“Compressive Behavior of High Strength Concrete Short Columns with Waste Marble Powder as Partial Replacement of Cement and Sand at Elevated Temperature”

A Thesis of

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in

Structural Engineering

By

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(NUST-2018-MS SE 00000274277)

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Department of Structural Engineering

Military College of Engineering, Risalpur

National University of Science & Technology

Islamabad, Pakistan

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Submitted to

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This is to certify that the

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This thesis is dedicated to **Muhammad wa Aal e Muhammad (SA. W)**; minaret of knowledge and wisdom, my beloved **Mother,** and my beloved **Father Haji Qadir Bakhsh** who always supported me through thick and thin of my life, and my beloved **brothers** who cheered me when I was sad and always motivated me. I would also like to extend my heart most gratification to respected **Dr. Syed Hassan Farooq** and my **advisor Dr. Muhammad Shahid Siddique** whose guidance made me able to finish my research work.

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Abstract

Fire is one of the most dangerous threats to which buildings are exposed. Concrete exposed to high temperatures undergoes significant physical and chemical changes. In order to tackle these threats, researchers have used different materials to prepare a sustainable fire resistance concrete mix. In this study, Waste Marble Powder (WMP) was used in the RCC short columns to improve its fire resistance. This investigation is divided into two phases. In the first phase, 10 % WMP was incorporated in concrete as a replacement of cement. In the second phase, 30% and 50% WMP were used as sand replacement in mortar with plastering of columns. All the samples were tested at unstress residual conditions with targeted temperatures of 200, 400, 600 and 800 ºC at a heating rate of 5 ºC/min. Different properties namely stiffness, ductility, load deformation curve and compressive toughness caused by elevated temperatures exposure, were measured. At increasing temperatures, waste marble powder-modified samples showed higher load carrying capacity, stiffness, and compressive toughness as compared to the control sample. Visual assessment also investigated after high temperature exposure revealed that modified columns exhibited lesser cracks as compared to control columns. On the other hand, the effect of 30 % sand replacement in mortar, load carrying capacity was slightly increased as compared to control sample at elevated temperatures.

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LIST OF ABBREVIATIONS

WMP	Waste Marble Powder
CR-WMP	Cement Replacement with Waste Marble Powder
SRP-WMP	Sand Replacement in Plastering with Waste Marble Powder
HSC	High Strength Concrete
NSC	Normal Strength Concrete
SRMs	Secondary Raw Materials
SCMs	Secondary Cementitious Materials
SCAM	Self-compacting architectural mortars
C-H	Calcium Hydroxide
C-S-H	Calcium silicate hydrate
fc’	28 days Compressive strength
Tc	Compressive toughness
TI	Toughness index
RG	Recycle glass
SP	Superplasticizers
AASHTO	American Association of State Highway and Transportation Officials

Chapter 1

1 INTRODUCTION

1.1 General

Concrete, for obvious reasons, is one of the most widely used material in construction industry around the globe, due to its ease of construction, tremendous strength, durability, elasticity, and cost-efficiency. It is a mixture of cement, aggregate, and water. During the life of a concrete structure, it is subjected to numerous forms of loads such as dead load, live load, wind load, and impact load. It also undergoes environmental hazards such as earthquakes and fire. Due to all these loads and environmental risks, concrete durability has become a top priority in concrete structures. As concrete's behavior is largely influenced by various factors such as proportioning of elements, chemical and physical properties of materials, curing conditions and type of cement etc., so for that purpose in-depth study of its mechanical behavior is necessary. In recent years Normal Strength Concrete (NSC) has been pushed to the sidelines, owing to its inability to meet performance demands. But on the other hand, high strength concrete is becoming popular due to its excellent mechanical qualities, including compressive and tensile strength. It is also more resistant to chemical assaults when compared to conventional strength concrete. Furthermore, because of its dense microstructure, high strength concrete has limited permeability [1].

Concrete's compressive strength is a direct indicator of its performance quality; concrete with a higher compressive strength has a larger modulus of elasticity, tensile strength, and lower permeability, and thus has a higher durability. The compressive strength of concrete determines most of its qualities. With developments in material science, Superplasticizers (SP) or High Range Water Reducers (HRWRs) have been used to manufacture concrete with extremely high compressive strength, and the use of HSC has become quite popular. In terms of greater durability and economics, HSC has a lot of advantages.

High Strength Concrete (HSC) is good in various ways, but it undergoes many undesirable chemical changes when it is subjected to elevated temperatures. When HSC is exposed to fire, it experiences a lot of thermal cracking and negative chemical changes, which puts its structural usage at risk [2]. At elevated temperature pore pressure increases due to the evaporation of water in the pores which causes the abrupt embrittlement and subject massive tensile load on the concrete inner core [3]. The concrete core has a smaller heat dispersion than the surrounding layer. Due to their greater surface temperature, the outermost concrete layers are susceptible to high temperatures. and relatively low thermal conductivity, and heat transfer to the core layers is slow. This mechanism slows total heat transport to the interior layers of concrete, resulting in thermal inertia [4]. Tensile thermal load are usually caused by an increase in heat gradient due to thermal inertia which results in fissures causing spalling and cracks [5].

Due to the issues high strength concrete faces when it is exposed to fire waste marble powder is used in this research. Waste Marble Powder (WMP) is obtained as a byproduct of the cutting of marble. Marble powder has a good resistance against fire as its melting point reaches up to 825 °C. Furthermore, its particle size ranges from 5 to 150 μm having angular shapes which form a good bond with the cement particles.

1.2 Waste Marble Powder concrete and mortar

Physical and chemical properties of concrete are degraded by high temperatures. In general, the performance of concrete at high temperatures is evaluated by assessing the change in its mechanical properties as a function of temperature exposure. For the retrofitting of a fire-damaged concrete structure, it is also necessary to evaluate the building's resistance to severe temperatures before to and after exposure. Concrete is often acknowledged as a non-combustible building material with superior fire ratings when compared to other building materials.

The use of finely ground wastes or by-products in concrete has grown increasingly popular since it can produce better results and more successfully, particularly in terms of the material's mechanical properties and durability. Several waste kinds have been mentioned in the literature, such as fly ash for making Portland cement with additives.

Since the construction industry is acknowledged as one of the most polluting in the world, sustainable construction has been an intriguing issue in the field of environmental and civil engineering during the last several decades. one of the most essential components of civilization raw material consumers. Raw materials like silica fume fly ash granite powder and GGBS etc. It’s very important to study because waste materials deposition is a concern all over the worlds. If waste materials are deposited to the surface of earth, it increases alkalinity and infertility of land. If waste materials are deposited to the under the earth its contaminated tour underground water. So, when a waste material used in construction industries it’s not only reduced the cost but also reduce use of natural resources. In this work waste marble use to take step towards the sustainability.

The use of Waste Marble Powder (WMP) in high strength concrete should be researched because of the possible benefits of WMP concrete, such as sustainability and thermal efficiency. In addition, the fire resistance of WMP must be tested in mortar. Likewise, there is no consideration of the thermal and mechanical performance of WMP high strength concrete in elevated temperatures/fire conditions in the literature. As a result, the current study is an attempt to address the issues raised.

1.3 Behavior of concrete under fire

When there are fires or when there are furnaces and reactors nearby, concrete is exposed to intense heat. These exposures can cause mechanical qualities including strength, volume stability, and elastic modulus to degrade, leading to structural failures. Its surface undergoes a considerable change in appearance when exposed to high temperatures. A structure's fire rating is the amount of time it can withstand fire loads without compromising structural integrity, stability, or temperature transfer [6]. Because concrete is a highly non-homogeneous material, a variety of factors influence its performance at high temperatures, including compressive strength, specimen size, initial moisture content, heating rate, maximum exposure temperature, water to cement ratio, size of aggregate, aggregate type, cement type, and so on. The major mechanism by which increased temperatures induce concrete degradation is the formation of tensile strains in concrete when steam pressures cannot easily escape [7].

