EXPERIMENTAL STUDY ON POTENTIAL OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

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With specialization in

STRUCTURAL ENGINEERING

Under the supervision of

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To

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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CERTIFICATE

This is to certify that the work which is being presented in this project report titled **"EXPERIMENTAL STUDY ON POTENTIAL OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT"** 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 **Vinay Kumar (152660)** 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.

The above statement made is correct to the best of my knowledge.

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ABSTRACT

Cement producing industry is one of the major Carbon Dioxide radiating source other than deforestation and smoldering of fossil fuels. The unnatural weather change or in simple words Global Warming is brought on by the discharge of greenhouse gases, for example, CO_2, to the atmosphere. Among all greenhouse gases, the contribution of Carbon Dioxide alone is about 65%. The cement producing industry all around the world contributes around 5% to 8% of total emission of Carbon Dioxide to atmosphere which increase the ultimate level of percentage of CO_2 among greenhouse gases. So as to address such environmental effects associated with cement production, there is a need to create elective folios to make concrete. Endeavors have been made to utilize waste glass powder as fractional substitution of concrete. This examination incorporates the experimental investigation of properties of cement and concrete made with cement partially replaced with waste glass powder and after that contrast these with properties of conventional cement. All the experiments included in this project satisfy all the specifications recommended by Indian Standard Codes. The considered glass powder content is 10%, 20% and 30% by weight of cement. Test results shows insignificant effects on soundness and setting time of cement whereas use of glass powder up to 20% as cement replacement enhance the compressive and tensile strength of cement mortar as well as concrete.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is one of the primary building construction materials. It is the world's most expended man-made material in fact it is second most utilized material after water. As per annual report of Cement Corporation of India, it produces 913 thousand metric tons cement in 2015-16 financial year [3]. Cement, which goes about as binder in concrete, is the primary and essential constituent in the production of concrete. The generation of cement needs a gigantic measure of raw material and vitality and in the meantime discharges Carbon Dioxide (CO_2) into the atmosphere. The expanding interest of cement prompts to higher rate of environmental degradation and more exploitation of natural assets for raw material. Generation of cement contributes approximately around 5% to 8% to global Carbon Dioxide emissions [17]. This high contribution is because of the fact that production of every ton of concrete radiates one ton of Carbon Dioxide to the atmosphere from both of fuel and cement raw materials smoldering. The utilization of solid waste materials or by-products of industries as supplementary cementitious material in the form of partial replacement of cement is a feasible strategy for diminishing the use of Portland cement and in this manner decreasing the ecological and energy impacts of production of concrete [14].

Glass is an inert material which can be recycled and utilized many times without changing its compound properties. Glass is an amorphous material with high silica content, in this way making it conceivably pozzolanic. For the most part waste glass is utilized by glass manufacturing industries as a part of the creation of new glasses however in reality an extremely constrained measure of waste glass can be utilized towards the generation of new glass. This is on account of the fact that glass manufacturing industries normally utilize squander glass that has been pre-sorted by shading, color, type and reject squander glass that is blended with color. This color mixed waste glass is generally disposed of and winds up at landfill site.

In India, the amount of waste glass has gradually expanded over the years because of the developing need and use of glass products, thus accounts for substantial amount of waste glass. A major portion of this waste glass can be reused in many ways. In the meantime, the global cement manufacturing has reached approximately 3.1 billion tons [7], and is expected to reach somewhere in the range of 4 billion tons for every year. The cement industry is confronting difficulties, for example, cost increments in energy supply, necessities to lessen CO_2 emissions and the supply of natural raw materials in adequate quantities. The utilization of waste glass to supplant cement could lessen the cost of concrete and furthermore the overall consumption of cement; there by straightforwardly diminish the CO_2 discharge which is identified with the generation of cement. Additionally this also decrease the cost of producing concrete since a waste material is utilized. Various researches have been carried out to utilize waste glass as a swap for coarse aggregates. However the utilization of waste glass powder as partial replacement of cement will be a great enhancement. The pozzolanic property of glass powder has demonstrated the likelihood to enhance the concrete property by utilizing waste glass as a part of cement. The small particles of powdered glass also works as filler material in concrete. The micro filler effect significantly diminishes permeability and enhance the paste – aggregate bond in concrete thus results in more dense and durable concrete.

The experimental work presented in this research looks at the use of glass in the form of fine powder, as an eco-friendly material to partially replace cement in the production of concrete. Thus this study experimentally investigates the potential of waste glass powder as partial replacement for cement.

1.2 NEED OF THE PROJECT

Some of the industrial wastes like Fly Ash, Silica Fumes, and Blast Furnace Slag etc. have already established their usage in making of concrete. Therefore there is increased desire to find a new post-consumer materials which can be used as partial replacement for cement.Waste glass after certain treatment when grinded and obtained in the form of fine powder, turns out to be one such material. Although there are studies being carried out on using waste glass powder as supplementary cementitious material but the extent of these studies is limited. Glass powder is rich in silica and therefore when blended with cement, the possibility of Alkali-Silica reaction (ASR) increases. Therefore there is need to address ASR problem and thus properly examine the potential of waste glass powder as partial replacement of cement.

Also, there is limit on the availability of natural raw material used for making cement, and it is important to reduce energy consumption and outflow of carbon dioxide coming about because of construction processes. Solutions of this issue are looked through considering the uses of waste glass powder as partial substitution of Portland cement. Replacing cement partially by pozzolanic material like waste glass powder in concrete, not only enhance the strength and introduces economy but also upgrade the durability.

1.3 SCOPE OF THE PROJECT

Glass powder is rich in Silica because of which there is very much possibility of Alkali-silica reaction. Due to higher content of Silica, glass powder possesses pozzolanic properties but it also contributes to higher possibilities of Alkali Silica Reaction because of presence of alkalis in waste glass powder as well as cement. The issue of Alkali-Silica reaction (ASR) which is a noteworthy measure for the utilization of glass powder as supplementary cementitious material is addressed by using waste glass powder with particle size up to 75 microns. Hence the study finds its scope not only in India but all around the globe.

Generally there is a presence of Chlorides and Sulphates of Sodium, Magnesium and Calcium in alkaline soils and water. Sulphates respond synthetically with products of hydration causes expansion and chloride within concrete tend to make the concrete more permeable. Therefore, the activity of chlorides and sulfates in concrete containing waste glass powder as partial replacement of cement need to be examined.

The concrete produced using cement modified with waste glass powder can also be examined for resistance to Chloride ion ingression and water penetration. Further the microstructure of concrete produced by using cement modified with waste glass powder can be examined so that durability properties like electrical resistivity and Interfacial transition zone can be analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Literature review is a critical summary of published research literature relevant to a topic under consideration for research. In this project, literature under-mentioned presents an objective and critical summary of work being carried out on utilization of waste glass powder in production of concrete and how incorporation of waste glass powder affects properties of cement and concrete. The purpose of literature review is to know research done and its future significance on this topic. Following literature review is presented in chronological order starting from recent work. This project work deals with research significance given by *Ali A. Aliabdo* and his team.

2.2 Waste glass powder as partial replacement of cement for sustainable concrete practice, G.M. Sadiqul Islam, M.H. Rahman, NayemKazi [1].

G. M. Sadiqul Islam, M. H. Rahman and NayemKazi carried out research work to use waste glass powder as partial replacement of cement for sustainable concrete practice. In this research, they have evaluated properties of both colored and clear glass. For chemical analysis they used X-ray fluorescence (XRF) technique and found that there is very minor difference between chemical compositions of colored and clear glass. ground glass was added upto 25% of weight of cement and mortar and concrete were produced by keeping water - cement ratio same for every replacement level. They found that with increase in replacement level of glass powder, mortar flow also increases while there was no significant effect on workability of concrete. To evaluate the packing and pozzolanic effects, they add 1% super plasticizing admixture. As a result they found subsequent increase in compressive strength of mortar. They prepare cube samples of concrete and tested them for compressive strength. The test results for compressive strength of concrete cube samples show significant enhancement in compressive strength as compared to control samples. 20% replacement level of ground glass was found to be convincing keeping cost and environment in mind. They also concluded that glass addition reduce the cost of cement production by 14%.

