AN EXPERIMENTAL STUDY ON POTENTIAL OF MAGNESIUM OXYCHLORIDE CEMENT WITH BAGASSE AS AN ADDITIVE

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TO

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CERTIFICATE

This is to certify that the work which is being presented in the project title **"An Experimental Study on potential of magnesium oxychloride cement with bagasse as an additive"** in partial fulfillment of the requirements for the award of the degree of Master of technology in Civil Engineering with specialization in **"Structural Engineering"** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Pawan Gupta (152656)** during a period from July 2016 to May 2017 under the supervision of **Mr. Saurav**, Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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Date: Signature:

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ABSTRACT

The several researches have done to produce an ecofriendly binding material as in the production of the OPC large amount of the carbon dioxide is produced. The different types of the environmental friendly cementitious material have been developed, MOC is one of them. This cement develops high strength without heat and the pressure treatment. The bonding of MOC can be achieved at lower temperature. Due to the energy saving and the environmental protection properties it draws the MOC draws the more research interest. MOC is mainly used for the non-structural elements and is used as a repairing material in civil engineering.

The Magnesium oxychloride cement is of high interest as it is having good abrasion resistance and strength as compared to the other cements. The method of production of the MOC is more sustainable, green and healthy as compared to the production of the traditional OPC. The production process of the MOC saves a lot of energy and does not emit carbon dioxide.

My research deals with the parametric study of the formulation of the MOC and use MOC as an alternative of the traditional OPC and maintaining the minimum performance level. The influence of the inert filler i.e. bagasse on the properties of the MOC like standard consistency, setting time, compressive strength and moisture ingress has been investigated. The standard consistency, compressive strength, moisture ingress and soundness get reduced but the setting time increases on increasing the amount of inert filler. The most important parameter to be selected in the design process is to decide the molar ratio of the $MgO/MgCl_2$ and the reactivity of the MgO powder.

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LIST OF ACRONYMS

1.	MOC	Magnesium Oxychloride Cement
2.	OPC	Ordinary Portland Cement
3.	MgO	Magnesium Oxide
4.	$MgCl_2$	Magnesium Chloride
5.	H_2O	Water
6.	GFMOC	Granite fragment magnesium oxychloride cement
7.	GS	Granite Sludge
8.	XRD	X-Ray diffraction
9.	XRF	X-Ray fluorescence
10.	IST	Initial Setting Time
11.	FST	Final Setting Time

CHAPTER 1

INTRODUCTION

1.1 General

This study deals with the use of Magnesium Oxychloride Cement as an alternative of the traditional Ordinary Portland Cement and maintaining the minimum performance level. The certain properties of the MOC are superior to that of OPC. MOC is also known as the Sorel Cement as it was invented by Sorrel in 1876 [1]. MOC is of more interest over OPC due to its environmental friendly and relative less energy consumption nature. The early strength attained by MOC is more as compared to the OPC. The MOC hardens quickly due to which it can be used effectively used for the immediate repair works [2]. The abrasion resistance and strength of MOC is high as compared to other cementitious material. MOC has adorable appearance so it can be used for the interior plaster work or for making the decorative panels [10]. The bagasse is incorporated into MOC so that the waste by product of sugar industry can be effectively utilized and an environmental friendly binding material can be produced. The pH of MOC ranges from 8.5-9.5 which is lower as compared to that of OPC, so it be used along with the glass fiber by omitting aging problems [10].The process of production of MOC is more sustainable, green and healthy as compared to the production of the traditional OPC.

The following are the properties of MOC that are superior to that of OPC:-

1. Early high strength: The MOC has a good early strength. The 1 day strength can reach to 80% of ultimate strength.
2. Light weight: The density of the MOC lies between 1600-1800 kg/m^3.
3. Less alkaline: The pH value of the MOC is about 8.5-9.5.
4. Proper adhesion: The intermolecular sticking property of the MOC is high.
5. High fire resistance: MOC has a fire resistance up to 2800°C.
6. Low thermal conductivity: The thermal conductivity of the MOC is good.

MOC does not require wet curing [8]. It has good load carrying capacity and can withstand vibrations without crack. MOC is degraded by excessive exposure to moisture especially at high temperatures.

MOC has many superior properties but its poor water resistance has restricted its outdoor applications [6]. Only few researches have been done on MOC worldwide. No research work is done on MOC for its application in roads and bridges. Therefore, there is a need to explore more through experimental work for developing standards for the use of MOC so that the properties of this cement can be effectively utilized in construction practices. The present study aims at exploring the potential and the scope of this cement in concrete works.

The various MOC specimens were prepared in the laboratory by mixing the light calcined magnesite and magnesium chloride of different concentrations. The MOC samples were now prepared by the partial replacement of MOC with bagasse by 5, 10 and 15 % by weight of MgO.

The consistency and the setting time of these MOC samples were determined. The compressive strength of the pure MOC samples and those with the partial replacement were calculated. Tests were performed to find the mechanical and durability characteristics. The results of the investigation have been presented and discussed in this report. From the results obtained from these investigations the relationships were developed and the best mix composition can be chosen for the high compressive strength of the MOC.

The hardening and setting of MOC takes place due to the chemical reaction. The primary response stages that happens in the arrangement of magnesium oxychloride bond are:- $9Mg(OH)_2.MgCl_2.5H_2O$ (phase 9); $5Mg(OH)_2.MgCl_2.8H_2O$ (phase 5); $2Mg(OH)_2.MgCl_2.4H_2O$ (phase 2) and $3Mg(OH)_2.MgCl_2.8H_2O$ (phase 3) [7]. The phase 3 and phase 5 are the only phases that remain stable in the room temperature. The high strength of this cement is due to the formation of phase 5. For the formation of phase 5 the water and magnesium oxide should be present in excess [3].

MOC has fine engineering properties but it has poor water resistance [8]. The strength of MOC is considerably decreased when it is exposed to the water which has limited its application in the construction practices. The various experiments have been carried so as to improve the water resistance of MOC. The good performance MOC can be obtained by ensuring the minimization of unreacted magnesium chloride cement, the production of phase 5 and have a reasonable workability with an appropriate setting time. The MgO content should be in excess in the ternary system of the MOC i.e. $MgO-MgCl_2-H_2O$ so as to obtain the desired properties [7]. The phase 3 is produced in more quantity if the molar ratio of $MgO/MgCl_2$ is lower than 11 and due to the production of the phase 3 the setting time also increases. The experiments performed suggest that the molar ratio of the $MgO/MgCl_2$ of 13 and $H_2O/MgCl_2$ of 12 is the best combination for the formation of this cement.

1.2 Background

MOC was discovered by a Sweden scientist "Sorrell" in 1876 [1]. But it was not employed for the construction practices till now. The OPC has been used since 20 th century as a main binding material due to which the other cementitious material remain unexplored. With the increase of the environmental awareness there is need of exploring the binding material other than ordinary Portland cement which does not have adverse effect on the environment and at the same time possesses superior properties. The main purpose of this review is to explore the modern use of MgO based cement. There is an ongoing research for alternative to ordinary Portland cement because of its large CO_2 emissions. The magnesium oxychloride cement is of high interest due to low carbon dioxide emissions. The main inspiration for the development and the use of MgO based cement is from an environmental point of view. The lower temperature is required for the production of MgO as compared to the conversion of $CaCO_3$ to Portland cement. The energy saving associated along with the reduced temperature have introduced the use of the MgO based cement as the future of the ecofriendly cement production.

1.3 Purpose

In India, the construction is the second largest economic activity nest to the agriculture. Construction plays an important role in the economic growth and also affects the other sectors of the economy. Due to the continuous rising of the cement production the serious impact on the environmental pollution and energy resource has been resulted [6]. So, there is a need of exploring a binding material which is safer, sustainable than traditional ordinary Portland cement and which uses the green technology. Magnesium oxychloride cement is a new binding material which is having more superior properties over the traditional Portland cement.

Only few researches have been done worldwide on magnesium oxychloride cement. There is need to explore the potential of the magnesium oxychloride cement by performing experiments so that magnesium oxychloride can be used for the construction practices.

Magnesium oxychloride cement is having the certain advantages over the ordinary Portland cement. It is having the high early strength, high bonding and quick setting property [9]. Magnesium oxychloride cement does not need wet curing. It is eco-friendly cement and does not require any heat or energy resource for its setting. The air curing at 60-70 % air humidity is done. Therefore it also reduces the water requirement and is efficient method to reduce the carbon content. The several additives can be used for enhancing the properties of the magnesium oxychloride cement so that it can be effectively used to replace the ordinary Portland cement while possessing the certain advantages over it [3].

Moreover the several additives which are the waste by product of the industries and agriculture can be incorporated into the magnesium oxychloride cement in small quantities which enhance the properties of the magnesium oxychloride cement and at the same time provides an effective method for the disposal of the industrial and agro waste [7]. The use of the waste material in cement provides a good solution to the problem associated with the waste management and to the environmental concerns.