1.4 High Strength Concrete (HSC)

HSC stands for high-strength concrete, which means it has a higher compressive strength than regular or standard concrete. The difference in their 28-day compressive strength is the main distinction between HSC and NSC. Among standards and writers, the maximum strength value that distinguishes between HSC and NSC is unclear. The value of this threshold varies between publications and standards. HSC is defined by as concrete with a compressive strength higher than 41.25 MPa (6000 psi) [8]. In this research, the strength threshold established by is considered the minimum strength of HSC. During their service life, HSC constructions may be subjected to greater temperatures in the event of a fire. Numerous studies have examined the performance of concrete at elevated temperatures. The results reveal that, despite its superior performance in all other conditions, HSC performs poorly at elevated temperatures as compared to NSC. The behavior of High Strength Concrete (HSC) is peculiar as compared to normal strength concrete at elevated temperatures. Fabrication of HSC requires a deep understanding of the knowledge of the usage of water reducers, superplasticizers, pozzolans, Secondary Raw Materials (SRMs) etc. Production and usage of HSC opened new paths in the construction industry and concrete technology and is widely used all over the world. HSC is a major advancement in the concrete industry, but various experimental research has shown that HSC members have less fire resistance than NSC members. (Lie and Woollerton 1988, Kodur, Khaliq et al. 2013). The lower high-temperature performance of HSC members may be related to their increased rate of strength degradation and fire-induced spalling. [7], [9].

1.5 Fire behavior of HSC

Fire is one of the most dangerous threats that might happen during the serviceability of a concrete structure. Due to fire strength of concrete reduced unevenly and degradation is non uniform so, it’s very important to study fire behavior of concrete. Furthermore, the building industry is rapidly transitioning to the use of high strength concrete due to its improved mechanical and durability performance. HSC, on the other hand, has a dense microstructure that makes it more susceptible to fire damage. Therefore, the purpose of this research is to enhance the fire resistance of concrete against fire. Therefore, we utilize marble powder to determine the degree to which the fire resistance of short columns might be improved.

1.6 Waste Marble Powder in HSC

Concrete's microstructure may be improved by using waste powder made from marble as a filler in the mixture. Up to a specific replacement ratio, which is often believed to be 10 % based on the findings of various experiments, the presence of marble debris may have a major impact on the capacity. The mineralogical analysis of marble waste particles indicated the presence of dolomite ($CaMg(CO_3)_2$ and calcite ($CaCO_3$) as the predominant minerals, with a negligible amount of quartz (SiO_2).

(a) (b) (c)

Figure 1: a= marble slurry, b= WMP, c= coarse aggregate WMP during cutting, sawing,

1.7 Research objectives

The primary aim of this research study is to investigate the fire behavior of CR-WMP in HSC (Waste Marble powder high strength concretes) and SRP-WMP in HSC (Waste Marble powder plaster high strength concrete) in terms of its material and mechanical properties in the temperature range between 23-800°C. The objectives of the study include:

- To study the mechanical properties of short Columns, in high strength concrete using waste marble powder as a replacement of cement at elevated temperatures.
- To study the effectiveness of waste marble powder as replacement of sand in mortar plastering columns to find the thermal resistance of concrete under elevated temperature.

1.8 Research significance

The annual worldwide production of concrete is around twelve billion tons. It is making it one of the world's top consumers of natural resources. By 2050, it is anticipated that the annual demand for concrete would rise to around eighteen billion tones. [10]. This massive use of concrete is responsible for the increased usage of natural aggregates and cement, which impacts on the environment. It has a substantial carbon impact. This study investigates the effect of increased temperatures on the mechanical and thermal characteristics of WMP-HSC and control HSC short columns. Numerous research is being done to assess the performance of HSC at extreme temperatures, since columns are the structural components, most impacted by a building fire. This research will explore the idea for WMP from Pakistan to be used as a binding material admixture. As a result, it will encourage the efficient use of WMP that would otherwise be dumped in Pakistan. Researchers from all over the world have studied the strength and durability of concrete mixes, mortars, and pastes containing varying doses of WMP, but no data on the effects of WMP-HSC Columns on the fire structural behavior is known. HSC under control sample and replacement sample both unstressed and residual fire scenarios, as a result, the current research will address this need. As a result, the current study is concerned with as a continuance of this subject, the impact of WMP usage on the performance of HSC columns at elevated temperatures.

1.9 Research layout

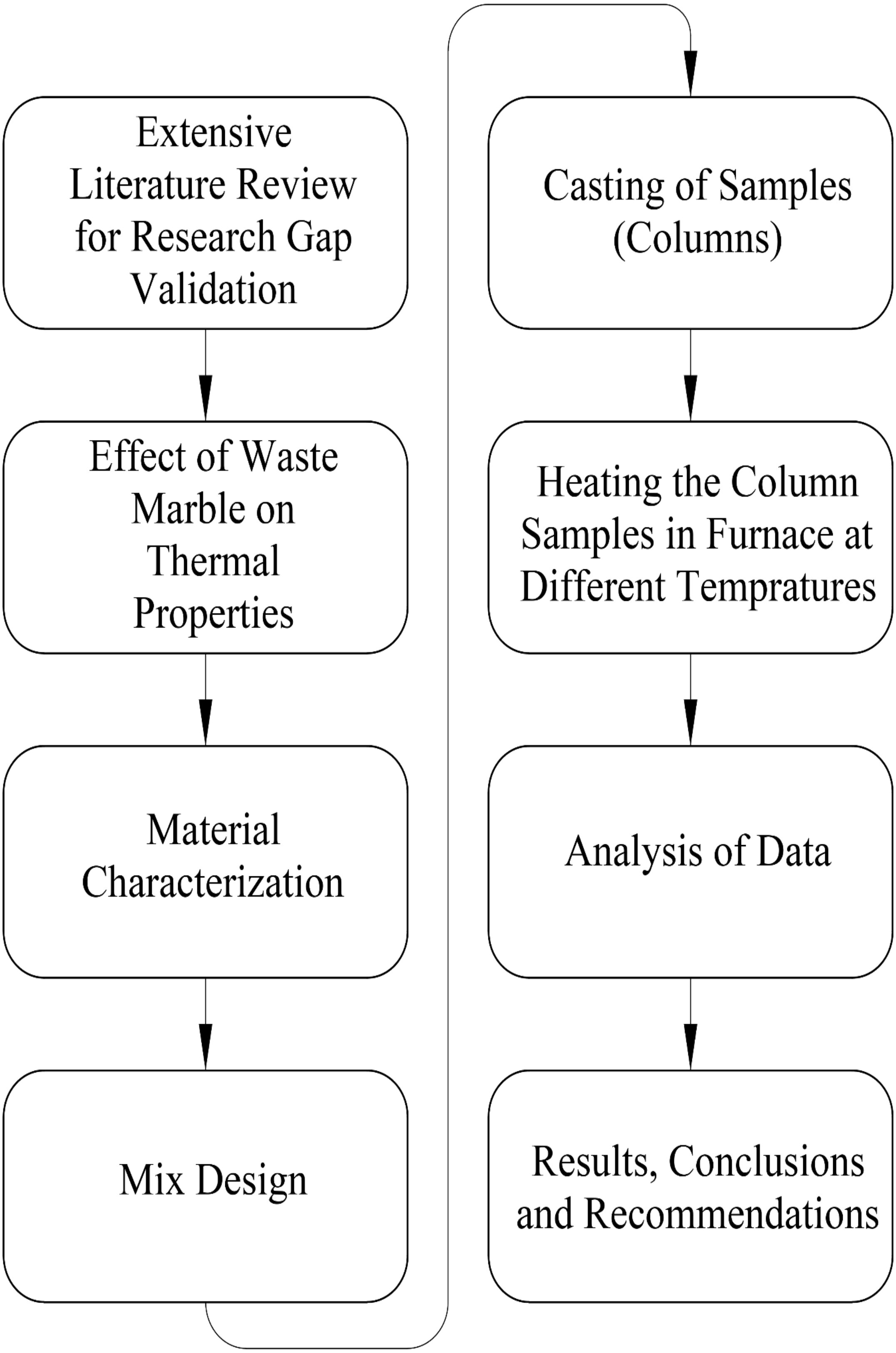


Figure 2: Research layout

1.10 Thesis Organization

This organization of the thesis is as follows.

Chapter 1: This chapter gives an overview of the role of concrete in our daily life along with the significance of high strength concrete. Furthermore, research objectives, waste marble powder role, and scope of research are also discussed in it.

Chapter 2: This chapter gives a detailed literature review about the brief revision of the previously related research on waste marble powder. It also gives an overview of the properties of materials and testing methods that are to be implemented in this research.

Chapter 3: This chapter explains methodology and experimental process followed for batching, specimen designation and testing of properties of waste marble powder blended HSC.

Chapter 4: This chapter presents all the test results carried out for concrete properties like physical appearance, compressive strength etc.

Chapter 5: “Conclusions and Recommendations” provides detailed conclusions based on the outcomes of this research and remarks for further studies.