2.3 Utilization of waste glass powder in the production of cement and concrete, Ali A. Aliabdo, M. AbdElmoaty, Ahmed Y. Aboshama [2].

The objective of this research was to experimentally study the utilization of waste glass powder in production of cement and concrete. This research work was carried out in three phases. The objective of each phase was achieved and study concluded the effects of utilization ofwaste glass powder in concrete industry. In the first phase, experiments were performed to evaluate the Pozzolanic effect of glass powder. These experiments were carried out in accordance with ASTM C618, whereas second phase involved the study of the properties of cement partially replaced with waste glass powderin accordance with ESS 2421-1993. Finally the experiments performed in third phase highlighted the properties of concrete prepared with cement partially replaced with glass powder. In this research, the grain size distribution for waste glass powder ranges from 0.0015 mm to 0.070 mm and it was used as cement replacement and as cement addition. The test results showed that the glass powder had pozzolanic characteristics and the use of waste glass powder had insignificant effect on setting time and cement soundness. The use of glass powder also refine the pores of cement paste and this reflects the mortar and concrete properties. Finally,the use of 15% glass powder as cement addition increased concrete compressive strength by 16% in average and achieved better performance compared with conventional concrete.

2.4 Waste Glass Powder as cement replacement in concrete, Hongjian Du, Kiang Hwee Tan [4].

The objective of this research was to examine the possibility of using waste glass powder as cement replacement in concrete. Hongjian Du and Kiang Hwee Tan experimentally studied the pozzolanic reactivity of waste glass powder at cement replacement levels of 0, 15, 30, 45 and 30% by cement weight. Their test results show that there was no decrement in compressive strength of concrete due to partial replacement of cement with waste glass powder upto 30%. This was because of pozzolanic reaction between cement constituents and waste glass powder constituents. They also determined the increase in resistance to water penetration and Chloride ion with increase in waste glass powder replacement level upto

60%. At 60% replacement level, they recorded reduction in water penetration depth and electrical resistivity by 80% and 95% respectively. It was because of refined microstructure, especially at Interfacial transition zone (ITZ). To confirm the impermeability against water and chloride, pore size distribution was also carried out. This study concluded that for High Performance concrete, 15% of glass powder can be used as additive so that it can contribute to pozzolanic reaction instead of filler material for compact packing.

2.5 Experimental investigation of waste glass powder as the partial replacement of cement in concrete production, Jitendra B. Jangid, Prof. A.C. Saoji [5].

In this study experimental investigation of waste glass powder as the partial replacement of cement in concrete production was carried out. This study shows that like Fly Ash and Silica Fumes, finer particles of waste glass powder can also act as filler material when cement is partially replaced with waste glass powder. In this research cement was partially replaced with waste glass powder at varying percentage ranges from 5% to 40%, at interval of 5%. Mix design was carried out for making M30 grade of concrete in accordance with IS 10262:2009. The results of mix design for M30 grade of concrete yields a mix proportion of 1:1:2 with water cement ratio of 0.48. The use of chemical admixtures was not preferred for carrying out this experimental work.Concrete specimens prepared with cement replaced atdifferent percentage was cured under normal conditions and were tested at 28 days and 60 days for determining the compressive and flexural strength. Same set of experiments were performed on specimens made with M30 grade of conventional concrete. The results of both sets of experiments were recorded and then compared with each other to determine the use of waste glass powder as partial replacement of cement at varying percentages. In this experimental work, the results show that the slump value of fresh concrete was in the range of 80mm to 100mm. Test results also conclude that higher strength was obtained when 20% cement was replaced with waste glass powder and from strength point of view replacement of glass powder at 20% of cement content shows positive results. The overall test results shows that Waste Glass Powder could be utilized in concrete as a good substitute of cement.

2.6 Utilization of waste glass powder in concrete – A literature review, Bhupendra Singh Shekhawat, Dr. Vanita Aggarwal [6].

In this paper Bhupendra Singh Shekhawat and Dr. Vanita Aggarwal presents a literature review on utilization of waste glass powder in concrete. This review paper concluded that Natural issues are playing a critical part in the practical advancement of the cement and concrete industry. Thus there is a need to replace a part of cement by some pozzolanic material to decrease the cement consumption and the natural contamination can be checked to some extent. Some of the industrial by-products like fly ash, silica fumes, blast furnace slag etc. had already established their usage in production of concrete. As of late the researches has demonstrated that the waste glass can be adequately utilized as a part of cement either as glass aggregates or as partially replacement of cement in the form of pozzolanic glass powder. Waste glass when grounded to a fine powder exhibit some pozzolanic properties because of rich silica content. Thus this conclude that glass powder to some extent can substitute the cement and contributes towards quality improvement and furthermore upgrades durability attributes. Demand of recycled glass has extensively diminished as of late, especially for blended glass. Glass is less expensive to store than to reuse, as conditioners require increased costs for recycling procedure. There are several alternates of composite-glass. As per late reviews, every one of these applications, which require pre-molding and smashing, are pretty much restricted and not able to retain every one of the amounts of waste glass accessible. So as to give an economical answer for glass stockpiling, a potential and motivating force way is to reuse this sort of glass in concrete. Thus this review paper present a literature review on replacement of ordinary Portland cement with waste glass powder.

2.7 Experimental study on replacement of cement by glass powder, R Vandhiyan, K. Ramkumar, R. Ramya [7].

In this research work, R Vandhiyan and team carried out an experimental study on replacement of cement by glass powder. For achieving the objectives of this research work, the recycled glass in the form of fine powder was used and tests were performed on specimens made of concrete and mortar made with cement modified partially with waste glass in the form of fine powder. Waste glass in the form of fine powder replaced cement in the proportion of 5%, 10% and 15%. Tests were performed on specimens made of modified concrete and mortar with glass powder and consistency, compressive strength, flexural strength and split tensile strength were determined. The test results showed that use of glass powder in the form of fine powder as partial replacement of cement enhance the mechanical properties of concrete and cement as compared to conventional concrete and conventional mortar. This experimental study also concluded that replacement of cement with glass powder in the form of fine powder results in economically cheap as well as more superior concrete from durability point of view can be made.

2.8 Experimental investigation of waste glass powder as partial replacement of cement in concrete, Dhanaraj Mohan Patil, Dr. Keshav K. Sangle [8].

The objective of this research was to carry out an experimental investigation on waste glass powder as partial replacement of cement in concrete production. The effect of glass powder on strength of concrete was also studied during this research. For carrying out this research work, the cement was replaced at 10%, 20% and 30% whereas for determining the size effect of glass powder, the powder was divided into two groups. One group contained glass powder having particle size less than 90 microns and other group contains glass powder having particle size ranges from 90 microns to 150 microns. Mix design was carried out for production of M30 concrete in accordance with IS 10262:2009 [16]. In this study total of four specimen groups were prepared. Specimen 1 group was prepared by replacing cement with fine glass powder having particle size less than 90 microns and specimen 2 group was prepared by replacing cement with fine glass powder having particle size ranges from 90 microns to 150 microns. The replacement of cement varies as 10%, 20%and 30% of cement weight. Groups three and four contained the specimens prepared with conventional concrete. Same set of experiments were performed on specimens of each group. From test results it was concluded that due to the replacement of cement with fine glass powder there was very less gain in initial strength on 7^{th} day but as the specimens approached 28^{th} day there is a significant increase in strength. From results it was also concluded that concrete prepared with cement blended with glass powder having particle size less than 90 micron get higher strength than that concrete prepared with cement blended with glass powder havingparticle size range from 90 to 150 micron.

2.9 Studies on glass powder as partial replacement of cement in concrete production, Dr. G.Vijayakumar, H. Vishaliny, Dr. D. Govindarajulu [9].

