial	After 20 Cycles	
0%	292.67	287.33	1.83%

5%	295.33	287.67	2.59%
7.5%	297.67	289	2.91%
10%	302.33	291.67	3.63%

During hydration process, C_3S and C_2S react with water to form calcium silicate hydrate (C-S-H) gel along with calcium hydroxide [$Ca(OH_2)$]. This calcium hydroxide reacts with sodium sulphate to form calcium sulphate which further react with C_3A and cause deterioration of mortar/concrete. As wood ash contains more amount of calcium oxides which are soluble in water and leached out and further react with sodium sulphate. That is why, on increasing the percentage of wood ash, loss in weight as well as loss in compressive strength.

As we increase the temperature upto 150^0C, dehydration of C-S-H gel is started which results in the decrease of strength properties of mortar as well as concrete. And as we increase the temperature, water present in the pores of mortar starts evaporating, cause shrinkage cracks in samples. After every cycle, we allow to cool down the samples at room temperature, due to sudden change in temperature, expansion cracks occur in the samples. Due to these alternating cycles, scaling of specimen occurs which cause loss in weight.

4.9 <u>RCPT TEST</u>

Results of rapid chloride permeability test in the form of charge passed in coulombs after 6 hours is shown in table 4.12.

Table 4. 12:Results of RCPT

Cylindrical Slices	**Charge Passed (coulombs)**	**Chloride Ion Penetrability**
0% WWA	7297	High
5% WWA	7137	High
7.5% WWA	6886	High
10% WWA	6386	High

Outcome given by software of RCPT is depicted in fig 4.10.

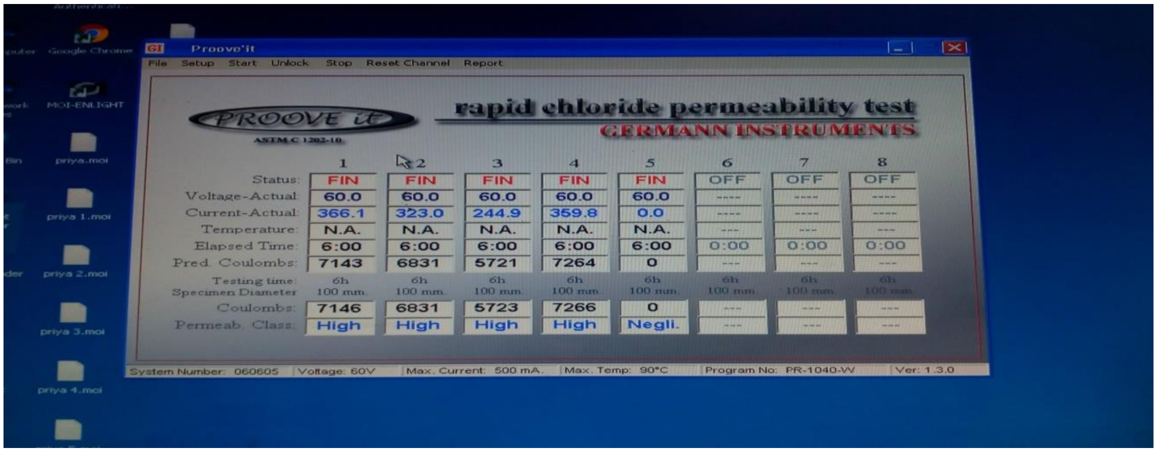

Fig 4. 10:Results of RCPT

As we can see from table and figure that chloride ion permeability is high in all the cases but as we increase the percentage of wood ash, chloride ion permeability decreases. Fig 4.11 shows the trend line of decreasing chloride ion permeability on increasing percentage of wood ash in cement mortar.