Chapter 2

2 LITERATURE REVIEW

2.1 General

Concrete is an extremely versatile building material that can be utilized for practically any kind of construction because of its low cost, ease of handling and molding in any desired shape. After water, it is the second most used substance on planet earth. The adaptability of concrete properties as per the demand and situation makes it the second most prevalent substance. Most of the constituent materials are usually available at low cost and locally or at a small distance from the construction site except cement, which just like other materials is a finite material. There is a necessity to search out alternate materials which can be used as a substitute of cement to lower the cost of concrete.

The material, mechanical, and physical characteristics of concrete are severely harmed by these temperature variations, which result in decreased compressive strength, splitting tensile strength, elastic modulus, and an increase in porosity, permeability, and concrete cover spalling. Higher temperatures can have an impact on the thermal, mechanical, deformational, material, and physical characteristics of concrete. When exposed to high temperatures, high strength concrete (HSC) exhibits unique behavior that differs significantly from that of normal strength concrete (NSC). A thorough knowledge of the use of water reducers, superplasticizers, pozzolans, secondary raw materials (SRMs), etc. is necessary to produce HSC. Due to a lack of knowledge about these incredibly beneficial compounds, pozzolans and SRMs are not commonly utilized in the building sector such pozzolans.

Concrete structure is increasingly being used. It faces extreme environmental conditions and accidents such as fires that break out accidentally or high temperatures. It has been found that concrete offers susceptibility to spalling when exposed to fire [11]. Concrete's fire resistance capacity is very complicated since it is not only composite material made up of a mixture with different thermal characteristics, but it also possesses moisture and porosity-related characteristics [12]. Concrete structures are regularly exposed to external conditions that might negatively influence their mechanical and durability characteristics [13]. Differences in the chemical and physical properties of concrete owing to temperature fluctuations are dependent not only on the contents, but also on the concrete's moisture content and porosity [14]. Several research on the behavior of concrete at high temperatures have been undertaken. [15] studied properties of different types of concrete at high temperatures while [16]–[18], tested the concrete qualities, namely the strength, of several types of concrete. In accordance with the findings, when the temperature rises, the strength and elastic modulus of concrete decrease, the peak strain increases, the stress strain curve of concrete flattens, and the location of the peak strain increase so curve shifts downward [19], [20].

In recent years, High Strength Concrete (HSC) has been extensively used in civil and infrastructure engineering projects. Although HSC offers substantial benefits in strength and durability, it performs worse at high temperatures than Normal Strength Concrete (NSC) [21]. Thus, keeping an eye on the severe environmental impacts associated with cement production, researchers started to quest for cement alternatives.

Their ongoing studies have introduced us to Secondary Cementitious Materials (SCMs), also called Mineral Admixtures (MAs), mostly by-products from other industries. Pozzolanas or Secondary Cementitious Materials (SCMs) such as Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF), Limestone Powder (LSP), and Fly Ash (FA), have been utilized as cement substitutes and have been introduced to the globe. SCMs are most often found in industrial or agricultural waste. These pozzolanas are not only available to make concrete production more environmentally friendly, but their right use may also result in higher-quality concrete.

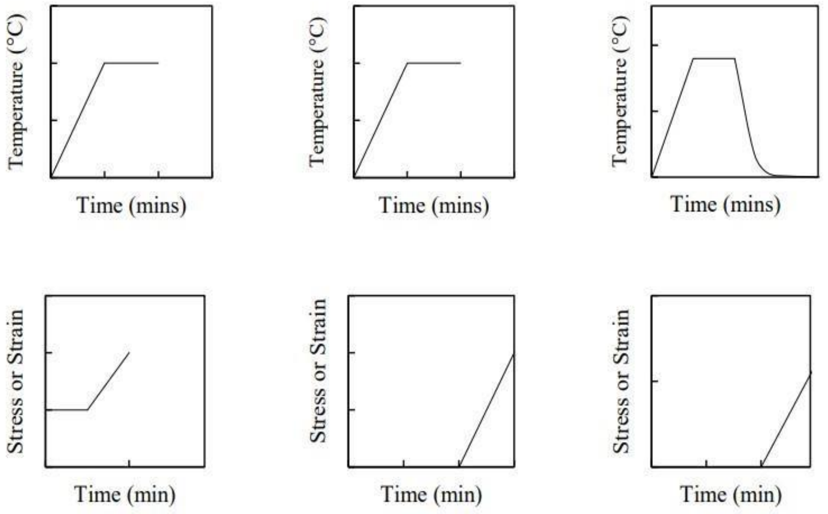
In addition, researchers have successfully included fibers, such as steel fibers [22], polypropylene fibers [23], [24], and To improve mechanical qualities at high temperatures, basalt fibers were included into concrete. These investigations, however, do not consider the effect of load on the mechanical characteristics of concrete at increased temperatures. If a building is destroyed by fire or must operate in a high-temperature environment, the concrete must be able to sustain the load given by the superstructure under such circumstances. Many components of the environment are negatively impacted by waste, including water, air, vegetation, human and animal health, and living situations. The worldwide trash production is expected to increase from 12 billion tons in 2002, of which 11 billion tons were industrial waste, to 25 billion tons by 2025 [25].

Such large consumption of concrete leads to increased usage of natural aggregates and cement, which ultimately has a negative impact on the environment. It has a significant carbon impact. Cement manufacturing is an unsustainable and ecologically damaging process. It consumes a considerable amount of energy, depletes natural resources of raw materials, and emits many harmful gases into the atmosphere. Cement manufacturing has a significant impact on our living environment. The construction sector is responsible for around one-third of the world's total energy consumption, which results in approximately 30 % of the world's total carbon dioxide emissions [26].

The reaction between reactive (amorphous) silica found in SCM and Portlandite (Calcium Hydroxide) produced during cement hydration creates extra C-S-H gel. The addition of the C-S-H gel results in a more dense and better microstructure in the concrete. When particles finer than cement particles are incorporated as SCM, they fill voids in cement, resulting in a dense microstructure. Another activity is hydration facilitation, which occurs when very fine particles smaller than 1 mm in SCM function as crystallites for the deposition of hydration products, resulting in quick growth of hydration products from many sites [27].

2.2 High temperature testing methods based on heating and loading regimes

Most tests examining the deterioration of concrete's material characteristics at increasing temperatures utilize one of three test methods: stressed, unstressed, or unstressed residual property tests. During the stressed test procedure, a preload of 20 to 40% of the ultimate compressive strength is maintained on the specimen while heated. The specimen is loaded to failure after the target temperature is attained. This test technique is a more accurate representation of an actual structure that has been subjected to high temperatures. The specimen is heated without a preload during the unstressed test procedure. After achieving the desired temperature, the specimen is loaded to failure.



Stressed test method Unstressed test method Unstressed residual test method

Figure 3: Three different high-temperature test methods [28]

During the unstrained test, the specimen is heated without a preload. During the non-stressed residual test, the specimen is heated without a preload. After the desired temperature is reached, the specimen is allowed to cool to room temperature. After the specimen has cooled to room temperature, it is loaded to failure. This test process is essential for rebuilding a structure that has been damaged by fire. It is crucial to remember that in all test techniques, the heating phase continues until the test specimen reaches thermal equilibrium [28]. These three test procedures are depicted in diagram form in Figure 3.

2.3 Previous investigation on waste marble powder

Marble has been one of the most popular construction materials since ancient. Marble is used for building and adornment, and its mineralogical components differ based on its origin. At quarries and processing companies, enormous amounts of trash are produced when marble is processed for various uses. China and India are the top-ranking countries for such production, responsible for approximately 50% of the world’s production. Generally, two different forms of waste during tiles manufacturing are produced i.e., fine materials of less than 2 mm size and large marble particulates, especially in granular forms. During the cutting operation of one cubic meter of marble block, roughly 25% of fine particles are produced as wastes. This is the main reason for trying to find a sustainable solution to this problem [29].

When used in low %age of the cement, marble Powder improve strength. However, at high replacement ratios, beyond 10% to 15%, the compressive and tensile strengths of the concrete reduce. Another importance of this material, in addition to its sustainable benefits, comes from the high degree of fineness that allows its utilization as filler [30].