Agro wastes such as rice husk ash and sugarcane bagasse ash can be used as an additive material for the development of magnesium oxychloride cement [1]. Also, the industrial waste such as fly ash, silica fume is also used as mineral additives for enhancing the properties of magnesium oxychloride cement.

CHAPTER – 2

LITERATURE REVIEW

2.1 General

The various efforts are being made to develop an environmental friendly construction material so that the emission of the carbon dioxide can be minimized and the environmental hazards can be reduced. There is need of such construction materials so as to reduce the greenhouse emissions. The use of magnesia as an alternative binding material is of importance because of its easy synthesis process, easy application and low cost. Various researches are being carried to make the magnesium oxychloride cement more environmental friendly by making use of locally available materials.

2.2 Researches and studies

2.2.1 The application review of magnesium oxychloride cement by Hongxia Qiao et al. (2014)[1]

The main objective of this was to study the applications of the magnesium oxychloride cement. He introduced the advantages and disadvantages of magnesium oxychloride cement and discussed the domestic research overview and proposed the future aspects of magnesium oxychloride cement.

The following are the advantages of the magnesium oxychloride cement:

1. Early high strength: The Magnesium oxychloride cement one day strength may reach 80% of the ultimate strength.
2. Light weight: Magnesium oxychloride cement is having less density that varies from 1600-1800 kg/m^3.

3. Good compressive quality: The compressive quality of magnesium oxychloride bond is for the most part more than 50 MPa.
4. Less alkaline: The magnesium oxychloride is less alkaline as compared to that of the ordinary Portland cement. The pH of magnesium oxychloride cement varies from 8.5-9.5.
5. Resistance for abrasion: The magnesium oxychloride concrete have high abrasion resistance, the magnesium oxychloride cement has 3 times more resistance to abrasion than that of ordinary Portland cement..
6. Fire resistance: The magnesium oxychloride cement can withstand high temperature upto 2800°C.
7. High thermal insulation: The magnesium oxychloride cement has good thermal insulation i.e. it does not transfer the heat form its surface to the other face.
8. Environment Friendly: Magnesium oxychloride cement does not need water curing and the process of manufacture does not emit carbon dioxide. Thereby protects the environment.

The following are the disadvantages of the magnesium oxychloride cement:

1. Low water resistance: There is significant loss in the compressive strength of magnesium oxychloride cement when it is exposed to water continuously.
2. Moisture absorption: When magnesium oxychloride cement is exposed to the humid environment it absorbs the water on its surface and gives rise to the accumulation of the white frost.
3. Buckling deformation: When magnesium oxychloride cement becomes unstable the volume expansion or contraction may take place and due to which the cracks and deformation may occur.
4. Rusting: The corrosion of the reinforcement occurs due to the presence of the free chloride. The volume of the consumption result of bar has 2-4 times more volume to that of the first volume of the non-eroded bar. This causes the stress generation in concrete and leads to cracking.

Magnesium oxychloride cement application status: it is used as a packaging material, green building material, flooring material and for making the sound proof panels.

Proposed development prospects: The main drawback of the magnesium oxychloride cement as a binding material is that it is having the poor resistance to corrosion and water. So to enhance the properties of the magnesium oxychloride cement the several measures are proposed which are as:

1. Use of the Cl^- capture agent.
2. Use of rice husk ash.
3. Use of fly ash.
4. Use of soluble phosphates.
5. Coating of the surface.
6. Use of urea formaldehyde composite admixture.

2.2.2 Compressive strength of fly ash magnesium oxychloride cement containing granite wastes by Ying Li et al. (2013)[2]

The main objective of this study was to investigate the influence of the granite waste on fly ash magnesium oxychloride cement. This paper discusses the influences of the granite waste on the magnesium oxychloride cement containing fly ash. The filling role and the water absorption of the fine particles of granite waste are good for the phase 5 of the magnesium oxychloride cement and a denser microstructure is obtained. In this investigation the light burnt magnesia delivered by Haicheng Magnesium Cement Mining, ltd Liaoning region, China was used. This light burnt magnesia contained 60% of active magnesia by weight hydrated at 101.3 kPa and 105°C. The fly ash used was 20% by weight of the light burnt magnesia. The granite fragments used were from sawing the block and granite sludge from polishing slab was provided by Lindun Quarry of Changtai Country of Fujian Province, China. The granite sludge contained about 40% of moisture. The molar ratio of the MgO to $MgCl_2$ was kept 7 with the 23° brine solution. The contents of the granite fragment and granite sludge was 10, 20, 30 and 40% by weight of light burnt magnesia. In this review different GFMOC example were set up with 23 or 25 saline solution and diverse extents of rock part (GF) or stone ooze (GS) running from 0% to 40% of magnesia weight. Pressure tests were directed at the age of 3, 7 and 28 days.

The X-Ray diffraction, electron microscopy and compressive quality were investigated. The denser microstructure with more closed packing of the particle is obtained. Samples in which the high concentration of brine is used have the higher compressive strength at the same amount of granite fragments and curing age. The compressive strength of the magnesium oxychloride cement decreases if fly ash is incorporated in a larger amount. The compressive strength decreases by 35% when 30% of fly ash by weight of magnesia is incorporated. The fine particles have better tendency to absorb the water which helps in the concentration of the brine in the slurry of GFMOC, leads to an increase of phase 5 and an increase of the compressive strength. The fine particles of the granite waste fill the large pores and the internal gaps which produces a compact microstructure thereby increasing the compressive strength of sample.

2.2.3 Influence of inert filler on cementing properties of magnesium oxychloride cement by R.N. Yadav et al. (2013)[3]

The principal goal of this study was to investigate the effect of the inert filler i.e. dolomite on the cementing behavior of the magnesium oxychloride cement. The various magnesium oxychloride cement samples were prepared using the dolomite as the inert filler in the ratio of 1:0, 1:1, 1:2 & 1:3. The magnesium chloride solution of 24°Be concentration was used for gauging the samples. The commercial grade magnesia was used in this study. The MgO content was 71.80%. The magnesium chloride used was of grade 3. The dolomite powder used in this study was fineness such that it was 100% passing through 125 micron sieve. The standard consistency, setting time, moisture ingress test, soundness test and compressive test were carried out. The setting time of the samples increased with the increase in the ratio of the dolomite in the dry-mixes. This is due to the reason that the inert filler does not take part in the chemical reaction. The moisture resistance of the samples decreases with the increase in the filler content. This is due to the reason that with the increase in the inert filler content the more uncombined magnesia and active lime is left and thus decreases the water resistance capacity. The soundness of the samples decreased with the increase of the inert filler. The compressive strength of the samples deceased with the increase of the filler ratio. The mix 1:0 had the highest strength and the mix 1:3 showed the lowest strength. This is due to the reason that the magnesia reacts with the gauging solution to give strength and as the inert filler quantity is increased the magnesia content is reduced.

2.2.4 Effect of temperature of gauging solution on setting characteristics and moisture ingress of magnesium oxychloride cement by R.N. Yadav et al. (2012)[4]

The main aim of this study was to investigate the consequence of temperature of gauging solution on setting properties and moisture access. The various dry compositions of magnesium oxychloride cement i.e. 1:0, 1:1, 1:2 and 1:3 on different temperatures 30°C, 35°C, 40°C and 45°C with the gauging solution of 28°Be solution were studied. The calcined magnesite, magnesium chloride of IS grade 3 were used. The dolomite powder with the 100% passing through the 250 micron sieve and 50 % passing through was used in this study. The consistency test, setting time test and moisture ingress test were performed. The volume of the gauging solution required for the consistency increases with the increase in the temperature of the gauging solution. This is due to the reason that the high temperature increases the exothermic reaction and there is increase in the amount of the gauging solution required. The initial setting time of the magnesium oxychloride cement samples decrease with increase in the temperature of gauging solution. Similarly the final setting time also decreases with the increase in the temperature. The final setting time decreases at a higher rate due to the temperature increase as compared to the initial setting time. The moisture ingress resistance is better for the dry mix 1:1.

2.2.5 Effect of magnesium chloride concentrations on the properties of magnesium oxychloride cement for nano SiC composite purposes by Y. Karimi et al. (2011)[5]

The principle goal of this review was to investigate the impact of the magnesium chloride fixations on the properties of MOC for nano SiC composite purposes. In this review the diverse MOC were examined with a settled 13 moles of magnesite and 12 moles of water with the distinctive moles of magnesium chloride. The mole of the magnesium chloride varies from 0.5 to 1.9. The calcined magnesite powder with a normal molecule size of 37 μm with an immaculateness of 96% shape Iranian Magnesite Company was utilized. The magnesium chloride was hygroscopic hexahydrate crystals having purity of 97% from India. The molar concentration of magnesia and water were kept constant i.e. molar ratio of magnesia was kept 13 and that of water was kept 12. The compressive strength, XRD analysis and the SEM test were conducted on the MOC samples. There was a decrease in the formation hydrated magnesia and a gradual increase in the formation of phase 5. The needle formed crystals of phase 5 are responsible for the reinforcement of the matrix of the MOC. The crushing strength, IST & FST increment with an increase in the magnesium chloride content. The magnesium chloride with 1.5 moles demonstrated the most noteworthy compressive quality. The high strength sample was used for producing a nano composite with the use of nano SiC particles.