The objective of this research was to examine the possibilities of using glass powder as partial replacement of cement in concrete production. In this research waste glass in the form of finely powdered was used as partial replacement of cement in concrete production.Cement was replaced with fine glass powder by 10%, 20%, 30% and 40% of cement. Experiments were performed on concrete produced by using such cement to determine physical and chemical characteristics of concrete. Same set of experiments were performed on control specimens prepared of conventional concrete. The compressive strength test on specimens made of both conventional and concrete containing cement partially replaced with fine glass powder, was performed on standard compression testing machine of 3000kN capacity in accordance with IS: 516-1959. Test results show that use of fine glass powder in concrete increases the compressive, tensile and flexural strength effectively, when compared with conventional concrete. Very fineparticles of waste glass powder also worked excellently as filler material and the effect of Alkali-Silica reaction got reduced with micro-filler properties of very fine particles of waste glass powder.

2.10 Performance of using waste glass powder in concrete as replacement of cement, Gunalaan Vasudevan, Seri Ganis Kanapathy Pillay [10].

The objective of this study was to investigate the effect of using waste glass powder in concrete. Experimental work was carried out to determine the performance of control sample and concrete with waste glass powder as partial replacement of cement. Workability test, density test and compressive strength test were performed to determine the performance of these types of concrete. Density test results show that due to the micro-filler properties of waste glass powderthe density of concrete containing waste glass powder as partial replacement of cement is reduced as compare to control specimens of conventional concrete. Hence concrete become lighter when its cement content is partially replaced with grounded glass powder. Workability test shows that concrete containing waste glass powder as partially replacement of cementpossess high workability as compared to control samples of conventional concrete. For every kind of concrete, a total of six 150mm×150mm×150mm cube samples were prepared. Theses cubes were tested after 7, 14 and 28 days to determine the development of compressive strength. Thusafter carrying out this research work, authors concluded that the concrete in which cement was partially replaced with waste glass powder possess increased workability and also the compressive strength as compared to that of conventional concrete.

2.11 Durability of concrete using waste glass powder as cement replacement, Ana Mafalda Matos, Joana Sousa-Coutinho [12].

The objective of this research was to examine the durability of mortar using waste glass powder as cement replacement. In this research glass powder was thoroughly analyzed as a partial replacement of cement in mortar. Experiments were also carried out for beyond the usual mechanical testing and Alkali-Silica reaction. From durability point of view, considerations were also made on chloride ingress, carbonation, sulphate attack and sorptivity. To achieve objectives of this research waste glass was crushed and grounded to fine powder and used in mortar as partial replacement of cement at 10% and 20% by cement content so as to ascertain the applicability in concrete. An extensive set of experiments were performed to achieve the objectives of the research. This set of extensive experiments included Pozzolanic activity, chemical analysis, X-Ray diffraction, scanning electronic microscopy (SEM), chloride ion penetration, capillarity absorption, accelerated carbonation, external sulphate resistance, setting time, soundness and specific gravity on mortar containing waste glass powder as partial replacement of cement. Test results of SEM showed that use of waste glass powder results in dense and mature gel which helps in enhancing durability of mortar thus concluded that waste glass powder can further contribute to achieve sustainability in construction without affecting the properties of conventional cement mortar and further conventional concrete.

2.12 Glass powder utilization in concrete production, J.M. Khatib, E.M. Negim, H.S. Sohl, N. Chileshe [13].

In this study J.M. Khatib and team investigated the performance of concrete containing glass powder as partial substitution of cement. The control mix had a proportion of 1:2:4 and water cement ratio was 0.5. The cement partially replaced with 10%, 20%, 30%, and 40% glass powder. For each mix, 15 cubes of 100mm in size were prepared. Before casting, the slump test was conducted to assess the workability. Specimens were casted in steel moulds and placed in a room at 20°C for 24 hours until demoulding. Thereafter, all specimens were placed in water at 20°C. The cubes were used to determine the compressive strength and ultrasonic pulse velocity (UPV). Testing for UPV was determined at 1 day, 7 days, 14 days, 21 days and 28 days whereas the compressive strength was determined at 28 days only. Using ground glass powder can reduce the use of cement and the concerned energy demand and adverse effects on air pollution and CO_2 emission. The slump of concrete seems to increase with the increase in percentage of glass powder in the concrete mix. At 10% glass powder content the compressive strength of concrete is higher than that of the control specimen. Above 20% glass powder content the strength of concrete specimen substantially decreases.

2.13 Experimental Investigations in developing concrete containing waste glass powder as pozzolana, M.N. Bajad, C.D. Modhera [15].

The objective of this research was to carry out experimental investigations in developing concrete containing waste glass powder as pozzolona. In this research efforts has been made to determine the strength of concrete containing waste glass powder as pozzolona. To carry out this experimental investigation, cement had been replaced with waste glass powder at varying percentages ranging from 5% to 40% with increment of 5% (5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%). OPC 43 grade cement, locally available sand and coarse aggregates were used in this experimental investigation. The sand used confirms to zone – II and maximum size of coarse aggregates was 12 mm. To complement workability, super-plasticizer from a reputed company was also used. The dosage of super-plasticizer was 1% by weight of cement. The waste glass powder used was obtained by crushing waste glass in cone crusher mill. The waste glass powder used has 600 micro passing fraction. M20 grade of concrete was prepared by carrying out Mix design in accordance with IS 10262:1982. Mix design for M20 grade of concrete yields mix proportion of 1:1.34:3.2 and water cement ratio of 0.45. To determine compressive strength of concrete, specimens of dimensions 150×150×150 mm were prepared and tests were performed using compressive testing machine (CTM) of capacity 2000KN as per IS 516:1959 over 30 and 90 days. Test results showed that highest increase in strength was about 24% and was achieved when cement was partially replaced with glass powder at 20%. Beyond 20% cement replacement, the compressive strength decrease significantly. Thus this experimental investigation concluded that 20% was the optimum level for replacing cement with waste glass powder.

2.14 Objective of the Project

After carrying above mentioned literature review, following objectives are predicted for this project:

1. To study the properties of cement blended with waste glass powder by performing various experiments.
2. To study the properties of concrete prepared by using glass powder as partial replacement of cement.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 GENERAL

In the first phase of research, test will be performed on cement which will be later partially replaced with waste glass powder. In the second phase, cubes of concrete will be cast and tests will be performed for determination of compressive and tensile strength. This research incorporates the use of M40 concrete. Test results of first phase and second phase will be recorded for later uses. After that cube specimens of cement mortar partially blended with waste glass powder and corresponding concrete cubes will be prepared and then various tests will be performed to obtain some basic engineering properties. The results of these test are then compared test results of first phase and second phase. With this the effect of partially replacing cement with waste glass powder at varying percentages will be determined and henceforth the potential of waste glass powder as partial replacement of cement can be known.

Phase 1 –This phase includes the experiments from which the basic properties of cement can be determined. This also includes the preparation of control specimens of cement mortar and corresponding testing to determine the compressive strength and tensile strength at 3 days, 7 days and 28 days. Sieve analysis for evaluating sand zoning and aggregates specifications is also carried out during this phase.

Phase 2 – This phase includes the process of preparing design mix of M40 grade of concrete. This also includes the preparation of control specimens of M40 concrete and corresponding testing to evaluate compressive strength at 3 days, 7 days and 28 days.

3.2 MATERIALS

A mixture of cement and sand when blended with water to form a paste is known as cement mortar and the composite material acquired by blending cement, water and an inert matrix of fine and coarse aggregates is called cement concrete. The recognizing property of concrete is its capacity to solidify when it reacts with water. The constituents of concrete can be organized into two groups, one being named as active and other as inactive. The active group comprises of cement and water, while the inactive group includes fine and coarse aggregates. The inactive group is also known as the inert matrix.

Cement –It is a well-known material and has occupied an irreplaceable place in construction works. There are various types of cements available in the market and every sort is utilized under specific conditions because of its extraordinary properties.Cement is by far the most important constituent of concrete or mortar because it works as primary binder. The function of cement is to not only bind the fine and coarse aggregates together but also to fill the voids between them so as to form a compact mass. The cement used for carrying out various experiments on mortar and concrete specimens so that objectives of this research can be achieved is Ordinary Portland Cement of 43 grade (OPC 43) as per IS 8112:1989 [11]. The cement used here as shown in Fig. 3.1 satisfies all the standards listed in IS 8112:1989 [11].