Hasan [31] concluded that when natural standard sand is substituted with marble dust at a ratio of 15 to 75 %, the compressive strength improves by 20 to 26 % and the splitting tensile strength increases by 10 to 15 %, according to the findings. However, coarse marble aggregates produced the greatest performance at a replacement ratio of 100 %. In addition, discarded marble in the form of coarse aggregate increases the mechanical properties. It was observed that replacing 20 % or more of the cement with marble powder has negative impacts on the compressive strength and workability of concrete. In addition to influencing the mechanical qualities of concrete, marble powder at a cement-replacement ratio of 5-10 % reduces worldwide yearly CO2 emissions by 12 % and reduces expenses from $40/m3 to $36/m3.

Since old age, Egyptians practiced quarrying and used marble for different purposes. This was improved by Romans in Italy. Economic activity in this field was established in the last decade of eighteen century. Today, more than 42 countries are producing dimensional marble stones. Amongst them are six from Europe, three from Asia and three from Africa leading the global marketplace. With the advent of technology in the last century, marble manufacture has enhanced up to 150 million tons, and usage reached about 9 billion square feet. World ‘s marble consumption is achieved through the material extracted in different countries. China is the leading extractor followed by Italy. Some academics have recently developed a new technique they term the "paste replacement approach." In this procedure, leftover marble is substituted for cement paste (water + cement) without altering the ratio of water to cement. This technology demonstrates that the durability and dimensional stability of mortar may be greatly enhanced. Additionally, the cement content may be lowered by as much as 33 %. The mean particle size of the WMP is comparable to that of the cement, and the particle size range of the WMP is wider than that of the cement (this means that some of the WMP particles are finer than the cement and some of the WMP particles are coarser than the cement). It may be due to marble has a Mohs hardness of around three and is thus not a hard rock. During the polishing process, some WMP particles are ground to a more suitable size than cement [32].

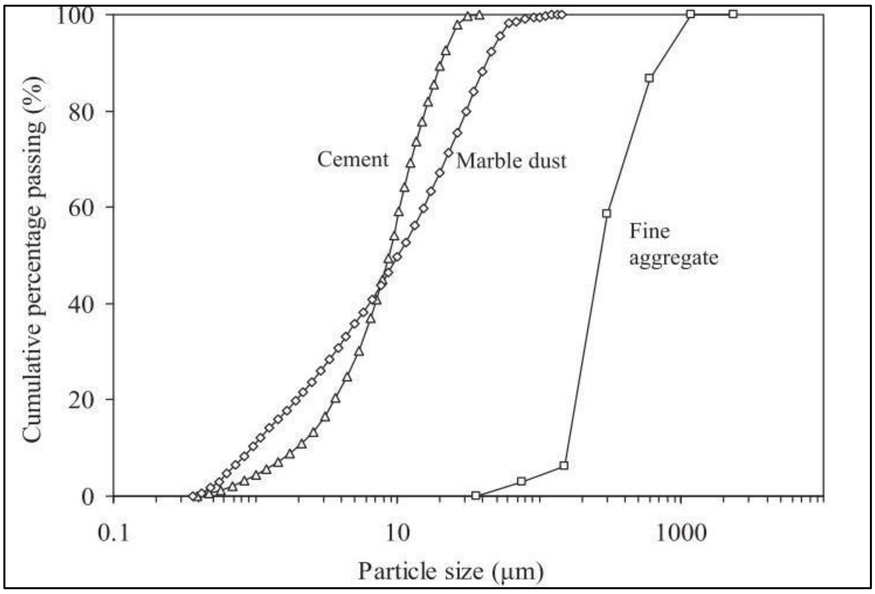


Figure 4 : Cumulative % of the passing size of a marble, cement, and sand [32]

2.4 Behavior of concrete under elevated temperature

Concrete fire behavior is complicated and depends on several things. There is still a lot of research to characterize the performance of concrete subjected to high temperatures to provide state-of-the-art guidance to assure the safety of concrete structures in the event of a fire. High temperatures harm concrete's physical and chemical qualities. Because concrete is a highly non-homogeneous material, a variety of factors, such as compressive strength, specimen size, water content, heating rate, maximum exposure temperature, water to cement ratio, type of aggregates, type of cement, and so on, influence its performance at elevated temperatures. It has been discovered that the constituent ingredients of concrete have a significant impact on its performance at high temperatures. As a result, researchers attempt to determine the effects of all regularly used concrete elements on the material's performance at high temperatures. During the service life of a concrete structure, fire is regarded one of the most serious hazards. Furthermore, due to its superior mechanical and durability performance, the construction sector is rapidly shifting to the usage of high strength concrete (HSC). Concrete constructions can face catastrophic failures because of fire. The Windsor Tower was a well-known structure in Spain, constructed in 1979 in Madrid's business district. It had 32 stories and a hybrid structure with reinforced concrete and steel parts. In 2005, it was destroyed by a massive fire that lasted 18 to 20 hours. Under the effects of high temperatures, it entirely collapsed. A detailed analysis revealed that the lack of fire protection on steel elements was the primary cause of the development of severe temperature fields in structural elements, which proved to be catastrophic.

For reconstructing a concrete structure damaged by fire loads, durability characteristics before and after exposure to elevated temperatures are also significant to evaluate. Concrete is commonly thought of as a non-combustible building material with high fire resistance compared to its alternatives. Fire rating is the duration of a structure in which it can resist fire loads without losing its structural integrity, stability, and temperature transmission [33]. Tensile stress created by obstructed team pressure escape cause significant microcracking inside concrete, resulting in a slow loss of concrete mechanical performance due to exposure temperatures. Thermal deficiencies between aggregates and pastes, the existence of a temperature difference between the surface and core of concrete, which results in severe relative shear load deformations, thermal decomposition of hydration products, and thermal decomposition of aggregates are all factors that contribute to the disintegration of concrete because of exposure to high temperatures [34].

2.5 Behavior of high strength concrete at elevated temperature

High Strength Concrete (HSC) performance under fire conditions is the best concern in the construction industry. Though concrete has relatively superior fire resistance when compared to its companion construction materials, it has been noted that prolonged exposure to high temperatures causes concrete to deteriorate rapidly. Concrete fire behavior is complicated and depends on a variety of factors. The primary mechanism through which elevated temperatures cause deterioration in concrete is the development of tensile load in concrete when the steam pressures have no easy escape it [35].

When concrete is exposed to high temperatures, steam pressures are formed because of the fire of physically and chemically linked water. As a result, the critical component determining how well concrete performs at high temperatures is its porosity (microstructure density), directly proportional to its compressive strength. The more porous the concrete is, the less it will deteriorate at high temperatures. Concrete's compressive strength and porosity are proportional, meaning that the higher the compressive strength, the more compact the microstructure and the lower the porosity. As a result, HSC has been found to function poorly in high-temperature environments compared to NSC. [28] HSC has been widely used in recent decades, although its performance at high temperatures is much poorer than that of NSC. When HSC is subjected to high temperatures, another catastrophic failure mechanism known as explosive spalling has been discovered. The behavior of concrete under fire is quite complicated and is influenced by various elements. The extraordinarily complex behavior of concrete at high temperatures can be attributed to two factors. The first is moisture migration at high temperatures, and the second is the high non-homogeneity of concrete component materials, which varies.

Explosive spalling is a mechanism connected with HSC. The microstructure of concrete becomes coarser and porous when the adsorbed and inter-layer water of the C-S-H gel is lost, and hydration products are degraded due to elevated-temperature exposure. Therefore, the permeability of concrete increases. Concrete's permeability and durability go together. As a result, increased permeability of concrete after exposure to high temperatures raises significant durability concerns, as demonstrated experimentally by measuring chloride ion penetration before and after exposure to high temperatures [33]. Concrete as a construction material has a wide range of applications, so structures made of it can be exposed to high temperatures in a variety of situations, such as nuclear reactors, oil refineries, and steel mills, where the functional requirements are to perform at high temperatures for the rest of its life. Concrete has the strongest fire resistance of all building materials, yet tests have revealed that its strength degrades when subjected to high temperatures. When HSC is subjected to high temperatures, another catastrophic failure mechanism known as explosive spalling has been discovered. The behavior of concrete under fire is quite complicated and is influenced by different elements. The extraordinarily complicated behavior of concrete at high temperatures can be attributed to two factors. The first is moisture evaporating at high temperatures, and the second is the high non-homogeneity of concrete component materials, which varies from different Mix proportions. Critically viewing at the literature, HSC at elevated temperature behaves differently from NSC in two ways,

- Higher value of strength loss caused by elevated temperature than NSC in a temperature range of 100°C to 400°C.
- Failure due to spalling of concrete with an explosion at rapidly increasing rate of temperature which is again in contrast with NSC.