2.2.6 Recent Development of magnesium-based cements – magnesium phosphate cement and magnesium oxychloride cement by Zongjin Li et al. (2010)[6]

This paper discusses the development of two environmental friendly cementitious material i.e. magnesium oxychloride cement and magnesium phosphate cement. This paper discusses the formulation, strength development, water resistance and the identification of the phase composition of the magnesium oxychloride cement. This paper also discusses the formation, mechanical properties and performance of the magnesium phosphate cement in patch repair, bond ability to old concrete substrate. The compressive strength and XRD patterns of the various samples i.e. M13/H12, M13/H16, M17/H16 and M19/H22 were carried out. The influence of the fly ash incorporation in the magnesium oxychloride cement was studied. The bond strength of the magnesium phosphate cement repair mortar and the ordinary Portland cement concrete was calculated. The flexural bond strength was calculated using four-point bending. The tensile bond strength was calculated using pull-off method. The flexural bond strength was done on the beam made by using half of the magnesium phosphate cement and half of the ordinary Portland cement. For the tensile bond the disk specimen with diameter of 75mm and height of 15mm were casted on the rough surface and the bond strength was evaluated by dividing the maximum force by bond area. From the results obtained it was concluded that the optimum molar ratio of $MgO/MgCl_2$ varies from 11 to 17 and that of $H_2O/MgCl_2$ varies from 12 to 18. The fly ash incorporation up to 30% by weight of magnesia in the magnesium oxychloride cement the water resistance and workability is increased but the resulting final compressive strength decreases. The water resistance increases due to the formation of the alumino-silicate gel formed. The magnesium phosphate cement mortars have high early strength and excellent bond strength to ordinary Portland cement concrete. The optimum molar ratio of M/P lies between 8 to 10 and the optimum sand ratio was 1.5.

2.2.7 Influences of fly ash on magnesium oxychloride mortar by C.K Chau et al. (2009)[7]

The fundamental target of this review was to examine the impacts of fly powder on magnesium oxychloride mortar. This paper discusses the influences of the incorporation of the Fly ash into the Magnesium Oxychloride Cement. The one of a kind microstructure and great interlocking coming about because of the intergrowth of the crystal is in charge of the quality advancement of MOC. MOC has a great bonding capability to different inert fillers which intensify its properties. In this test the magnesium oxide utilized was calcined magnesite fueled with a virtue of 96% and the magnesium chloride utilized was hygroscopic hexahydrate gem with an immaculateness of 98%. The natural river sand with a fineness modulus of 2.3 was used. For each mixture the cubic specimens with a size 40mm×40mm×40mm were prepared for the strength measurement and water resistant test. The microstructure of the magnesium oxychloride was evaluated using scanning electronic microscope and X-ray diffractograms. The process of obtaining the MOC by the light burnt magnesia requires much lower calcination temperature as that for the Portland cement. The fly ash is a waste byproduct of the industry and it can be effectively used in the MOC to enhance its properties. By incorporating the fly ash up to 30% by weight of MgO in the MOC the workability increases, the setting time is decelerated and the water resistance is improved but the resulting final compressive strength decreases. The improvement of the water resistance of the MOC incorporated with the Fly Ash is due to the amorphous alumino-silicate gel formed.

2.2.8 Magnesium oxychloride cement concrete by A.K Mishra and Renu Matuhur (2007)[8]

The main objective of this study was to investigate the compressive strength, abrasion resistance, durability studies on the different mix proportions of MOC cement concrete. In this experiment the different mix proportions (MgO:aggregate.), dry mix proportion(MgO:sand:coarse aggregate) with different concentration of $MgCl_2$ solution were examined for their strength and durability. The calcined magnesite, magnesium chloride, magnesium sulphate and coarse and fine aggregates were used in this experiment. The calcined magnesia passing 97% through 150 micron sieve and 95% through a 75 micron sieve was used. The magnesium chloride of grade 3 of IS: 254-1973 having magnesium chloride as $MgCl_2.6H_2O$ % by mass as 95. The magnesium sulphate used was of commercial grade having $MgSO_4.7H_2O$ % by mass 85. The dolomite powder was used as the inert filler which was passing 100% through 150 micron IS sieve and 50% retained on the 75 micron sieve. The locally available blue quartz passing through a 20 mm and retaining on 4.75 mm sieve were used as the coarse aggregates. Locally accessible characteristic sand going through 4.75 mm sieve was utilized. $MgO/MgCl_2$ arrangement was set up in water. The magnesium chloride flakes were put into a container and the portable water was added to prepare the concentrated solution. The solution was allowed to stand up to 20- 25 hours so that the impurities can settle down. The standard consistency and the setting time test were carried out. The IST and FST were done as per IS 10132-1982 by using the Vicat’s apparatus. The compressive and the transverse strengths of the cement mortar paste were carried out. The specimen were tested at the age of 7 days and 28 days as per IS 10132-1982. The abrasion resistance of concrete was determined. The durability of the magnesium oxychloride cement was carried out by exposing it to 30 alternate cycles of the freezing-thawing, wetting-drying and the strength retention factor coefficient was determined. With the increase of the concentration of the magnesium oxychloride solution the mix tends to become more viscous and their setting times were also found to increase due to the formation of strength the phase 3 and 5 . The magnesium oxychloride bond cement is having high flexural quality and high compressive quality when contrasted with the Portland concrete. MOC cement is early setting cement with high strength and binds the high proportions of the aggregates and fillers. MOC cement concrete composition has good workability and placing characteristics. It does not require the water curing after setting. MOC cement concrete of desired strengths can be prepared by using the various dry compositions and the concentrations of the gauging solution. If the magnesium chloride solution in replaced by the 10% of the magnesium sulphate solution of same concentration it makes it resistant to the extreme weather conditions.

2.2.9 Influences of molar ratios on properties of magnesium oxychloride cement by Zongjin Li, C.K. Chau (2007)[9]

The main objective of this study was to investigate the influences of the molar ratios on properties of the magnesium oxychloride cement. This paper discusses the influences of the molar ratios of $MgO/MgCl_2$ and $H_2O/MgCl_2$ on the properties of MOC. The molar proportion of $H2O/MgCl_2$ relies on upon the molar proportion of $MgO/MgCl_2$ in order to control the workability of the glue. In this review the magnesium oxide utilized was calcined magnesite powder with molecule size of 20 µm with a virtue of 96% from Jinan, Shandong area, China. Magnesium chloride utilized was hygroscopic hexahydrate ($MgCl_2.6H_2O$) precious stone with virtue of 98% from Israel. The molar ratio of $MgO/MgCl_2$ ranges from 7 to 19. In this study the setting time of the fresh mixture, compressive strength along with the X–ray diffractograms were carried out For a blend with a similar molar proportions of $H_2O/MgCl_2$, the higher the molar proportion of

$MgO/MgCl_2$, the lesser will be the water content. For a settled molar proportion of $MgO/MgCl_2$, the quality of the blends increments with the reduction of molar proportion of $H2O/MgCl_2$. The main requirement for obtaining the high performance MOC is to ensure the production of the phase 5, minimize the unreacted $MgCl_2$ content and obtain a reasonable workability with an appropriate setting time. In this study the best combinations of the molar ratios for MOC is $MgO/MgCl_2$ of 13 and $H_2O/MgCl_2$ of 12. As for this ratio the desired workability and strength development were achieved.

2.2.10 The mechanism for soluble phosphates to improve the water resistance of magnesium oxychloride cement by Dehua Deng (2003)[10]

The main objective of this study was to improve the water resistance of magnesium oxide cement by using soluble phosphates, explained the reasons how the expansion of the dissolvable phosphates to magnesium oxychloride concrete enhances the water resistance. In this study MgO used was Magnetite powder which was calcined at 900ºC. $MgCl_2$ used was a halogenide $MgCl_2.6H_2O$ obtained after KCl is refined from $KMgCl_3.6H_2O$ in Qianghai Potash Fertilizer Plant, China. The phosphoric acid (H_3PO_4 85% solution), sodium dihydrogen phosphate ($NaH_2PO_4.2H_2O$) and ammonia dihydrogen phosphate ($NH_4H_2PO_4$) used were chemical grade compounds. Aggregate used in mortar specimens was standard silica sand. In this study XRD analysis along with water resistance capacity tests were performed. The addition of small quantities of the soluble phosphates, such as H_3PO_4, $NaH_2PO_4.2H_2O$ and $NH_4H_2PO_4$ to MOC paste can greatly increase strength retention coefficients of the hardened MOC paste thereby improving the water resistance of the MOC. The key components responsible for the improvement of water resistance are the anions H_2PO^{4-} , HPO_4^{2-} and PO_4^{3-}. These anions decrease the lowest concentration of Mg^{2+} ions and increase the stability of the phases of MOC in water. The addition of the soluble phosphates leads to the formation of the insoluble phosphate complexes and the phosphate is absorbed onto the surface of the grains resulting in the formation of the insoluble layer on the surface and thus it protects the surface from water. In this test the MOC paste sample were cured at air for 15 days and taken after by submerging in the streaming water for 28 and 60 days, individually and their compressive qualities were measured by including the distinctive mass portions (%) of H_3PO_4 (85% arrangement) to the MOC paste. The compressive strength of the samples with the phosphoric acid decreases but the water resistance is greatly increased.