Fig. 3.1 – OPC 43 grade cement

Fine aggregates **–** The aggregates which passes through 4.75 mm IS sieve and contains only that much coarser particles as is specified in code standards. Fine aggregates are described as fine, medium and coarse sands on the basis of its particle size. Depending upon the particle size distribution, IS 383:1970 [27] has classified fine aggregates into four grading zones. As grading zones progress from zone I to zone IV, fineness of concerned sand also increases.

For this experimental work, locally available river sand (medium sand) with 2.87 fineness modulus confirming to Zone II as per IS 383:1970 [27] is used. Table 3.1 shows the results of sieve analysis of fine aggregates.

Table 3.1 – Sieve analysis of Fine aggregates

Total weight of sample = 1000 g			
Sieve Size	**Weight retained (g)**	**Cumulative weight retained (g)**	**Cumulative percentage weight retained (%)**
4.75 mm	0	0	0
2.36 mm	103	103	10.30
1.18 mm	214	317	31.70
600 microns	311	628	62.80
300 microns	197	825	82.50
150 microns	175	1000	100.00
			Sum = 287.30
Fineness Modulus = (sum of cumulative percentage weight retained) / 100 = 287.30/100 = 2.87			

Coarse aggregates – The aggregates which are retained on 4.75 mm IS sieve and contains only that much fine particles as is specified in code standards. Generally coarse aggregates derive their chemical properties and mineral composition from their parent rocks because of the fact that the natural disintegration of rocks results in their formation. Nominal size of aggregates describes the grading of coarse aggregates *i.e*. 40 mm, 20 mm, 16 mm, 12.5 mm and 10 mm, etc. In this research, the grading of coarse aggregates is done in accordance with IS 2386 (part 1):1963 [28] and for preparing concrete specimens the nominal maximum size of coarse aggregates used is 20 mm. Table 3.2 presents the grading analysis for coarse aggregates as per IS 2386 (part 1):1963 [28].

Table 3.2– Sieve analysis of Coarse aggregates

Total weight of sample = 5000 g			
Sieve Size	**Weight retained (g)**	**Cumulative weight retained (g)**	**Cumulative percentage weight retained (%)**
20 mm	0	0	0
16 mm	1646	1646	32.96
12.5 mm	3082	4728	94.56
10 mm	214	4942	98.84
6.3 mm	47	4989	99.78
4.75mm	11	5000	100.00

Water **–** It is one of the most important and least expensive constituent of concrete. When water is mixed with other constituents of concrete, a part of it is utilized in the hydration of cement so as to form a binding matrix in which aggregates are held in suspension until the matrix hardens. The remaining part of water provides a flow medium to fine and coarse aggregates which results in workability of concrete. Water is also important as it is also used for carrying out curing of concrete. Curing is a necessary and important process as it affects the durability of concrete. In this experimental work, as per IS 456:2000 [18] recommendations, potable water is used for mixing of mortar and concrete and curing of corresponding control specimens.

Glass Powder **–** Industrial waste glass is crushed and finely powdered glass powder is obtained. Glass is rich in SiO_2 thus providing pozzolanic properties to glass powder as well. Due to high content of SiO_2 there is very much chance of Alkali-Silica Reaction (ASR). To overcome this problem, glass powder as shown in Fig. 3.2, used is having particles finer than 75 microns. Specific gravity of glass powder is 2.62.

Fig. 3.2 – Glass Powder

***Chemical Admixtures*–** These are the chemical compounds that are added to the concrete at time of mixing so as to modify some specific properties of concrete. The use of chemical admixtures should not affect the overall performance of concrete. In this research work, Polycarboxylate Ether Super-plasticizer confirming to IS 9103:1999 [19] is used as water reducing agent (WRA). It enables fresh concrete mix to have higher workability even at lower water – cement ratio.

3.3 Experimental Parameters

The experimental program extended in this research work has been carried out in accordance with Indian Standards laid by Bureau of Indian Standards. All the materials used in this project satisfy the standards given in their respective codes. Tests performed during this experimental research are also in accordance with the standards given in IS codes.

3.4 Testing

As mentioned earlier, the research work is divided into four phases. Each phase includes preparation of samples and then performing corresponding tests on them so as to determine the various properties.

Phase I:-

Normal Consistency of Cement – It is the percentage water of cement paste at which of the paste becomes such that the plunger in a specially designed apparatus (Vicat's apparatus having plunger with 10 mm diameter and 50 mm length as per IS 5513:1996) [20] penetrates a, depth 5 to 7 mm measured from the bottom of mould. This test is performed in accordance with IS 4031(Part 4):1988 [23]. Take 400 g of cement and place it in the enameled tray. Mix about 25% water by weight of dry cement thoroughly to get a cement paste. Total time taken to obtain thoroughly mixed water cement paste *i.e.* "Gauging time" should not be less than 3 minutes and not more than 5 minutes. Fill the Vicat's mould, resting upon a non-porous base plate, with this cement paste. After filling the mould completely, smoothen the surface of the paste, making it level with top of the mould with the help of trowel. Place this whole assembly (*i.e.* mould + cement paste + base plate) under the Vicat's plunger as shown in Fig. 3.3. Lower the plunger gently so as to touch the surface of the test block and quickly release the plunger allowing it to sink into the paste. Measure the depth of penetration and record it. Prepare trial pastes with varying percentages of water content and follow the above steps until the depth of penetration becomes 33 to 35 mm.

Fig. 3.3 – Vicat's apparatus for Normal Consistency

Setting time of cement – Initial setting time is required to delay the process of hydration or hardening. It is the time period between the time water is added to cement and time at which needle having 1 mm^2 cross – sectional area fails to penetrate the cement paste, placed in the

Vicat's mould, 5 mm to 7 mm from the bottom of the mould. Final setting time is the time when the cement paste completely loses its plasticity. It is the time taken for the cement paste or cement concrete to harden sufficiently and attain the shape of mould in which it is casted. It is the time period between the time water is added to cement and the time at which needle having 1 mm^2 cross-sectional area makes an impression on the paste in the mould but attachment having 5 mm diameter does not make any impression. This test is performed as per IS 4031(part 5):1988 [24]. According to IS 8112:2013 [11], initial setting time should not be less than 30 minutes and final setting time should not be more than 600 minutes for OPC 43 cement.

Fig. 3.4 – Vicat's apparatus for initial setting time

A neat cement paste with 0.85 P of water by weight of cement is prepared. P is normal consistency of cement and weight of cement is 400 g. This cement paste is filled in Vicat's mould as shown in Fig. 3.4, resting on a non-porous base plate. This mould is placed under the rod bearing the needle having cross sectional area of 1 mm^2. The needle is gently lowered so that it completely penetrates the test block. Time is recorded when this needle fails to penetrate the block for about 5 mm measured from the bottom of the mould. Now needle is replaced with annular attachment and time is recorded when needle within attachment leaves an impression while the annular attachment fails to do so.

Fineness of cement – It is measured by sieving cement on standard sieve. The proportion of cement of which the grain sizes are larger than the specified mesh size is thus determined.

Fineness of cement has great effect on the rate of hydration. Finer cement particles offers great heat of hydration and hence faster development of strength.

Fig. 3.5 – 90 microns sieve

This test is performed in accordance with IS 4031(part 1):1996 [21]. 100 g of cement sample is sieved manually on 90 microns sieve as shown in Fig. 3.5 for 10 to 15 minutes. Weight of cement retained on 90 micron sieve is recorded and fineness modulus of cement is determined.

Soundness of cement – It is the property of cement by virtue of which the cement does not undergo or does not show any appreciable expansion or change in volume after it has set. Thus soundness means the ability to resist volume expansion. This test is performed in accordance with IS 4031(part 3):1988 [22]. Cement paste is prepared by adding 0.78 P of water by weight of cement, where P is the normal consistency of cement and weight of cement is 100 g. Le-Chatelier mould is filled with this paste and then mould is covered by placing non-porous glass plates on top and bottom of the mould. A small weight is also placed on the top glass plate so as to resist the expansion in upper direction. Le-Chatelier apparatus as shown in Fig. 3.6 confirming to IS 5514:1996 [20] is then submerged in water for 24 hours in water bath. After 24 hours, whole assembly is kept in water bath at boiling temperature for 3 hours. Then the distance between two indicator points is recorded.