Different test variables influence the rate of strength loss as temperature rises and the rate of explosive spalling. Combination of load application time and heating scenario (stressed, un-stressed, and unstressed residual [28] initial moisture content of the specimen before fire testing [1],water-cementitious ratio (w/cm), sand ratio, quantity of silica fume and its ratio [36], heating and cooling [37], aggregate type (light weighted or normal weighted), and polypropylene addition are some of them. When study the fire behavior of concrete, whether HSC or NSC, there is a shortage of testing criteria. Different authors use different testing parameters, but for HSC, the rate of heating concrete specimens is kept to (2°C-5°C)/min and a cylinder size of 200mm height x 100mm diameter is used, [4] but other sizes are also used by some researchers, such as 300 mm x 150 mm diameter [15]

2.5.1 Spalling issues in High Strength Concrete (HSC)

When concrete constructions (especially HSC) are subjected to rapidly increasing temperatures, as in a fire, spalling is said to occur when layers or pieces of concrete are observed to disintegrate or separate, typically with an explosion. Spalling provides the biggest threat to a building because it exposes the concrete's deeper layers or core to fire. This exposure raises the temperature in the concrete core, which is the primary load-bearing area. If steel reinforcements are present in the vicinity of thermal exposure, reinforcement strength begins to deteriorate, the fire resistance of the entire structure decreases rapidly, and the structure ultimately collapses due to spalling. Spalling caused by fire is an uncommon phenomenon in NSC. Sanjayan [21] Measured the weight of the concrete structure with relation to time or temperature (since temperature increased with time) to capture the spalling behavior of HSC and NSC, as illustrated in Figure 5.

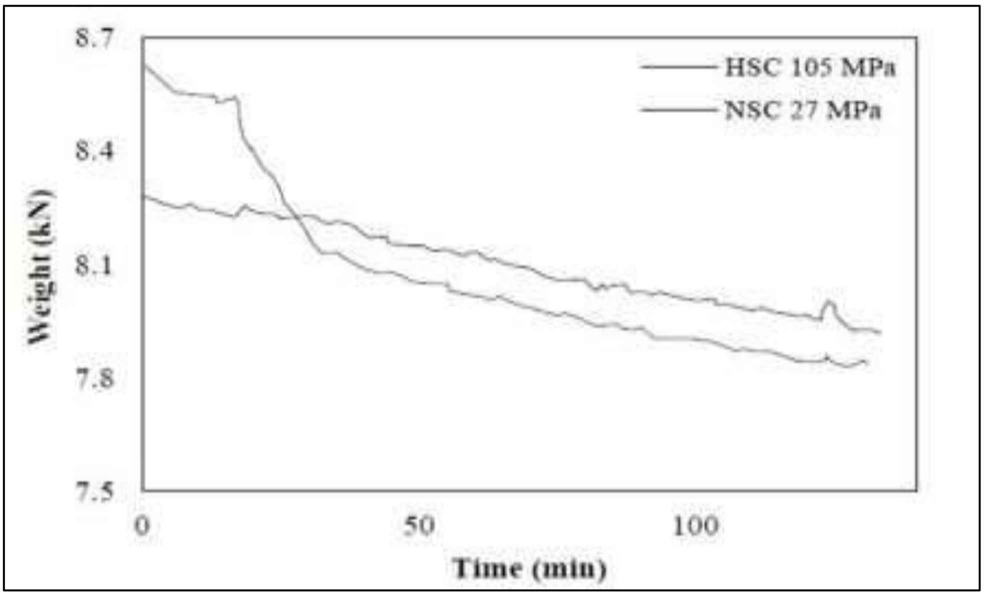


Figure 5: Mass loss measured for NSC and HSC [21]

As seen in above Figure 5, there is a dramatic decline in weight of the structure after almost 17 minutes, which corresponds to spalling in HSC, demonstrating that HSC is more prone to spalling than NSC. [28] found that concrete spalling caused by fire is explosive in character. The investigations on explosive spalling by various authors are listed.

It is vital to have a comprehensive understanding of the causes of concrete spalling to prevent it. Prevention is difficult without understanding the mechanism of spalling and its interdependencies. Different mechanisms of spalling have been proposed in the literature. The inconsistency may emerge because of the several elements that influence spalling. Furthermore, these variables are interdependent on one another. According to [4], different researchers have proposed two basic theories to explain the spalling activity of HSC. These are discussed below.

2.5.2 Internal pore pressure

When HSC is subjected to fire, the water vapors are unable to find a way to escape from the concrete surface due to its limited permeability. Pore pressure builds up as a result of the impediment caused by the concrete's poor permeability. At 300°C, pressure can reach 8 MPa, which is more than concrete's tensile strength (generally not more than 6 MPa).

As a result, chunks of concrete fall off the surface, which, depending on the concrete and fire properties, might be explosive [4].

2.5.3 Release of thermal load

The explanation of spalling due to pore or vapors pressure growth, according to [38], is only a weak point. The actual phenomena that cause explosive concrete spalling is that when a concrete surface is directly exposed to fire, the hotter zone expands, which is restrained by the adjoining concrete, creating thermal strains in the hotter region. The release of stored energy because of thermal load is the primary cause of explosive spalling. Fracture mechanics must be used to examine this release.

2.6 Techniques to mitigate fire induced spalling

According to [38], the pore pressure buildup mechanism is merely a trigger for spalling rather than the primary cause. The inclusion of polypropylene fibers in concrete is the most acknowledged and widely utilized approach for preventing spalling from occurring. By maintaining all of the characteristics the same, concrete specimens cast with and without polypropylene fibers (PPF) demonstrate the efficiency of these fibers. [39] similar experiments and found that polypropylene is a very effective technique for dealing with spalling. A synopsis of the many studies on mortar conducted in higher temperatures will be reviewed in this part to make comparisons. [40] investigated the influence that nanoparticle admixtures The effect of Fe3O4 and Fe3O4/SiO2 on the behavior of cement mortars when heated to high temperatures was investigated. To generate a core-shell nanostructure (Fe3O4/SiO2), pure magnetite (FeO4) particles were covered in a solid silica shell using the method of chemical vapor deposition (Strober technique). This resulted in the formation of a nanostructure with a core and a shell. The cement mortars had a Fe3O4/SiO2 admixture ratio of 3 weights % Fe3O4 and 5 weight % SiO2, which was the optimal ratio for a Fe3O4/SiO2 admixture. The specimens were heated to 200, 300, 450, 600, and 800 ºC, respectively. After the specimens were allowed to cool, their mass loss and flexural and compressive strengths were evaluated. According to the results, magnetite-silica (Fe_3O_4/SiO_2) nanostructures are much more beneficial than pure Fe_3O_4 nanoparticles when cement mortars increase heat resistance. The silica (SiO_2) shell in the nanoparticles in cement mortars that are heated to high temperatures results in an increase in the residual compressive strength and a reduction in the extension of fractures. Methods such as optical and scanning electron microscopy were used to support the results of this investigation. Studied the effects of Fe_3O_4 and Fe_3O_4/SiO_2 nanoparticle admixtures on the behavior of cement mortars exposed to high temperatures. After cooling, the specimens' mass loss and flexural and compressive strengths were evaluated. Magnetite-silica (Fe_3O_4/SiO_2) nanostructures are much more efficient than pure Fe_3O_4 nanoparticles for strengthening the heat resistance of cement mortars, according to the results. In cement mortars subjected to high temperatures, the silica (SiO_2) shell of the nanoparticles increases residual compressive strength and decreases fracture extension. The conclusions of this investigation were supported by optical and scanning electron microscopy methods.

[41] has an important goal to see how waste material (lightweight concrete blocks) may be used to replace fine aggregate partially. To achieve so, 168 mortar specimens (84 cubes and 84 prisms) were prepared using seven mixed designs with replacement ratios of sand. When 10 % and 20 % waste material fine aggregate is substituted for normal sand at temperatures of 23, 200, 400, and 600 ºC, the aggregate density increases. In one batch, waste lightweight concrete blocks were blended with waste clay bricks or waste lightweight concrete blocks were coupled with waste glass and evaluated with and without fiber (1 % polypropylene fiber by volume). It was determined the flow rate, new density, weight loss, compressive strength, flexural strength, and water absorption characteristics of mortar samples. At the age of 28 days, the toughened tests were implemented. The results showed that when using recycled materials, notably scrap lightweight concrete blocks; fresh density decreased by 20%. When normal sand was replaced with waste materials, compressive strength improved, and this improvement was visible at high temperatures. At various temperatures, the specimens that used waste lightweight concrete blocks with waste glass aggregate showed a significant reduction in water absorption compared to the control mix.