2.2.11 Study of the new type of light magnesium cement foamed material by Ji Yunsong (2000) [11]

The principle goal of this review was to explore the new kind of light magnesium cement foamed material .The lightly calcined magnesium oxide with the measure of 120 mesh, and magnesium chloride arrangement is set up by blending the appropriate amounts of the magnesium chloride with water The additives used were prepared by the industrial phosphoric acid with phosphate as well as inorganic foamer, along with the foam stabilization agent. The XRD analysis was done by apparatus of 12kW. The light weight magnesium cement foamed material is obtained. The density of this light weight material lies between 0.15-0.60 g/cm^3. This has high strength, good water resistance and excellent fire proofing properties.

2.2.12 The formation mechanism of the hydrate phases in Magnesium Oxychloride Cement by Zhang Chuanmei et al. (1999)[12]

The main objective of this study was to investigate the formation mechanism of the hydrate phases in magnesium oxychloride cement. The main reaction products if the MOC paste are $5Mg(OH)_2.MgCl_2.8H_2O$ phase5; $3Mg(OH)_2.MgCl_2.8H_2O$ phase3; $2Mg(OH)_2.MgCl_2.4H_2O$ phase2 and $9Mg(OH)_2.MgCl_2.5H_2O$ phase9. The major reaction products responsible for the hardening and the strength of the MOC are the phase 5 and the phase 3. The process of the medium-gel formation is responsible for the initial setting of the MOC phases. The phase 5 and the phase 3 are the basic salts of the Mg^{2+} ions. The dissolution of the $MgCl_2$ crystals in the water along with the reaction of the MgO in

$MgCl_2$ solution was carried out. The acidity of the $MgCl_2$ solution with the different concentration was measured with the help of the Px-215 ion meter of Shanghai analytic instrument co. Shangahi, P.R China. On performing these tests it was found that the pH of the solution was less than 7 and it decreases with the increase of their concentration. The acidity of the $MgCl_2$ solution is because of the hydrolysis of the Mg^{2+} ions. The setting and the hardening of the MOC paste is due to the neutralizing reaction of the MgO in $MgCl_2$ as only the neutralizing reaction induce the hydrate phases to from. MgO is neutralized with the free H^+ ions in the $MgCl_2$ solution and provides the free OH^- ions for the hydrolysis of Mg^{2+} ions.

2.2.13 The Effect of Aluminate Minerals on the phases in Magnesium Oxychloride Cement by Zhang Chuanmei et al. (1996) [13]

The main objective of this study was to investigate the effects of the aluminate mineral on the phases and strength of the magnesium oxychloride cement. In this experiment the magnesium oxide used was the calcined magnesite powder at 800°C. The $MgCl_2$ used was the halogenide $MgCl_2.6H_2O$ which was obtained after KCl is obtained from $KMgCl_2.6H_2O$ in Quinghai potash fertilizer plant. High alumina cement was the commercial refractory cement supplied by Zheng Zhou cement plant. The aluminate mineral were synthesized by the calcination of the paste mixtures of alumina ore/iron ore at 1250-1350°C. The specimen of magnesium oxychloride cement, the $MgCl_2.6H_2O$ was dissolved in water to form the $MgCl_2$ solution with 28°Be concentration and the small quantities of high alumina cement/aluminate powder was mixed in an appropriate ratio with the weight of the $MgCl_2$ solution. The XRD analysis of samples with and without aluminate minerals was done. The addition of the aluminate minerals cause the phase conversation of the reaction products in MOC paste but the aluminate mineral must be hydraulic. The stable phases below 100°C are 5.1.8 and 3.1.8 phases. If the $MgO/MgCl_2$ molar ratios are 5 and over, then the reaction products formed are in 5.1.8 phase and if $MgO/MgCl_2$ molar ratios are below 5 then the reaction product formed are in 3.1.8 phase. The 3.1.8 phase is formed more slowly than 5.1.8 phase. The phase conversion occur when the initial molar ratios Mgo/$MgCl_2$ are 5 and over & the reaction products in the MOC paste with the hydraulic aluminate minerals are in 3.1.8 phase. The addition of the small hydraulic aluminate minerals/ high alumina cement does not affect the strength of the magnesium oxychloride cement.

2.2.14 Magnesium Oxychloride Cement Concrete with recycled tire rubber by Timothy D. Biel and Hosin Lee (1996)[14]

The main objective of this study was to use the magnesium oxide cement concrete with recycled tire rubber and investigate their effects on the mechanical properties. The fine rubber aggregates are incorporated ranging from 0 to 25% by volume. The tests were conducted on the Portland cement and the MOC, along with the incorporation of the recycled tire rubber. The concrete mix was made by using the MOC and Portland cement. The coarse and fine mineral aggregate along with the recycled tire rubber was used. The specific gravity of the MgO powder was 2.06 and the $MgCl_2$ gauging solution was 1.20. The specific gravity of the rubber aggregate was 1.16. The gradation of the rubber satisfies the requirements as per ASTM C33. The Portland cement with a specific gravity of 3.15 was used. The comparison of the compressive and tensile strength of MOC and Portland cement was done. The tensile strength retained by Portland cement was 20% whereas the MOC retained 35% of tensile strength. The compressive strength of the magnesium oxychloride cement rubber concrete was higher than the Portland cement rubber concrete.

2.2.15 Strength Development in Magnesium Oxychloride and Other Cements by J.J Beaudobin et al. (1975)[15]

The principle target of this review was to investigate the strength development in magnesium oxychloride and Portland cement. In this the experimental studies were conducted and the relationship of the porosity-mechanical property, micro hardness-porosity was observed. The MgO powder used in this experiment was supplied by basic chemicals, Cleveland, Ohio. The active CaO was 1.5%, ignition loss was 4% and the fraction passing through 200 mesh was 98%.The MgO satisfied the requirement as per A.S.T.M C-245-61. The magnesium oxychloride solution was prepared by mixing $MgCl_2.6H_2O$ in a dry form with the distilled water having specific gravity 1.18. The helium pycnometer was utilized to measure the solid volume of the cement specimens of known geometry and the modulus of elasticity was measured on discs with a distance across of 3.2 cm and a thickness of 1.3 mm. The differential thermograms were obtained by using the 990 dupont thermal analysis system. X-ray examinations were completed with a Debye Scherrer Camera. Chloride estimation was finished by the chloride particle particular anode. For a particular porosity, in situ hydrated magnesium oxychloride cement has a mechanical behavior superior to that of hydrated PC. The mechanical behavior of magnesium oxychloride cement improves when treated in water at 85ºC and the surface area also increases. The magnesium hydroxide forms the strongest bodies.

2.3 Mix proportion and molar ratio

Zongjin Li and Chau studied the influence of the molar ratios on the properties and strength [9]. From this study they concluded that the optimum molar ratio of $MgO/MgCl_2$ varies from 11-17 and the molar ratio of $H_2O/MgCl_2$ varies from 12-18. The molar ratio also depends upon the desired workability and the reactivity of the magnesium oxide used.

2.4 Research gap

1. Poor water resistance: The Magnesium oxychloride cement specimen is damaged to a greater extent on exposing to the moisture conditions. Due to the poor water resistance its use a binding material has been limited. There is significant loss in its strength when immersed in water.

2. Moisture absorption and efflorescence: White powder may produce on the surface of the magnesium oxychloride cement if the humidity is high. This white powder is known as the white frost. Due to the formation of the white frost at the surface the active ingredients are also brought out and due to this the binding properties are lost.
3. Buckling deformation: The Magnesium oxychloride cement is prone to the volume deformation. It may undergo the volume expansion or contraction. The various factors affecting the volume deformation are temperature, humidity and the mix ratio.
4. Corrosion of the reinforcement: The free chloride ion from the residual magnesium chloride is the main reason for the corrosion of the reinforcement. There is increase in the volume as the corrosion occurs. Due to increase in the volume the stresses are induced in the concrete which leads to the cracking and peeling in the concrete. Due to corrosion the reinforcement is also degraded so the load bearing capacity is reduced significantly.