Fig. 3.6 – Le-Chatelier apparatus

Specific Gravity of cement – It is generally a ratio of density of cement to that of any known material.Generally water is used as reference material butin this research, Kerosene oil is used because it does not react with cement whereas water reacts with cement as soon as it came in contact. Specific gravity of Kerosene oil is 0.79. This test is performed in accordance with IS 4031(part 11):1988 [26]. Le-Chatelier flask as shown in Fig. 3.7 of 250 ml capacity is used. 64 g of cement is used. Flask is filled with kerosene oil up to upper mark (*i.e.* 1 ml) of graduations below the central bulb. After this 64 g of cement is poured gently into the flask which results in increased level of Kerosene oil in the flask. The ratio of weight of cement to displaced volume of kerosene gives the specific gravity of cement.

Fig. 3.7 – Le Chatelier flask

Compressive strength of cement mortar –Compressive strength is the ability of a material or structure to withstand compressive loads. It is determined by performing compressive strength tests on cube specimens prepared with cement mortar as shown in Fig. 3.8. The dimensions of these cubes are 7.06 mm×7.06 mm×7.06 mm. These tests are performed to determine the compressive strength of cement mortar at 3 days, 7 days and 28 days. This test satisfies the standards given in IS 4031(part 6):1988 [25]. Cement mortar is prepared by adding water equal to $\{\frac{P}{4}+3\}$ % by weight of cement. Here P signifies the normal consistency of cement. A total of nine cubes were casted and placed at room temperature for next 24 hours. After that moulds are removed and cubes are then submerged in potable water for curing. Cubes are taken out of water only at the time of testing. Three cubes are taken out after 3 days, 7 days & 28 days and tests are performed on these cubes in Compressive Testing Machine (CTM). The test results should satisfy the standards given in IS 8112:2013 [11].

Fig. 3.8–Cement mortar cube specimens

Tensile Strength of cement mortar – Tensile strength is the ability of a material to withstand loads tending to elongate or tensile loads. To determine the tensile strength of cement mortar, briquette specimens were prepared with cement mortar as shown in Fig. 3.9. For preparing briquette specimens, cement mortar was prepared by adding water equal to {(P/5) + 2.5} % by weight of cement, where P indicates the normal consistency of cement.

Fig. 3.9 – Briquette specimens

Total of 9 briquette specimens were prepared and then placed in room temperature for next 24 hours. After 24 hours, briquette moulds were removed and briquette specimens were submerged in potable water for curing. Specimens were taken out of the water only at the time of tests. Tests were performed on three briquettes in tensile testing machine at 3 days, 7 days and 28 days. The test results should satisfy the standards given in IS 8112:2013 [11].

Phase II:-

Design Mix – It is the process of selecting suitable ingredients of concrete and determines the relative proportions with the object of certain minimum strength as economically as possible. The objective of concrete mix design is to achieve the stipulated minimum strength and to make the concrete in the most economical manner. Cost wise all concretes depends primarily on two factors, namely cost of material and cost of labor. Labor cost, by way of formwork, batching, mixing, transporting and curing is normally same for good concrete. In this research design mix is carried out for making M40 grade concrete. The process of making M40 concrete follows the guidelines given in IS 10262:2009 [16]. Stipulations for proportioning are minimum water content equals to 320 Kg/m^3, maximum water-cement ratio equals to 0.45 and maximum cement content equals to 450 Kg/m^3. Super-plasticizer is used as chemical admixture for improving workability of concrete. Table 4.6 shows the mix proportions for design mix of M40 grade concrete for control mix as well as mix made with modified cement.

Compressive Strength of concrete - It is the capacity of a material or structure to withstand loads tending to reduce size. It is generally measured on a Compression Testing Machine (CTM). The tests performed in this experimental investigation for determination of Compressive strength of concrete control mix and concrete modified with glass powder are in accordance with IS 516:1959 [29]. Three specimens are prepared in cubical moulds having size 150mm×150mm×150mm for testing after mentioned age. Tests are performed after 7 days, 28 days and 56 days of curing.

Tensile Strength of concrete – It is the capacity of a material or structure to withstand loads tending to elongate the geometry of material or structure. The tests performed in this experimental investigation for determination of Tensile strength of concrete control mix and concrete modified with glass powder are in accordance with IS 516:1959 [29]. Three specimens are prepared in cylindrical moulds having 150 mm diameter and 300 mm length for testing after mentioned age. Tests are performed after 7 days, 28 days and 56 days of curing.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Normal Consistency of cement

Table 4.1 and Fig 4.1 shows the Normal Consistency values for OPC 43 grade cement and cement modified with waste glass powder.

Table 4.1 – Normal Consistency of OPC 43 modified with glass powder

Glass Replacement Level (%)	Normal Consistency (%)
0	31
10	30
20	28
30	27

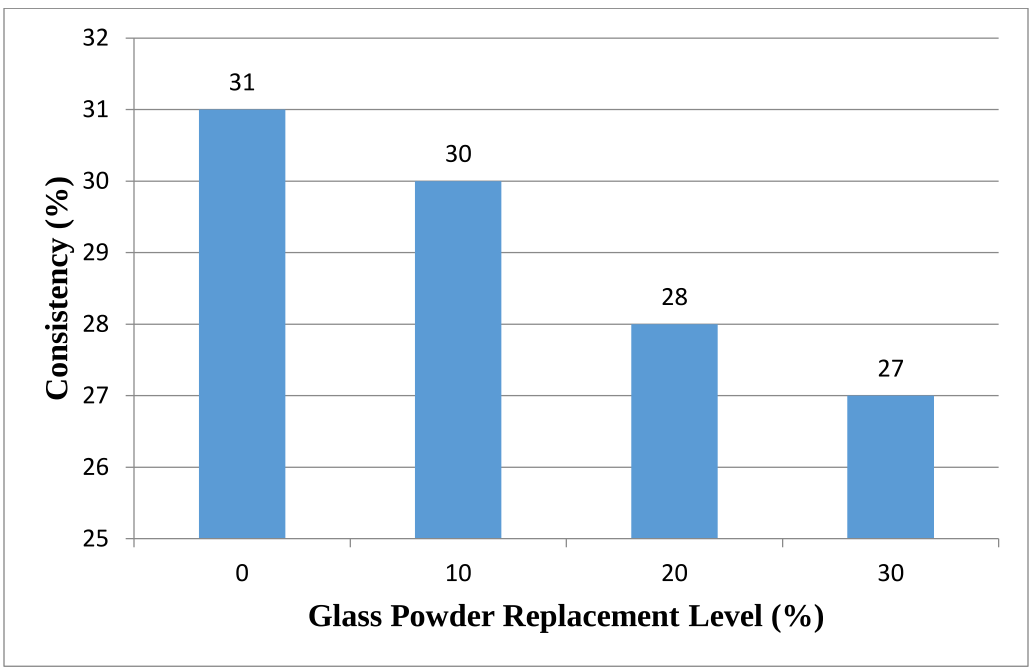

Fig. 4.1 - Normal Consistency of OPC 43 modified with glass powder

4.2 Setting time of cement

Table 4.2 and Fig. 4.2 shows the initial and final setting time of OPC 43 grade cement modified with waste glass powder

Table 4.2 – Setting times of OPC 43 modified with glass powder

Glass Replacement Level (%)	Initial Setting Time (Minutes)	Final Setting Time (Minutes)
0	105	290
10	112	305
20	115	300
30	125	315