[33] concluded that when use in real-world situations, the self-compacting architectural mortars (SCAM) that use recycled glass (RG) that have been investigated might be at risk of catching fire. The influence of exposure to high temperatures on RG acting in the SCAM and its roles is now the focus of study. In this investigation, RG was employed as a stand-in for river sand in weight ratios ranging from 0 % to 25 %, 50 %, 75 %, and 100 %. According to the findings, raising the RG content had no impact on the chloride-ion penetration rate. Still, it did have a modestly negative effect on the SCAM samples' thermal conductivity, compressive strength, and elastic modulus when measured at room temperature. Although increasing the exposure temperatures of the SCAM as the compressive strength and elastic modulus of the samples decreased, the melting and re-

solidification of the RG produced a pore-filling action that filled micro-cracks and pores in the mortar matrix. When the temperature was increased to 800 °C, the benefits of the elastic modulus were more apparent than those of the compressive strength. At 800 ºC, the advantages of compressive strength were more evident than those of elastic modulus. It was also shown that the 100% RG-integrated SCAM could retain its attractive appearance even after being exposed to temperatures of 800 ºC. (no discernible changes in its appearance). As a result of incorporating RG into the SCAM at a rate of one hundred %, the researchers were able to achieve the desired combination of high strength (45.7 MPa) and an aesthetically attractive appearance, even after exposing the material to 800 ºC. Because of this, an increasing number of RG-based SCAM goods could join the market. However, the melting capabilities of RG may have a negative impact on the mechanical properties of the SCAM sample under loading circumstances. As a result, more study is required to elucidate such a potential limit

2.7 Previous investigations on the mechanical behavior of concrete exposed to elevated temperatures

[42] provided a case study of a fire that caused the collapse of an 8-story reinforced concrete frame supported masonry construction. They also used data from other researchers and laboratories in China to conduct a complete numerical study of the fire-induced collapse. This fall resulted in the deaths of 20 firemen and the severe injury of 16 others. The ground level, which was built for commercial usage, was used as a warehouse to store various chemical products such as nylon rope, polyethylene films, and linoleum (all of which are very explosive and emit a lot of heat). This floor was set on fire, and it burned for around 3 hours. They concluded that the ground floor's heavily strained columns had temperatures more than 800°C. Initially, two inner columns heated to about 1300°C broke, causing loads to be transferred to other columns that the high temperatures had also softened. The redistribution of wealth proceeded until the entire structure collapsed. They blamed the collapse of the whole structure on the degradation of concrete due to high temperatures.

2.7.1 Compressive strength

[41] identifies the mechanical effects of increased temperatures and cement doses on concrete. This research examined the impact of cement dosage (250 and 350 kg/m3) on the post-fire behavior of concrete using two concrete mix designs. After being cast, the test samples were subjected to increased temperatures ranging from 100 to 800 °C and

then allowed to cool gently to 20 °C before being subjected to failure testing. Several tests were then conducted to establish the mechanical characteristics of the concrete samples after they had cooled. The test findings demonstrated that at temperatures exceeding 400 °C, concrete has a considerable decrease in strength compared to control concrete. As shown in figure 6.

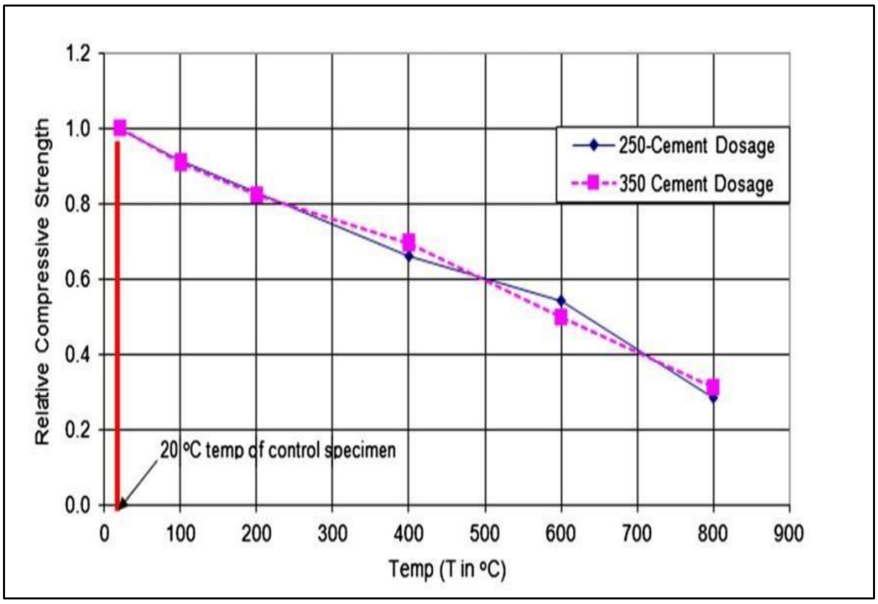


Figure 6: Normalized compression strength trends at various temperatures [28]

2.7.2 Stress Strain Curve

Cheng [42] investigated the stress-strain behavior of HSC at various high temperatures under residual circumstances. The heating rate was 2 °C/min—the compressive strength at room temperature. The pressure was 71.4 MPa. Cylinders are measuring 100 X 200 mm were used as test specimens. The strain-controlled system was used. Loading strategy for stress-strain response measurement They discovered that the slope of stress-strain plots was significant. Diminishes when the exposure temperature rises. They also found that the maximum stress high temperatures could be four times the corresponding stress at room temps.

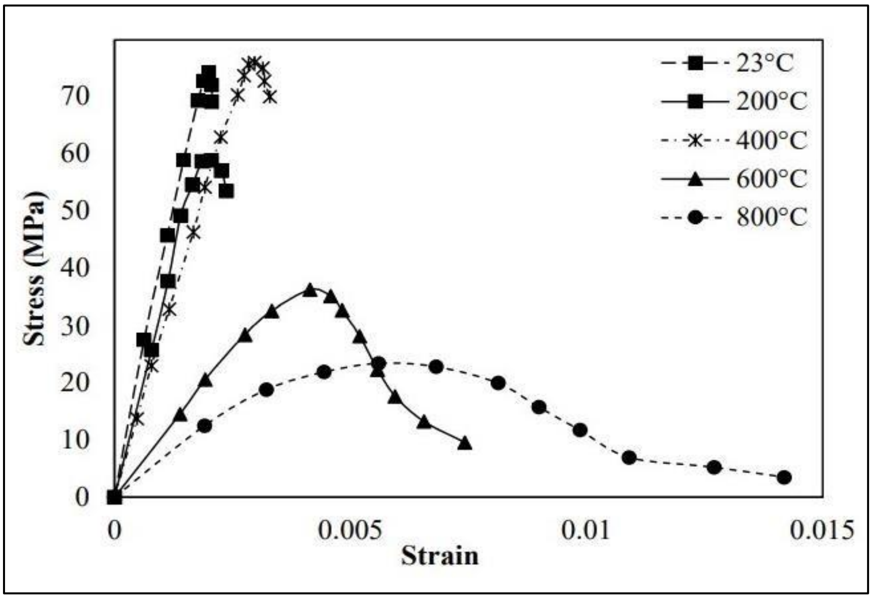


Figure 7: Stress-strain response at elevated temperature [42]

The stress-strain response measured as show in Figure 7 depicts various raised temperatures.