2.5 Objectives and scope of project

The main objectives of the project are as follow:

1. Design mix for the magnesium oxychloride cement.
2. Selection of the proper molar ratios of the $MgO/MgCl_2$ and $H_2O/MgCl_2$.
3. Studying the setting characteristics of magnesium oxychloride cement.
4. Calculating the compressive strength of the magnesium oxychloride cement cube.
5. Analyzing the effect of bagasse filler replacement in the properties of magnesium oxychloride cement.
6. Analyzing the durability of the pure magnesium oxychloride cement specimen and those with the partial replacement with bagasse.

CHAPTER – 3

MATERIALS AND METHODOLOGY

3.1 General

3.1.1 Magnesium Chloride

It is an essential material utilized for making MOC bond. This material ought to be in crystalline state. The bonding phase that forms due to the reaction with the MgO requires the magnesium chloride to be in crystal form for having water of crystallization in them [5]. Magnesium oxychloride salts are ionic halides that are profoundly dissolvable in water. Many salt lakes and common saline solutions are the essential wellspring of magnesium chloride.

The magnesium chloride in the amorphous type does not give the good holding capacity with the magnesium chloride and so the quality of the specimen is lessened**.** Magnesium chloride solidifies to frame cadmium chloride, in which the structure of magnesium is octahedral fit as a fiddle. Due to increase in the temperature the water content decreases in the magnesium chloride.

The hexahydrate shape of the magnesium chloride ensures the advancement of quality of its strength**.** The standout procedure utilized for the production of magnesium chloride hexahydrate is the vanishing of ocean water and normal saline solutions by evaporation. The main issue with the way toward extracting process of magnesium chloride with evaporative procedures is the high vitality input required and along these lines the expenses related with the generation of $MgCl_2.6H_2O$**.** The substitute techniques for generation of magnesium chloride is as by performing chlorination of magnesium oxide within the sight of any diminishing agent or as a by- result of the potash business. These substitute techniques are even a great deal more costly than the generation by dissipation of saline solutions**.**

To compress the focuses specified above the most ideal way in the generation of magnesium chloride from seawater or brackish waters is dissipation by the utilization of sun based vitality. In this procedure the concentration of the diluted solution is increased by sun based dissipations. The method employed for the formulation of magnesium chloride is the Dows method. The large quantity of magnesium chloride is produce by ensuring its precipitation product as magnesium hydroxide that is trailed by change to magnesium chloride by using hydrogen chloride. By utilizing the hydrochloric acid the magnesium chloride is recovered from magnesium hydroxide.

$$\mathbf{Mg(OH)_2\,(s) + 2HCl \rightarrow 2H_2O(l) + MgCl_2\,(aq)}$$

3.1.2 Magnesium Oxide

The magnesium oxide is obtained by warming magnesite so as to drive off a large portion of carbon dioxide. The magnesium oxide has a good electrical resistivity and good thermal conductivity at high temperatures. Magnesium oxide is utilized as a fundamental hard-headed material for coating pots which is presented to high temperatures [1]. So it can be stated that magnesium oxide is a central fixing in development materials utilized for insulating. It likewise discovers its utilization as a source of perspective white shading in colorimetry. Magnesium oxide is a natural occurring material.

Regular magnesium oxide gets changed over to magnesium hydroxide in type of vapors in the air and does not frame shakes and salt store. For mechanical reason a lot of magnesium oxide is separated from sea water and magnesite. Magnesium oxide is viewed as a recalcitrant material i.e. a material strong which is stable at high temperatures. It is utilized in different fields because of its intrinsic resistance to corrosion, low electrical conductivity and high liquefying point [6].

Magnesium Oxide is obtained from the magnesite through mining process. The other source for obtaining the magnesium oxide is from sea water. For the extraction of the magnesium oxide the calcium oxide which is also known as quick lime is required. Contingent upon the level of warmth treatment and reactivity the magnesium oxide has three different classes which are as below:

Light burnt MgO:

This class of magnesium oxide is obtained by the calcination of magnesite at temperatures extending from 700°C to 1000°C.

Hard burnt MgO:

This class of magnesium oxide is obtained by the calcination of magnesite at temperature extending from 1000°C to 1500°C. This type of magnesium oxide has limited scope of reactivity.

Dead burnt MgO:

This class of magnesium oxide is obtained by the calcination of magnesite at temperature extending from 1500°C to 2000°C. It is known as the dead burnt magnesia as its reactivity is reduced. It is utilized as a hard-headed material in the creation of brick blocks.

$$\mathbf{MgCO_3 + heat \rightarrow CO_2(\ gas) + MgO}$$

3.1.3 Bagasse:

Bagasse is likewise known as “megass”. It is obtained as a residual material after the extraction of juice from sugarcane. This residual material is basically a fiber buildup. The bagasse has different utilizations as it can be scorched to supply warmth to the sugar refining operation and can also be utilized as wellspring of cellulose. The bagasse fiber has a moderate length that lies in the scope of 1 to 4 mm. it has thick fiber wall.

Bagasse is easily accessible where sugarcane is cultivated. The bagasse is available abundant quantity at the sugar mills as it is a waste by product of the sugar industries. The bagasse obtained from the sugar industry is to be burnt at high temperatures so as to reduce the carbon content and increase its pozzolanic activities. The bagasse is used for the partial replacement of the magnesium oxide in the magnesium oxychloride cement to improve the properties of this cement.

3.2 Raw material used

The raw materials used in this study were magnesium oxide, magnesium chloride and bagasse. The Table 3.1 provides the specification of the material used in this study. The Table 3.3 provides the specific gravity of magnesium oxide and magnesium chloride used.

3.2.1 Magnesium Oxide: The magnesium oxide used in this study was calcined magnesite powder of industrial grade. The percentage passing through 150 micron sieve was 97% and through 90 micron sieve was 91%. The composition of the industrial grade of magnesium oxide used in this study is given in the Table 3.2.

3.2.2 Magnesium chloride: The magnesium chloride used was hygroscopic hexahydrate crystal i.e. $MgCl_2.6H_2O$ with a purity of 70% conforming to grade 3.

3.2.3 Bagasse: The bagasse ash was obtained from the sugar factory. The bagasse was incinerated at approx.250°C to reduce the carbon content.

Table 3.1 – Material specification

S.No.	**Material**	**Specification**
1.	Magnesium Chloride	70% pure
2.	Magnesium Oxide	Calcined magnesite of 85 % purity
3.	Bagasse	Bagasse ash from sugar industry

Table 3.2 - Chemical Composition of MgO used

Components	Weight Percentage
MgO	85%
CaO	5.6%
SiO	3.7%
Fe_2O_3	0.8%
Al_2O_3	0.6%
SO_3	4.3%

Table 3.3 - Specific gravity of MgO and $MgCl_2$

S.No.	Material	Specific Gravity
1.	Magnesium Oxide	3.27
2.	Magnesium Chloride	1.56

The results obtained from the material used in the testing showed deviation in results. Main reason for the deviation of the results is the inadequate purity of the materials which are put to use. The pure material available in the Indian market is very costly and is available in small packages. Therefore using the purest material is not feasible.

3.3 Design Mix

The mix design of the MOC is based on the molar ratios of $MgO/MgCl_2$ and $H_2O/MgCl_2$. The setting of MOC takes place through a reaction. There are mainly four reaction phases in the MOC system. The phase 5 is responsible for the high strength of MOC. The molar ratios of $MgO/MgCl_2$ of 11-17 and $H_2O/MgCl_2$ of 12-18 are suitable for the design purposes [3].

In this experiment the molar ratios used was $MgO/MgCl_2$ of 11 and $H_2O/MgCl_2$ of 12 as it gives the high strength with a good workability.

Molar weight of MgO = 40.30 g/mol

Molar weight of $MgCl_2$ = 95.21 g/mol

Molar weight of H_2O = 18 g/mol

No. of moles = weight/molecular weight.

Molar ratio = (No. of moles of 1)/ (No. of moles of 2)

Now for the molar ratios of $MgO/MgCl_2$ = 11

Let x be the weight of MgO and y be the weight of $MgCl_2$, then

$$\frac{x}{40.3} \div \frac{y}{95.21} = 11$$

$$\frac{x}{40.3} \times \frac{95.21}{y} = 11 \qquad -------(1)$$

For the molar ratio of $H_2O/MgCl_2$ = 12

Let z be the weight of H_2O, then

$$\frac{z}{18} \div \frac{y}{95.21} = 12$$

$$\frac{z}{18} \times \frac{95.21}{y} = 12 \qquad -------(2)$$

From equation (1), we get

y = 0.21x gm.

Now putting the value of y in equation (2), we get

$$z = \frac{12 \times 18 \times 0.21x}{95.21} = 0.47x$$

Thus for the corresponding molar ratios the relationship in terms of mass is obtained. Using this relationship the various MOC compositions were prepared in the laboratory.