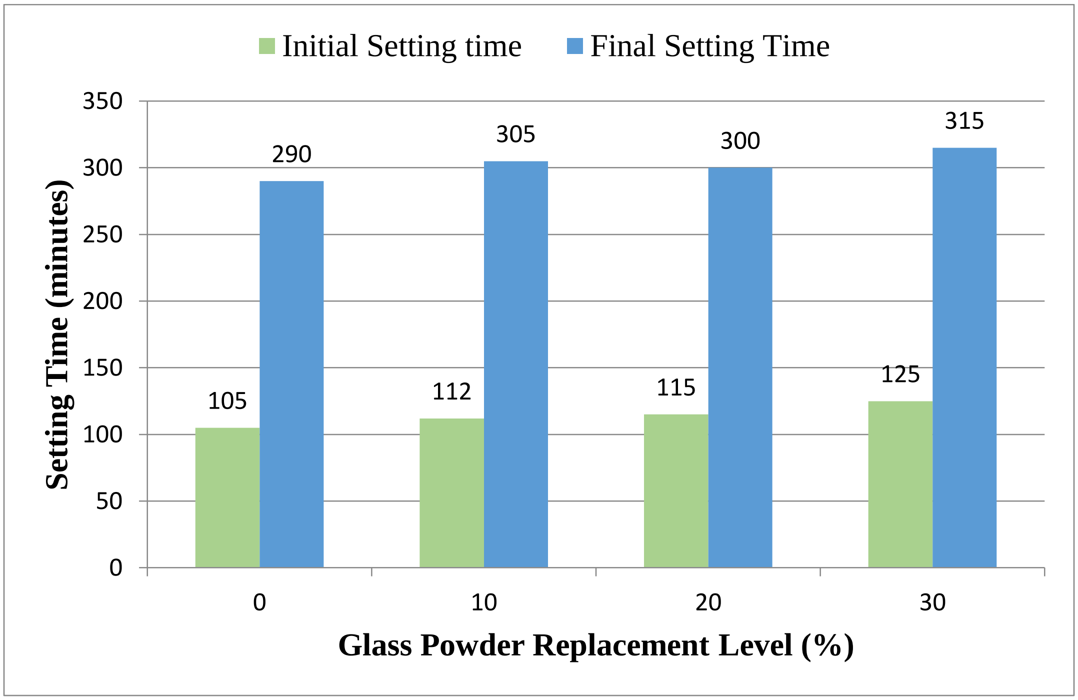

Fig. 4.2 - Setting times of OPC 43 modified with Glass Powder

4.3 Fineness Modulus of cement

When 100 g of cement was sieved manually using 90 microns sieve, 2.3 g cement got retained on sieve. This gives fineness modulus (FM) of cement as 2.3. Following formula is used to determine the Fineness Module of cement.

$$\text{F.M} = \left\{\frac{\text{Weight retained on 90 microns sieve}}{\text{Total weight}}\right\} \times 100$$

………. [21]

Weight retained on 90 microns sieve = 2.3 gms

Total weight = 100 gms

Fineness Modulus (F.M) = 2.3

4.4 Soundness of cement

Soundness of cement is calculated according to following formula

$$Soundness = L_2 - L_1$$

………. [22]

L_1 – Distance between indicator points after 24 hours of immersion in normal water

L_2 – Distance between indicator points after 3 hours of immersion in boiling water

Table 4.3 and Fig 4.3 shows the value of soundness for OPC 43 grade cement modified with waste glass powder.

Table 4.3 - Soundness of OPC 43 modified with Glass Powder

Glass Replacement Level (%)	Soundness (mm)
0	2.10
10	2.40
20	2.30
30	1.98

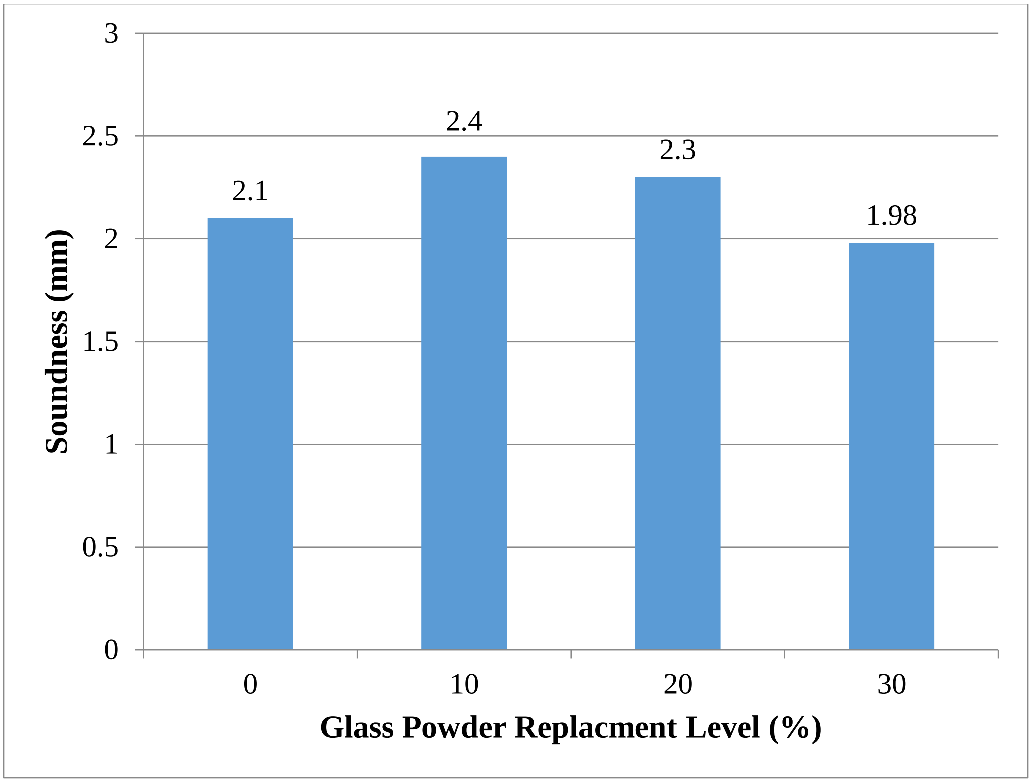

Fig. 4.3 - Soundness of OPC 43 modified with Glass Powder

4.5 Specific gravity of cement

Weight of cement, W = 64 g

Initial reading after kerosene oil is poured, V_1 = 1 ml

Final reading after 64 g cement is poured, V_2 = 20.9 ml

Increase in volume = $V_2 - V_1$

= 20.9 – 1

= 19.9 ml

Specific gravity of cement = W/ $(V_2 - V_1)$

= 64/ 19.9

= 3.21

Thus, specific gravity of cement is 3.21

4.6 Compressive strength of cement mortar

Table 4.2 presents the results for compressive strength of cement mortar modified with Glass Powder at 3 days, 7 days and 28 days. Fig 4.4 shows a cube specimen after curing for 3 days.

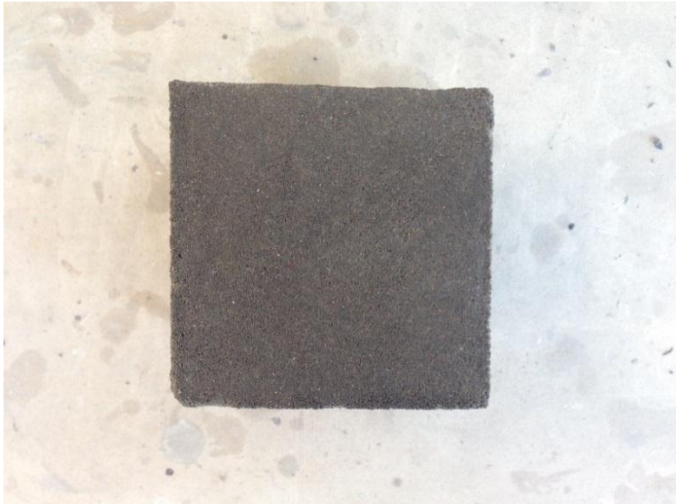

Fig. 4.4 – 3 days cube specimen

Table 4.4 – Compressive strength of cement mortar on various days of curing

Age	Replacement Level	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
3 days	0	20.46	20.26	19.86	20.19
	10	21.06	21.32	21.24	21.20
	20	22.52	22.08	22.20	22.27
	30	18.27	17.68	18.52	18.16
7 days	0	31.30	31.70	31.74	31.58
	10	33.06	32.78	33.10	32.98
	20	34.46	34.10	34.27	34.28
	30	27.70	28.01	27.64	27.78
28 days	0	41.32	41.52	41.52	41.45
	10	42.12	42.27	42.18	42.19
	20	42.56	42.68	42.46	42.56
	30	39.68	40.02	39.80	39.83