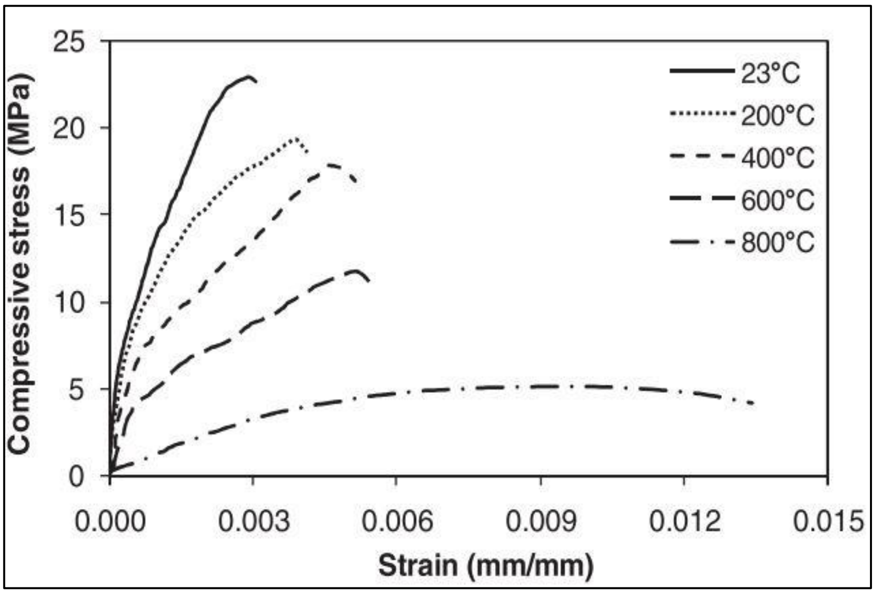


Figure 8: Stress strain curve of NSC [34]

The stress-strain response of concrete is a crucial analysis since it is a mandatory input parameter in mathematical analysis is that predict the reaction of a structural element made of concrete. To analysis the response of concrete using a numerical technique such as finite element analysis. It is necessary to construct a constitutive analysis of concrete that can capture the behavior of a structural component subjected to fire. The strains at various temperatures and stress levels. As temperature increases, concrete expands more porous, and this increase in porosity increases the ductility of concrete compression.

In normal strength of concrete is also shows that when temperature rises then the load deformation response also decreases [34] as in figure 8 above.

2.7.3 Elastic modulus

Figure 8 depicts the reported variation in elastic modulus with increasing temperature. They discovered a significant decrease in elastic modulus in the exposure range of 23 to 200°C.

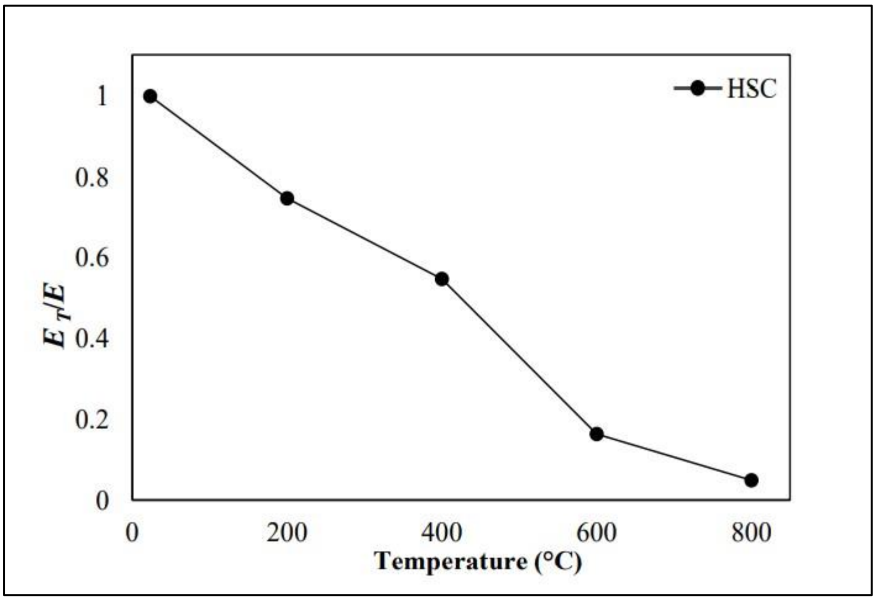


Figure 9: Variation in normalized elastic modulus as a function of temperature [17]

This drop became more consistent between 200 and 400°C, but the most pronounced degradation rate was observed between 400 and 600°C. A decrease in the reduction rate of elastic modulus was observed at temperatures above 600°C [17].

Similarly, [44] discovered that the elastic modulus of high-strength concrete samples decreases as temperature rises; at 600°C, it was reduced by up to 40 %. According to another study [45], the elastic modulus of high-strength concrete exposed to high temperatures decreases by 25 % at 200°C and 57 % at 400°C, compared to room temperature.

2.7.4 Mass loss

The mass of concrete decreases with rising temperature. Measuring the mass loss of material as temperatures rise is a technique material analysts use to ascertain the composition of a material in question. Thermogravimetric analysis, in which the sample is gradually heated at a rate of 10°C/min and the associated mass loss with increasing temperature is observed. A graph of % mass losses versus temperatures is created. This is compared to similar graphs of known materials, and thus vital information about the chemistry of the material in question is drawn. This approach is typically used in concrete technology on pastes rather than concretes since concrete comprises aggregates with varying mineral compositions that would interfere with the precise assessment of the proper chemistry of a concrete's pastes. The same approach is used to assess the extent of pozzolanic activity of different pozzolanas by measuring the mass loss of pastes at temperatures equivalent to calcium hydroxide dissociation (400 to 600°C) [46].

Still, different scholars present mass losses of concrete at elevated temperatures, possibly to create an overall picture of the changes in concrete at elevated temperatures. Concrete mass loss with increasing temperature can be attributed to three factors: moisture migration, thermal degradation of the concrete's ingredients, and spalling (Kodur, 2014).

Most of the spalling of concrete exposed to higher temperatures occur in HSC. Large chunks of concrete are separated from the surface of the concrete specimen during explosive spalling, which can account for a significant portion of the mass loss. Because mass loss measurements are used to access the microstructural changes in concrete caused by elevated temperatures, the mass loss of spalled specimens is ignored because it does not reveal any information about the microstructural changes [15]. As chemically bound water in C-S-H starts to liberate at 400°C, concrete loses its strength rapidly beyond 400°C. Initial mass loss up to 600 °C is mainly due to moisture migration, either free moisture or chemically bound moisture. In this temperature range, the amount of mass loss is highly influenced by the moisture content and permeability of concrete. NSC contains more water due to the higher w/c ratio, and [47] is also more absorbent than HSC, so up to 600°C, the extent of mass loss is more in NSC.

Moisture migration accounts for most of the mass loss in concrete at high temperatures. C-S-H gel and calcium hydroxide are the main components of hardened cement pastes. As the temperature of concrete rises, the free moisture (which is not chemically bound) evaporates out of the concrete until 150°C, the second main mass loss occurs between 400-500°C as calcium hydroxide is decomposed into calcium oxide and water vapors, and the third main mass loss occurs beyond 600°C from the decomposition of calcium carbonate (if the coarse aggregates are calcareous) into carbon dioxide and calcium oxide.

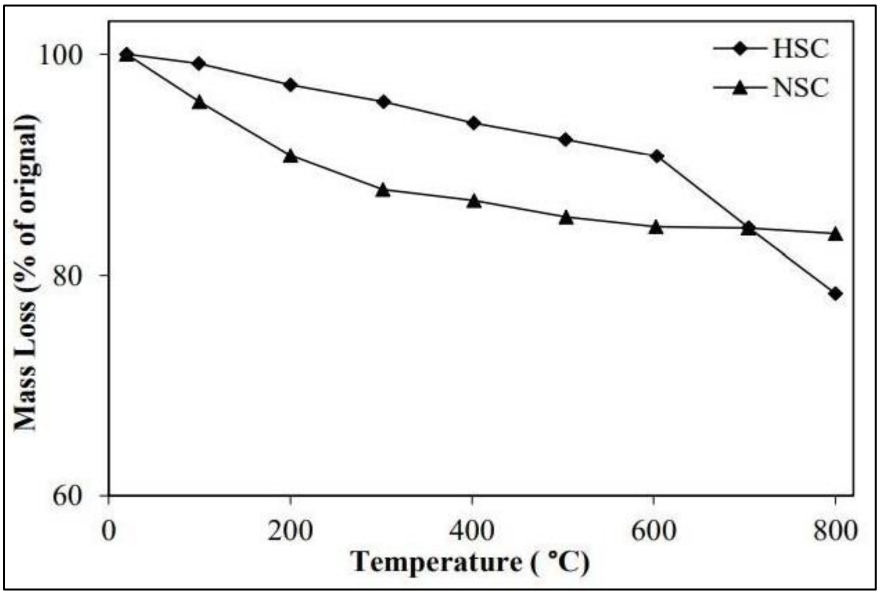


Figure 10: Mass loss as a function of temperatures [6]

These three temperature stages have peaks in mass losses. Still, there is also a relatively continuous mass loss due to C-S-H dehydration that begins at 400°C and continues until around 900°C [31].

Because chemically bound water in C-S-H begins to liberate at 400°C, concrete loses strength rapidly above that temperature. Initial mass loss up to 600 °C is primarily due to moisture migration, either free moisture or chemically bound moisture, so the amount of mass loss in this temperature range is heavily influenced by the moisture content and permeability of concrete. Because NSC contains more water due to a higher w/c ratio and is also more permeable than 28 HSC, the extent of mass loss in NSC is greater up to 600°C.