3.4 Methodology

3.4.1 Flow of the work:-

1. The raw material i.e. the magnesium oxide and magnesium chloride were obtained from Delhi.
2. The inert filler i.e. the sugarcane bagasse was obtained from the sugar factory.
3. Mix design is performed so as to find the appropriate quantities of material to be used.
4. The various cubes are casted using the mix design.
5. The partial replacement of magnesium oxychloride with bagasse at an interval of 5%, 10% and 15% is done and the cubes are casted.
6. The air curing of the samples is done.
7. The casted cubes are tested for mechanical properties i.e. for the compressive strength, initial and final setting time and durability after 7, 14 &28 days.

3.4.2 Burning of the Bagasse

The Bagasse contained a large amount of the carbon content. To achieve the required properties the carbon content is to be decrease and the amorphous silica content is to be increased. To decrease the carbon content the bagasse is burnt at a temperature of 200-250°C. The bagasse was burnt with the help of flame in the open. The Figure 3.1 shows the burning of the bagasse under flame. The burning is done until the color of the bagasse changes from black to greyish color. The visual inspection of the Figure 3.2 shows that the color of the bagasse before burning was black, which indicates that the carbon content was more. The visual inspection of the Figure 3.3 shows that the color of the bagasse after burning turned greyish, which indicates that the relative carbon content is decreased.

Figure 3.1 – Burning of bagasse

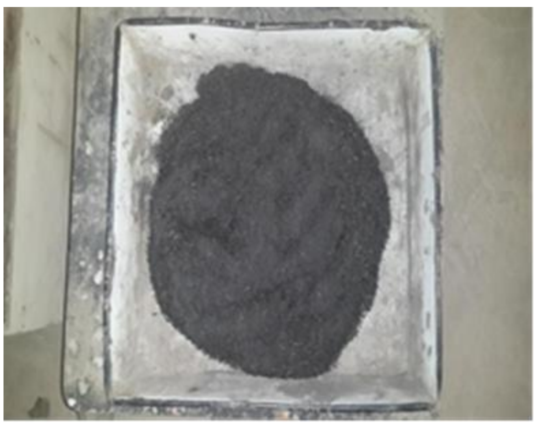

Figure 3.2 – Bagasse before burning

Figure 3.3 – Bagasse after burning

3.4.3 Preparation of the specimens

Magnesium Oxychloride cement specimen is prepared by mixing of the powdered Magnesium oxide with a concentrated solution Magnesium Chloride. Magnesium Chloride is firstly dissolved in water to make a solution before mixing it with the magnesium oxide powder to form the magnesium oxychloride cement. The magnesium chloride is dissolved in water and is continuously stirred up to 10 minutes. The Figure 3.4

shows the mechanical method of mixing the MOC paste. This solution is left as such overnight so that the impurities can settle down. The settled impurities are removed and the concentrated solution of the magnesium oxychloride is mixed with the magnesium oxide to form the MOC.

The quantity of the material required is dependent on the molar ratios of the materials i.e. $H_2O/MgCl_2$ and $MgO/MgCl_2$. The molar ratio of $MgO/MgCl_2$ and $H_2O/MgCl_2$ were kept constant in this study i.e. 11 and 12. The percentage fineness test, setting time test and compressive strength test were conducted for this molar ratios. The replacement content of bagasse ash at interval of 5 % was done and all the above tests were conducted.

Figure 3.4 – Mixing of the MOC paste

The following sequence is adapted for preparing the mix of MOC samples:

- The solution of magnesium oxide is formulated. Then the magnesium chloride crystals are blended in water and stirred continuously up to 10 minutes. Then after stirring this solution is left undisturbed overnight to allow the polluting influences to settle down. The settled polluting influences are evacuated so as to obtain the concentrated solution of magnesium chloride.

- The magnesium oxide is blended with the concentrated solution of magnesium chloride. The blending is with the use of mechanical blender for around 10 minutes. The blending can also be done using hand blending in case there is absence of blender. The blending provides the homogeneity to the paste formed.
- The paste formed above is employed for casting the cubes of dimension 7.06cm× 7.06cm×7.06cm.
- The casted cubes are to be demoulded after 24 hours. Then these demoulded cubes are kept for air curing. These cubes of magnesium oxychloride cement are highly susceptible to weakening in existence of water near it. The cubes should be placed in the room having no dampness.
- The magnesium oxide is then partially replaced with bagasse as filler at an interval of 5%, 10% and 15%. The molar ratios of the material used is also to be modified accordingly to the replacement of the filler made This implies that the quantities of the magnesium oxide, magnesium chloride and water will be changed according to the replacement of the bagasse made.

The compressive strength of the cubes is to be calculated and comparisons of the results obtained are to be done.

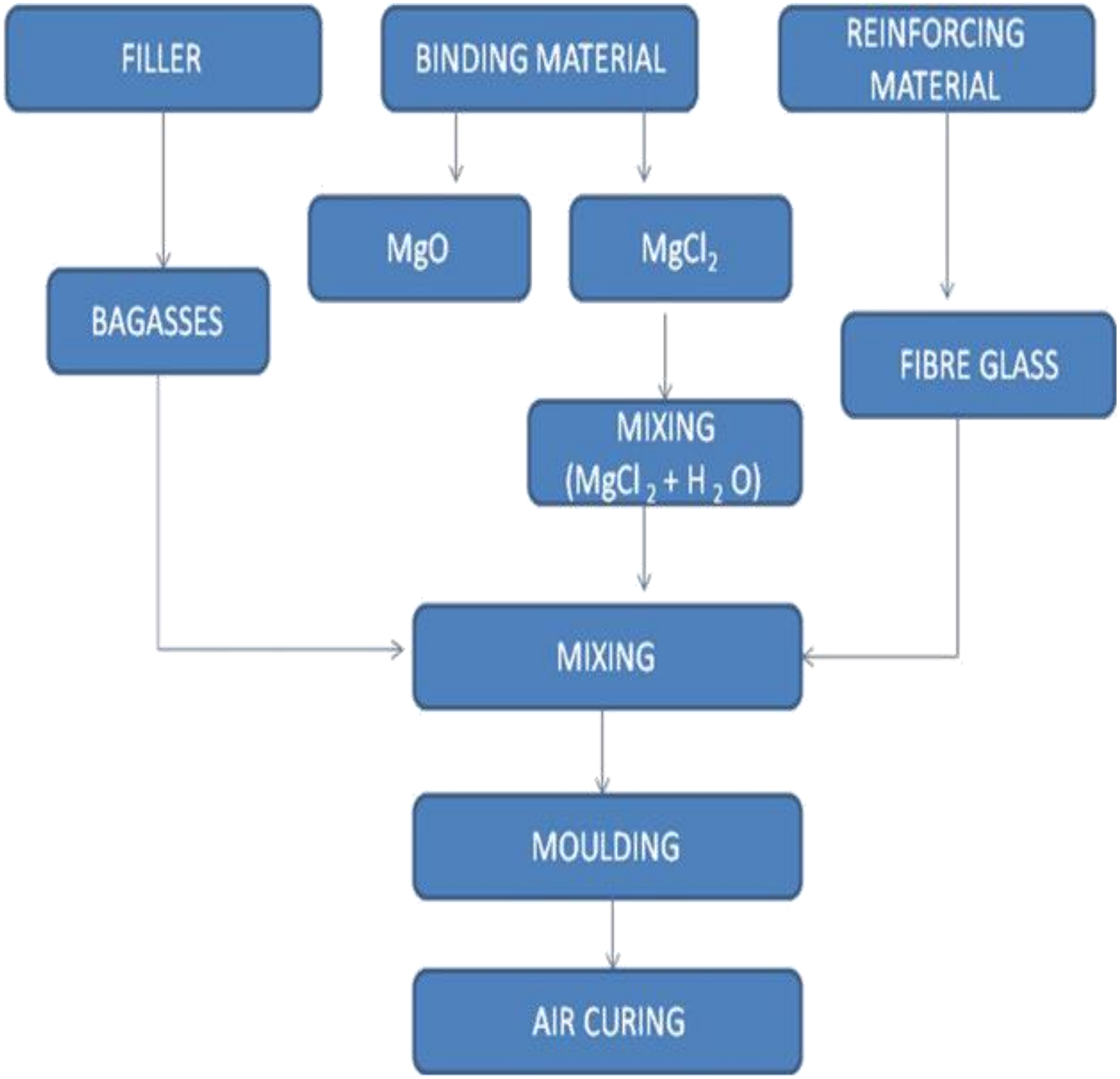

Figure 3.5 – Sampling process chart

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Properties of sugarcane bagasse ash

The calculated specific gravity of SCBA by using Le-chatlier's apparatus is equal to 2.6. Property of the sugarcane bagasse ash is studied for their pozzolanic properties. The chemical properties of the SCBA are obtained by XRF (X-Ray Fluorescence).