4.7 Tensile strength of cement mortar

Table 4.5 presents the results for tensile strength of cement mortar modified with Glass Powder at age of 3 days, 7 days and 28 days. A test ready briquette specimen after curing for 3 days is shown in Fig 4.5

Fig. 4.5 – 3 days briquette specimen

Table 4.5 – Tensile strength of cement mortar

Age	Replacement Level	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
3 days	0	2.05	2.02	1.96	2.01
	10	2.15	2.13	2.10	2.13
	20	2.07	2.05	2.05	2.06
	30	1.92	1.96	1.95	1.94
7 days	0	2.46	2.46	2.49	2.47
	10	3.01	2.98	2.94	2.98
	20	2.54	2.54	2.60	2.57
	30	2.35	2.36	2.41	2.37
28 days	0	3.07	3.05	3.00	3.04
	10	3.21	3.18	3.12	3.17
	20	3.14	3.11	3.02	3.09
	30	3.01	2.92	2.90	2.94

4.8 Mix proportions for M40 concrete

After carrying out design mix procedure for M40 grade of concrete Table 4.6 presents the mix proportions yield for Control Mix and mix after replacing cement with glass powder at varying percentages

Table 4.6 – Mix proportions for M40 concrete modified with Glass Powder

Mix No.	Notes	Cement (kg/m^3)	Glass powder (%)	Glass powder (kg/m^3)	Water content (kg/m^3)	Water-cement ratio	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)
1	Control Mix 1	350	0	0	140	0.40	896	1140
2	Glass powder Replacement	315	10	35	140	0.40	893	1137
3		280	20	70	140	0.40	890	1133
4		245	30	105	140	0.40	887	1129

4.9 Compressive Strength of Concrete

Table 4.7 presents the test results for Compressive strength of concrete modified with Glass Powder at different ages. Fig 4.6 represents graphical representation of compressive strength of control mix and concrete made with modified cement at various ages.

Table 4.7 - Compressive strength test results of concrete

Concrete grade	Age	Replacement level	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
M40	7 days	0	29.94	30.05	30.01	30.00
		10	31.09	31.42	31.27	31.26
		20	34.78	34.90	34.86	34.87
		30	29.52	29.61	29.54	29.56
	28 days	0	41.02	41.50	41.45	41.32
		10	43.73	43.86	43.75	43.78
		20	46.90	46.00	46.83	46.91
		30	38.78	39.05	38.81	38.87
	56 days	0	43.02	43.28	43.14	43.15
		10	44.71	44.89	44.80	44.80
		20	47.77	47.91	47.80	47.87
		30	40.79	40.93	40.88	40.87

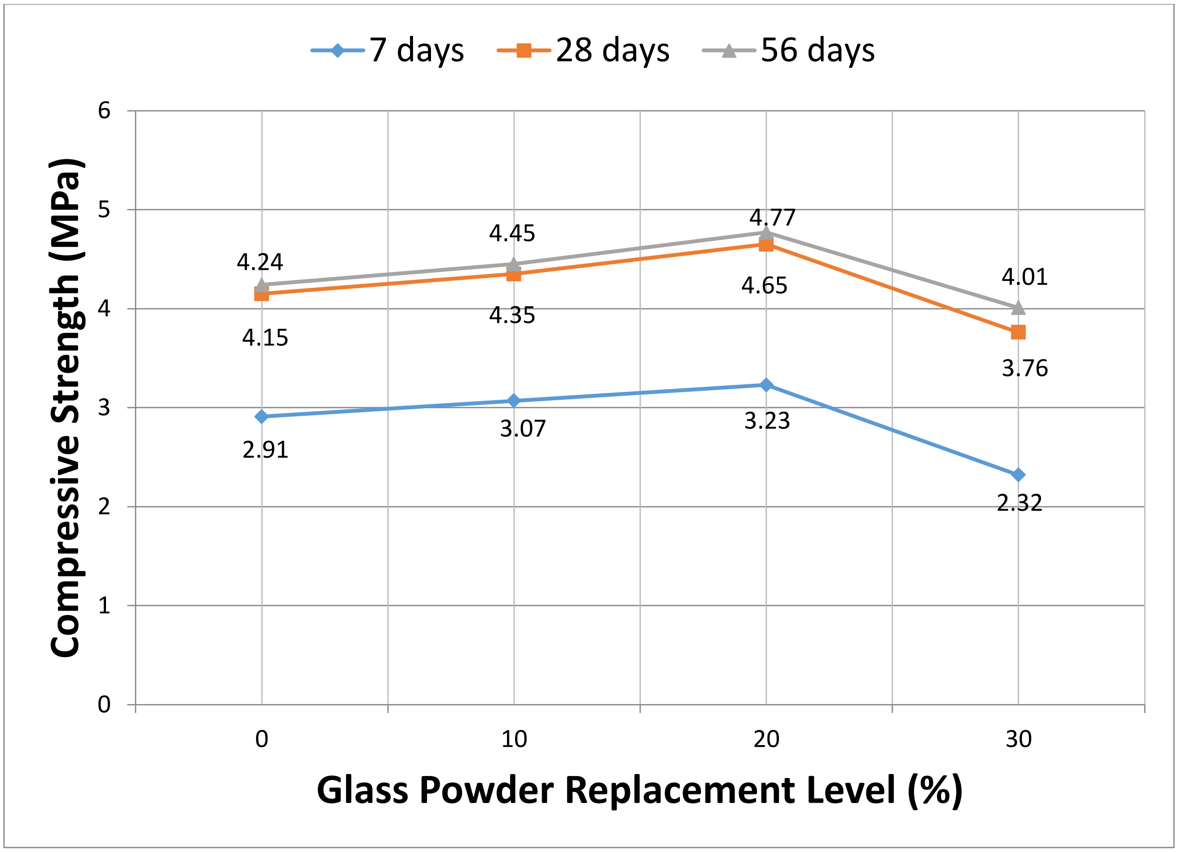

Fig. 4.6 - Compressive strength of M40 modified with waste glass powder

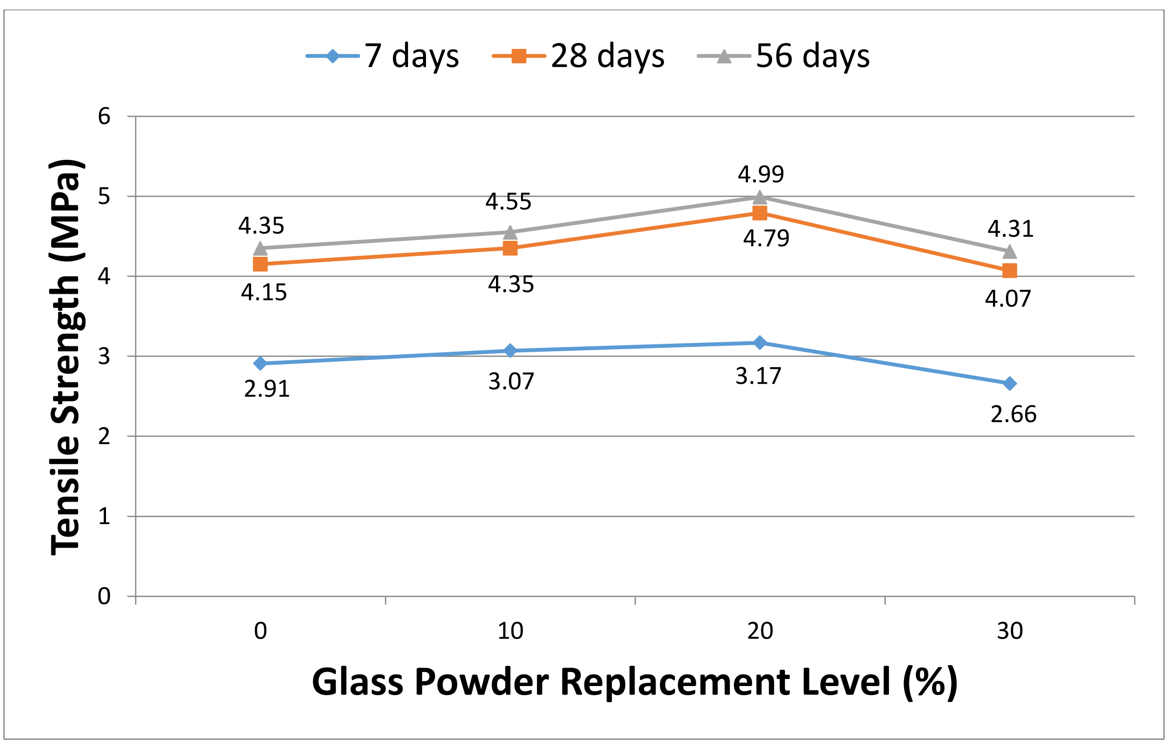

Fig. 4.7 – Tensile strength of M40 modified with waste glass powder

4.10 Tensile Strength of concrete

Table 4.8 presents the test results for tensile strength of concrete modified with glass powder at varying percentages at different ages. Fig 4.7 represents graphical representation of tensile strength of control mix and concrete made with modified cement at various ages.