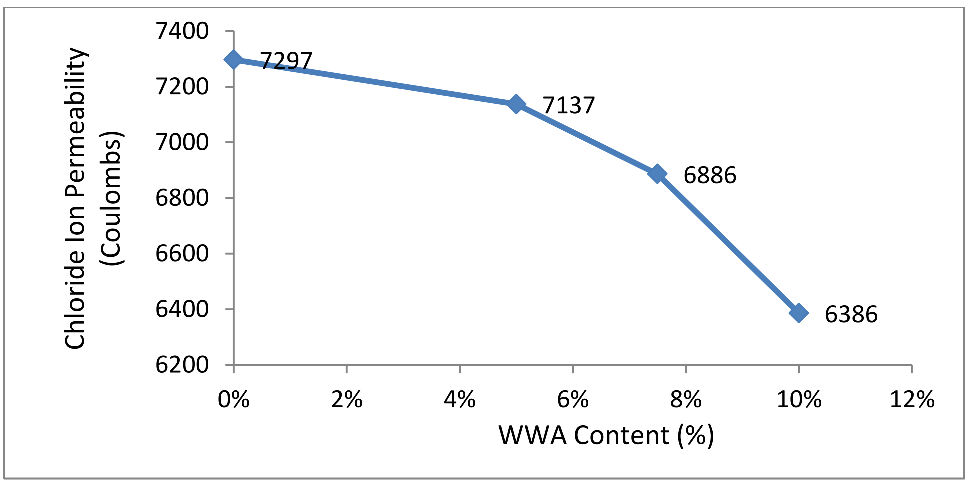

Fig 4. 11:Variation in Chloride Permeability with Increase in WWA Content

As discussed earlier, on increasing replacement of cement by wood ash, porosity decreases because particles of wood ash are finer than particles of cement. And permeability is directly proportional to porosity. If porosity decreases, permeability decreases. So, passage of charge is also less.

CHAPTER 5: CONCLUSIONS

In the research work, experiments are done to check the performance and behavior of wood waste ash in cement mortar by varying replacement percentages. This attempt is done to check that either we can partially replace the cement by wood waste ash or not so that we can make construction economical and ecofriendly because lot of carbon dioxide is released in atmosphere in production of cement. So, for this purpose, we performed some experiments such as workability test, compression and flexure test, RCPT, thermal cycling and salt crystallization etc. From the outcomes of these tests, we conclude that

(1) Workability decreases with increase in replacement percentage of wood ash.

(2) Porosity also decreases with increase in replacement percentage of wood ash. Porosity at 0% replacement level is 21.6% and at 10% replacement level is 17.28%. There is a reduction of 4.32% in porosity at 10% replacement as compared to 0% replacement.

(3) Bulk density increases from 1993.73 kg/m^3 at 0% wood ash to 2019.23 kg/m^3 at 10% wood ash level. This increase is due to decrease in porosity.

(4) As porosity decreases, water absorption capacity also decreases because they are directly related to each other. Water absorption coefficient at 0% wood ash is 0.196 $kg/(m^2*min^{0.5})$, at 5% wood ash is 0.164 $kg/(m^2*min^{0.5})$, at 7.5% wood ash is 0.148 $kg/(m^2*min^{0.5})$ and at 10% wood ash is 0.140 $kg/(m^2*min^{0.5})$.

(5) Compressive strength of 40mm cubes at 0% replacement of WWA is 24.07 N/mm^2 at 7days of curing and 28.13 N/mm^2 at 28 days of curing while at 10% replacement of WWA, the compressive strength is 17.28 N/mm^2 at 7 days of curing and 20.67 at 28 days of curing. It is clear from results that at replacement of 10%, compressive strength decreased by 26.52% in comparison to control mortar.

(6) Flexural strength results show that there is a significant decrease in flexural strength at upto 10% replacement level of wood ash. At 0% replacement of cement by WWA, the flexural strength is 7.1 N/mm^2 and at 10% replacement, strength is 5.82 N/mm^2.

(7) On treating with thermal cycling and salt attack, there is a decrease in weight of samples as well as well as decrease in compressive strength as compare to untreated samples.

(8) From the test results, it is clear that chloride ion permeability is high for all replacement percentages. But it is also concluded that chloride permeability decrease with increase in percentage of wood ash. Chloride ion permeability at 5% replacement is 1.37% of control mix and at 7.5% replacement, it is 5.63% of control mix while at 10% replacement level, it is about 13.86% of control mix.

From these outcomes, it is clear that wood waste ash cannot be used as cement replacing material as it decreases the compressive strength, flexural strength, less resistant to salt attack. It can be used as an additive by keeping constant amount of cement because it decrease porosity, decrease water absorption capacity, decrease permeability.

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