As indicated by the ASTM C618 the determination for the coal fly cinder or calcined characteristic pozzolan use as a mineral admixture in cement is that the substance creation of common pozzolan should have SiO_2+Al_2O_3+Fe_2O_3 content more than 70% of composition. The Table 4.1 indicates that the Fe_2O_3+SiO_2+Al_2O_3 content are 71.97% so bagasse can be effectively used as a partial replacement material. The material qualifies to be used as mineral admixture as class F pozzolan which has pozzolanic properties.

Table 4.1 – Chemical properties of SCBA obtained by XRF

Oxide	**SCBA (%)**
CaO	2.71
SiO_2	53.35
Al_2O_3	16.77
Fe_2O_3	1.85
K_2O	4.60
MnO	0.07
P_2O_5	2.37
SO_3	0.232
SrO	0.04
TiO_2	0.66
BaO	0.09
MgO	3.26
Na_2O	0.60
Fe_2O_3+SiO_2+Al_2O_3	**71.97**

4.2 Percentage fineness

Table 4.2 – Percentage fineness of MgO

MgO	**Weight in grams**	**Weight of MgO passing 150μ sieve**	**% of fineness**
Sample 1	200	195	97.5
Sample 2	200	194	97

Table 4.3 – Percentage fineness of bagasse

Bagasse ash	**Weight in grams**	**Weight of bagasse passing 150μ sieve**	**% of fineness**
Sample 1	200	165	82.5
Sample 2	200	161	80.5

Table 4.2 and Table 4.3 indicate the average particle size of the magnesium oxide and of bagasse used in this study. The percentage passing through the 150μ sieve was compared to know the average particle size. The bagasse ash used for the replacement should be fine so as to improve the microstructure of the MOC by ensuring the proper packing of the particles.

4.3 Specific gravity tests

The specific gravity test for the Magnesium oxide and bagasse was found out using density bottle. The results were as follows:

Table 4.4 – Specific gravity of MgO

Material	**Specific Gravity**
MgO	3.1

Table 4.5 – Specific gravity of Bagasse

Material	**Specific Gravity**
Bagasse	2.6

Table 4.6 – Specific gravity of $MgCl_2$

Material	**Specific Gravity**
$MgCl_2$	2.7

Table 4.7 - Specific gravity of ordinary Portland cement of 43 grade

Material	**Specific gravity**
Ordinary Portland cement	2.9

From the Table 4.4 and Table 4.7 it is seen that the specific gravity of MgO is more than that of ordinary Portland cement. As the specific gravity of the MgO is more it is concluded that the magnesium oxide is finer than the ordinary Portland cement. The particles size of the magnesium oxide is smaller so there will be the better packing density and the void filling property will be greater.

4.1 Setting time of MOC

The initial and the final setting time of the controlled MOC and the partial replacement with the bagasse by 5%. 10% and 15% were found using the Vicat's apparatus. The Figure 4.1 shows the setting time test being performed using Vicat's apparatus.

Figure 4.1 – IST & FST by using Vicat's apparatus

Table 4.8 – Setting time of the MOC samples

Sample	**Initial setting time**	**Final setting time**
CS	136 min	6 hrs 54 min
P-5	141 min	7 hrs 04 min
P-10	155 min	7 hrs 17 min
P-15	162 min	7 hrs 42 min

In the above Table 4.8, CS denotes the controlled sample i.e. the pure MOC sample, P-5 denotes the partial replacement of the MOC by 5%, P-10 denotes the partial replacement of MOC by 10% and P-15 denotes the partial replacement of MOC by 15% by weight of MgO. The Figure 4.2 is the chart representing the initial and final setting time of the MOC samples.

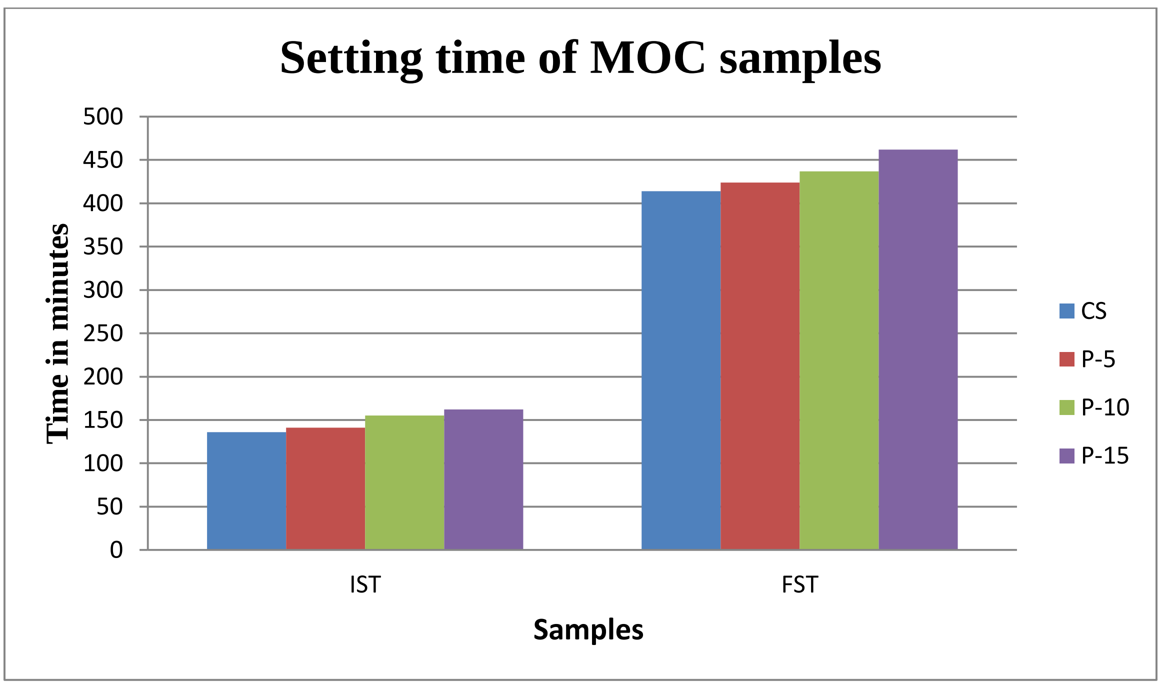

Figure 4.2 – Setting time of MOC samples

4.5 Compressive Strength

The compressive strength of the MOC cubes of 70.6×70.6×70.6 mm^3 were calculated using the Compression Testing Machine after 7, 14 and 28 days of air curing.

Figure 4.3 – Compression Testing Machine

The Figure 4.2 indicates the compression test being performed on the magnesium oxychloride cement specimen casted so as to obtain their compressive strength.

Table 4.9 – Compressive strength of the MOC samples

Material	Sample	7 days strength (MPa)	14 days strength (MPa)	28 days strength (MPa)
CS	1	22.0	27.6	34.2
	2	22.4	27.6	34.6
	3	21.9	27.5	34.1
	Average strength	22.1	27.6	34.3
P-5	1	21.2	25.9	32.4
	2	21.4	26.3	32.6
	3	21.0	25.8	32.1
	Average Strength	21.2	26	32.3
P-10	1	25.7	30.5	37.9
	2	25.9	30.8	38.1
	3	25.5	30.4	37.6
	Average Strength	25.7	30.5	37.8
P-15	1	18.4	23.7	31.3
	2	18.7	23.8	31.6
	3	18.2	23.5	31.1
	Average Strength	18.4	23.6	31.4