Table 4.8 – Tensile strength test results of concrete

Concrete grade	Age	Replacement level	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Average (MPa)
M40	7 days	0	2.91	2.93	2.88	2.91
		10	3.04	3.01	3.16	3.07
		20	3.15	3.21	3.16	3.17
		30	2.61	2.69	2.67	2.66
	28 days	0	4.15	4.19	4.11	4.15
		10	4.32	4.38	4.35	4.35
		20	4.80	4.82	4.74	4.79
		30	4.02	4.1	4.08	4.07
	56 days	0	4.33	4.36	4.35	4.35
		10	4.52	4.57	4.55	4.55
		20	4.97	5.01	5.00	4.99
		30	4.31	4.34	4.32	4.32

CHAPTER 5

CONCLUSIONS

This research work recorded experimental results of test specimens prepared by using cement partially replaced with waste glass powder. Based on these test results following conclusions regarding potential of waste glass powder as partial replacement of cement can be drawn:

1. The use of glass powder as partial replacement of cement decreases the normal consistency of cement.
2. The use of glass powder has insignificant effects on soundness and setting times of cement.
3. The use of glass powder as partial replacement up to 20% enhances the compressive strength of concrete by 15%.
4. The use of glass powder as partial replacement up to 20% increases the tensile strength of concrete by about 10%.

This research deals with only waste glass powder obtained from clear waste glass so there is scope to examine the same for waste glass powder obtained from colored glass. Sulphates respond synthetically with products of hydration causes expansion and chloride within concrete tend to make the concrete more permeable .Therefore, the activity of chlorides and sulfates in concrete containing waste glass powder as partial replacement of cement need to be examined. The concrete produced using cement modified with waste glass powder can also be examined for resistance to Chloride ion ingression and water penetration. Further the microstructure of concrete produced by using cement modified with waste glass powder can be examined so that durability properties like electrical resistivity and Interfacial transition zone can be analyzed.

REFERENCES

[1] Islam, G.M.S., Rahman, M.H. and Kazi, N. (2016). "Waste Glass Powder as Partial Replacement of Cement for sustainable concrete practice," *International Journal of Sustainable Built Environment*, in press.

[2] Ali, A.A., Elmoaty, M. Abd. and Ahmed, Y.A. (2016)."Utilization of waste glass powder in the production of cement and concrete," *Construction and Building Materials*, 124, 866–877.

[3] 52^{nd} Annual Report (2015-16), "*Cement Corporation of India Ltd.*" Page 6.

[4] Du, H. and Tan, K.H. (2014). "Waste Glass Powder as Cement Replacement in Concrete," *Journal of Advanced Concrete Technology*, Volume 2, 468–477.

[5] Jangid, J.B. and Prof. Saoji, A.C. (2014). "Experimental investigation of waste glass powder as the partial replacement of cement in concrete production," *IOSR Journal of Mechanical and Civil Engineering*, 55 – 60.

[6] Shekhawat, B.S. and Dr. Aggarwal, V. (2014). "Utilization of waste glass powder in concrete – A literature review," *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, Issue 7.

[7] Vandhiyan, R., Ramkumar, K. and Ramya, R. (2013). "Experimental study on replacement of cement by glass powder," *International Journal of Engineering Research and Technology*, Vol. 2, Issue 5.

[8] Patil D.M and Dr. Sangle, K.K (2013). "Experimental investigation of waste glass powder as partial replacement of cement in concrete," *International Journal of Advanced Technology in Civil Engineering*, Vol. 2, Issue 1.

[9] Dr. Vijayakumar, G., Ms. Vishaliny, H. and Dr. Govindarajulu, D. (2013). "Studies on glass powder as partial replacement of cement in concrete production." *International journal of emerging technology and advanced engineering*, Vol. 3, Issue 2.

[10] Vasudevan, G. and Pillay, S.G.K., (2013), "Performance of using waste glass powder in concrete as replacement of cement," *American Journal of Engineering Research*, 175 – 181.

[11] IS 8112:2013. Ordinary Portland Cement 43 grade – Specifications. *Bureau of Indian Standards*, New Delhi.

[12] Mafalda, A. and Sousa-Coutinho, J., (2012), "Durability of concrete using waste glass powder as cement replacement," *Construction and Building Materials* 36, 205 – 215.

[13] Khatib J.M., Negim, E.M., Sohl, H.S. and Chileshe, N., (2012), "Glass powder utilization in concrete production." *European Journal of Applied Sciences*, 173 – 176.

[14] Gopalakrishnan, R. and Govindarajan, D. (2011). "Compressive strength of concrete subjected to Sulphate attack," *International Journal of Civil Engineering*, 01–13.

[15] Bajad, M.N. and Modhera, C.D., (2010), "Experimental Investigations in developing concrete containing waste glass powder as pozzolana," *Journal of information, knowledge and research in civil engineering*, Vol. 1, Issue 1.

[16] IS 10262:2009. Concret Mix Proportioning – Guidelines. *Bureau of Indian Standards*, New Delhi.

[17] Pade, C. and Guimaraes, M. (2007). "The CO_2 uptake of concrete in 100 year perspective," *Cement and Construction Research* 1348-1356.

[18] IS 456:2000. Plain and Reinforced Concrete – Code of Practice. *Bureau of Indian Standards*, New Delhi.

[19] IS 9103:1999. Concrete Admixtures – Specifications. *Bureau of Indian Standards*, New Delhi.

[20] IS 5514:1996. Apparatus used in Le-Chatelier Test – Specifications. *Bureau of Indian Standards*, New Delhi.

[21] IS 4031(Part 1):1996. Method of Physical Test for Hydraulic Cement, Part 1 - Determination of Fineness by Dry Sieving. *Bureau of Indian Standards*, New Delhi.

[22] IS 4031(Part 3):1988. Method of Physical Test for Hydraulic Cement, Part 3 - Determination of Soundness. *Bureau of Indian Standards*, New Delhi.

[23] IS 4031(Part 4):1988. Method of Physical Test for Hydraulic Cement, Part 4 - Determination of Consistency of standard cement paste. *Bureau of Indian Standards*, New Delhi.

[24] IS 4031(Part 5):1988. Method of Physical Test for Hydraulic Cement, Part 5 - Determination of Initial and Final Setting Times. *Bureau of Indian Standards*, New Delhi.

[25] IS 4031(Part 6):1988. Method of Physical Test for Hydraulic Cement, Part 6 - Determination of Compressive Strength of Hydraulic Cement. *Bureau of Indian Standards*, New Delhi.

[26] IS 4031(Part 11):1988. Method of Physical Test for Hydraulic Cement, Part 11 - Determination of Density. *Bureau of Indian Standards*, New Delhi.

[27] IS 383:1970. Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete. *Bureau of Indian Standards*, New Delhi.

[28] IS 2386(Part 1):1963. Methods of Test for Aggregates for Concrete, Part 1 - Particle Size and Shape. *Bureau of Indian Standards*, New Delhi.

[29] IS 519:1959. Methods of Tests for Strength of Concrete. *Bureau of Indian Standards*, New Delhi.