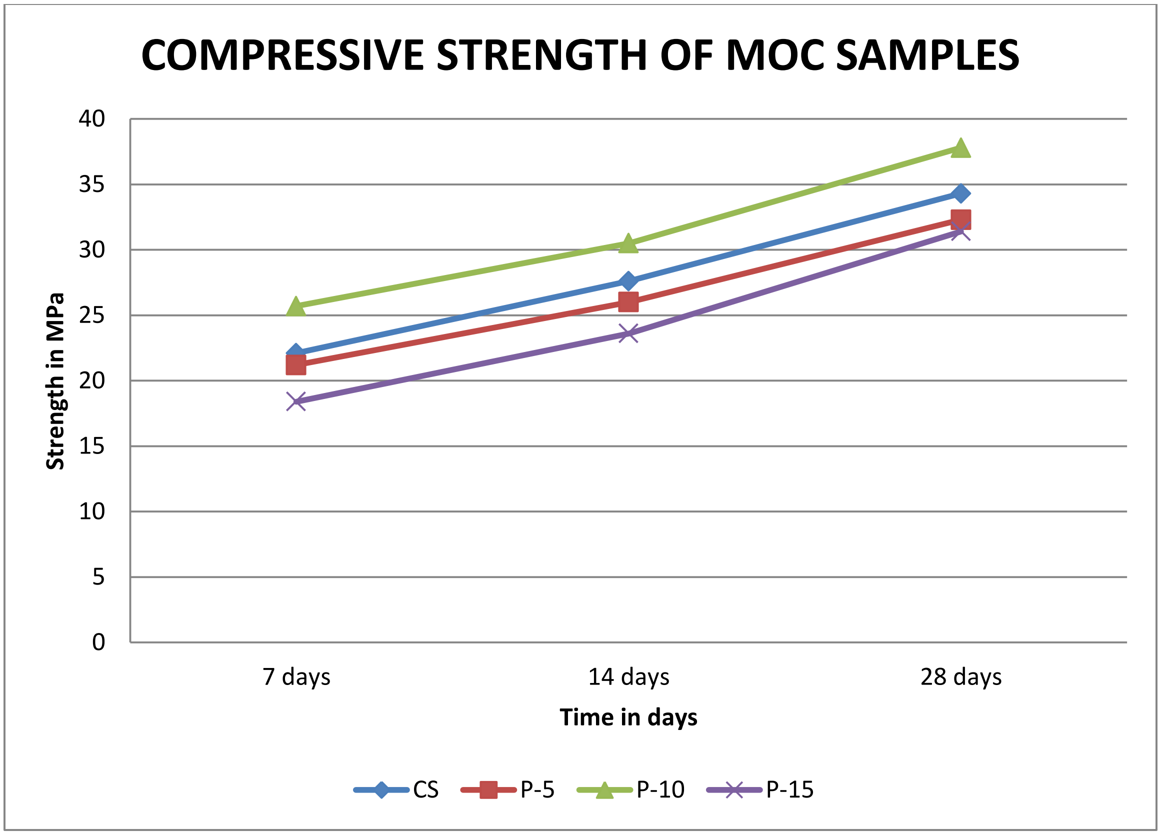

Figure 4.4 – Graphical representation of compressive strength of MOC samples

Consequently from the outcomes got it can be presumed that the specimen P-10 gives the most extreme compressive quality. So in the MOC the Magnesium Oxide can be effectively replaced by 10% of bagasse without losing the strength. The Figure 4.4 is a graphical representation of the compressive strength of the MOC samples and from this graph it is seen that the sample P-10 gives the best compressive strength. The 10% replacement with the bagasse not only increases its strength but also reduces the quantity of MgO thereby reducing the cost. The use of the bagasse improves the microstructure of the paste and the binding properties are also enhanced.

4.6 Durability of the MOC samples:

The durability tests are to be performed on the magnesium oxychloride cement samples to find out its performance in the working environment conditions and exposure conditions during its service life. The main factors influencing the durability of the magnesium oxychloride cement are its permeability to the ingress of water, oxygen and other harmful substances.

4.6.1 Water resistance test

The pure MOC cube was immersed in water for 24 hours. The weathering action was seen and the sample was deteriorated. This is due to the loss of the binding action. When MOC is exposed to the water for long time the pahse-5 gets unstable. The phase 5 is responsible for the setting and hardening of MOC. Therefore this test shows that the MOC has a poor water resistance. The Figure 4.3 indicates the degradation of the MOC cube when it is exposed to the water. The sample P-15 when exposed to the water showed a little water resistance. Thus the water resistance can be improved significantly by the partial replacement with bagasse. The several researches showed that soluble phosphates can be used to improve the water resistance.

Figure 4.5 – Deterioration of the MOC cube when exposed to water

4.6.2 Water Absorption

Table 4.10 – Water absorption of the different MOC samples

Material	Sample	dry weight (In grams)	Surface saturated weight (in grams)	% water absorption
CS	1	495.6	854	72.3
	2	501	859	71.45
	3	503	850	68.94
	Average	499.86	854.33	70.89
P-5	1	450	732	62.37
	2	454	737	62.33
	3	456	740	62.78
	Average	453.33	736.33	62.49
P-10	1	430	680	58.13
	2	433	684	57.96
	3	436	687	57.56
	Average	433	683.66	57.88
P-5	1	405.8	625.65	54.17
	2	401.5	624.34	55.50
	3	410	627.54	53.05
	Average	405.76	625.84	54.24

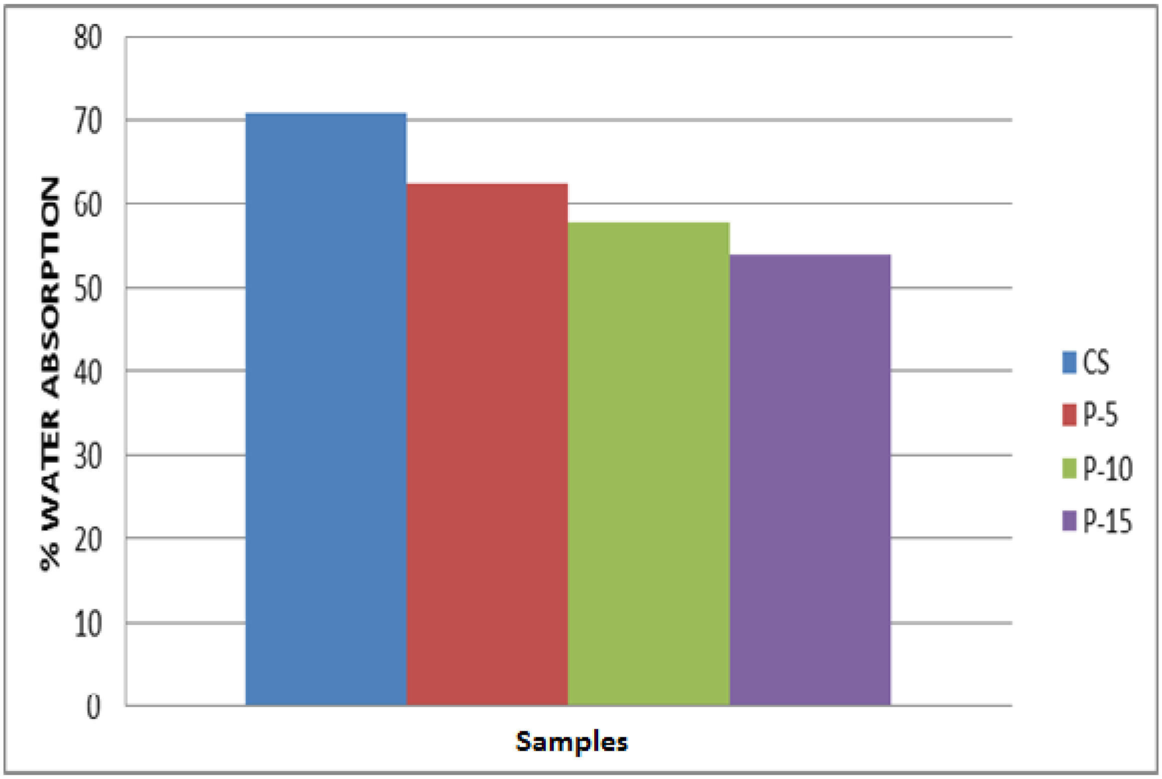

Figure 4.6 - % Water absorption of MOC samples

The various MOC samples were exposed to the water for 5-6 hours. The weight of the dry MOC samples and the weight of these samples after being exposed to 5-6 hours were measured. The Figure 4.6 is the chart representing the % water absorption of the various MOC samples.

The CS i.e. the pure MOC sample without any partial replacement shows higher water absorption of 70% which makes it less reliable. Whereas it can be observed that the samples P-5, P-10, P-15 in which the bagasse is used as an partial replacement of the MOC in the ratios of 5%,10% and 15% respectively have relatively less water absorption. The water absorption is improved by the partial replacement by the bagasse as the above results shows that water absorption is reduced from 70% to 54%.

4.6.3 Fire Resistance Test

The MOC cube is casted and cut to form a plate of 2.5cm thickness. The Figure 4.4 shows a MOC cube plate exposed to the direct flame. Then these plates are exposed to the flame for 5-7 minutes. The plate showed good insulation properties as the heat from the exposed face was not felt on the hand on the other face. Thus it can be concluded that MOC has good fire resistance and good thermal insulation.

Figure 4.7 – MOC sample exposed to flame

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CHAPTER – 5

CONCLUSIONS

1. The compressive strength of the MOC depends upon the molar ratio of the MgO and $MgCl_2$. The cubes made from the MOC are lighter than the ordinary Portland cement. The weight was further reduced when bagasse filler was added.

2. The addition of filler increased the compressive strength of MOC. The best combination for the partial replacement of the MOC is the 10% replacement by the bagasse as this combination gives the higher compressive strength

3. The moulds used for casting were corroded. The corrosive nature of the MOC is due to the free chloride ions. To reduce the rate of corrosion the chloride ion capture agent or the soluble phosphates can be used.

4. The MOC samples when exposed to the water they starts degrading. Their compressive strength is reduced greatly.

5. The water absorption of the pure MOC is more as compared to the samples that were partially replaced by bagasse. The water absorption is reduced to 54%.

6. The MOC has a good fire resistance and good thermal insulation properties.

So it can be concluded that this material is surely an alternative binding material but it cannot be effectively used for the structural purpose of construction. The several researches are being carried out to eliminate its poor resistance to water and corrosion problems. It can be used for the purposes like aesthetics and patch work.

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