[36] published mass losses as a function of temperature for two concrete mixes, NSC and HSC, shown in figure 2.12. Similar calcareous aggregates were used to prepare these concrete mixes. The extent of mass loss in NSC is more significant than in HSC, up to 600 °C. Beyond 600°C, both compounds lose mass simultaneously because of the decomposition of calcareous aggregates found in both HSC and NSC. Figure 10. Temperature dependence of mass loss. The retention of mass in concrete at temperatures above 600°C is solely determined by the type of aggregates used. Beyond 600°C, concretes made with calcareous aggregates exhibit significant mass loss, attributed to the decomposition of calcium carbonate present in the totals. However, there is a negligible mass loss beyond 600 °C for concretes containing siliceous aggregates (Kodur, 2014) compiled data on mass loss as a part of temperature published by various researchers for

concretes containing either calcareous or siliceous aggregates is depicted in figure 10 above showed. The different temperature (23,100, 200, 400, 600, 800 and 1000) ºC for calcareous concretes Massive Loss as compared of control.

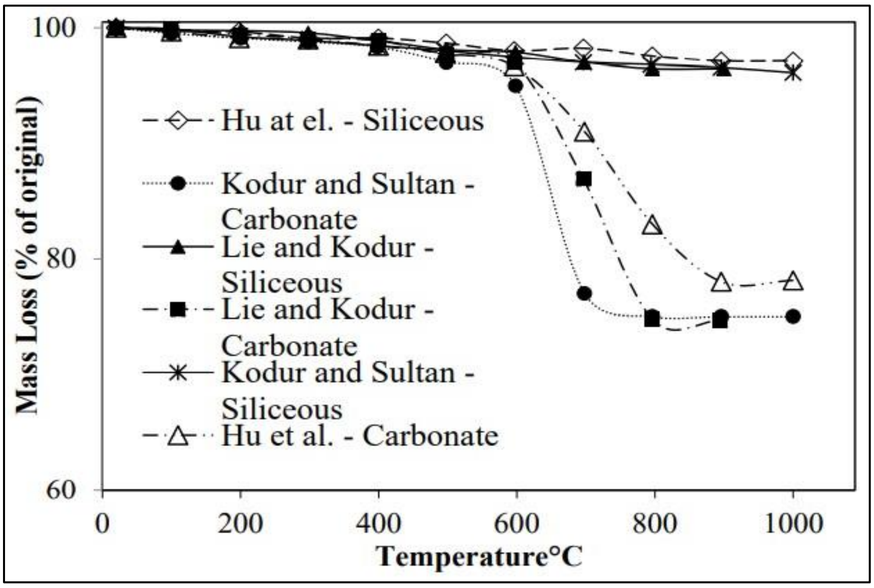


Figure 11: Mass loss as a function of temperature [15]

2.8 Research gap

This research covers the influence of elevated temperatures on the mechanical and thermal properties for both WMP-HSC and control HSC short columns. This work was divided into two parts. The first one deals with the properties of concrete with partially replacement of cement with WMP, whereas the second section discusses the properties of plastering contained WMP as a partially sand replacement. Previous research concluded that 10 % replacement of cement with WMP and in mortar 50% sand replacement is positively improved the mechanical properties of concrete. So, that is why in this study WMP was used as cement replacement in concrete (0, 10%) CR-WMP and in mortar (30%, and 50%) as a sand replacement in plastering SRP-WMP to develop fire resistance.

- There is a need to evaluate the role of marble waste powder as supplementary cementitious material in high-strength concrete in structural member at elevated temperature
- There is a need to evaluate the role of marble waste powder as filler in plastering mortar at elevated temperatures.

Chapter 3

3 METHODOLOGY

3.1 General

The approach of this chapter is to discourse the methodology of this study to attain research goals. The detailed process for the preparation of specimen is explained along with the test procedures implemented to achieve the results. The details of the testing procedure and technique, testing equipment, testing variables and specimen construction are discussed in this section. For studying and assessing the performance and response of both control and modified columns at elevated temperatures, mechanical, material properties and physical properties of both the concrete mixes are required. Material properties of concrete which are of concern are a load carryying capacity, stiffness, ductility, mass loss. There is adequate data available in the literature for the material properties of control but for CR-WMP and SRP-WMP in columns there is not enough data available for its different properties at higher temperatures.

Then all the different properties results are generated in the forms of graphs and, this produced information was used to for different material properties as a component of temperature in the scope of 23°C to 800°C. Detailed experimental work, test equipment, test procedures, and standards used are discussed in this chapter.

3.2 Specimen columns designation

Each specimen column was given a unique name so that it could be distinguished from the others. CR-WMP stands for "cement replacement with waste marble powder," whereas SRP-WMP stands for "sand replacement in plastering with waste marble powder." For instance, a composition of 10% CR-WMP indicates that used in the production of the concrete contains 10% waste marble powder as replacement of cement in concrete. In addition, 30% SRP-WMP indicates that high-strength concrete is covered with a layer of plaster that contains 30 % waste marble powder as replacing sand in mortar.

3.3 Columns cross-section details

All the columns were design reinforced according to ACI code. All Specimen provided 1% minimum reinforcement [48]. Main reinforcement provided dia of 9mm bar and ties are provided 6mm dia of bar with 100mm center to center spacing.

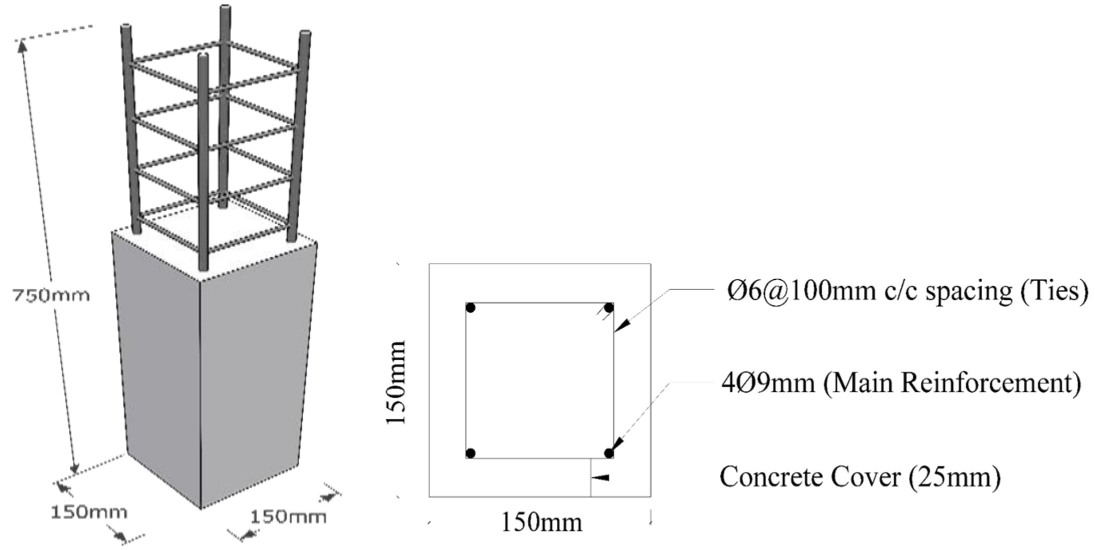


Figure 12: Column cross-sections and reinforcement details

3.3.1 Short Column

Short column is always failure in crashing. As ACI code eq define short columns or not so calculated below,

$\frac{kl}{r} \leq 22$ (ACI 6.2.5a) slenderness ratio

K= 1 Both ends are Hing

L =750mm

Area= 150mmx 150mm

$$r = \sqrt{\frac{I}{A}}$$

$$r = \sqrt{\frac{150 * \frac{150^3}{12}}{22500}}$$

r =43.30

$$\frac{kl}{r} = \frac{1 * 750}{43.3} \leq 22$$

17.38 ≤ 22 So, short column

3.3.2 Calculation of Spacing

Spacing of ties in columns calculated according to ACI code (318-19). All calculation is given below

(a) Clear spacing 4/3(12.5) = 16.5 mm (minimum)

(1) Not grater than 16db = 16 (3/8*25) =150mm

(2) Not grater than 48db =16*(2/8 *25) = 300mm

(3) Least dimension Cross-section 150mm * 150mm

So, provided **100 mm** c/c spacing

3.4 RCC short Columns matrix

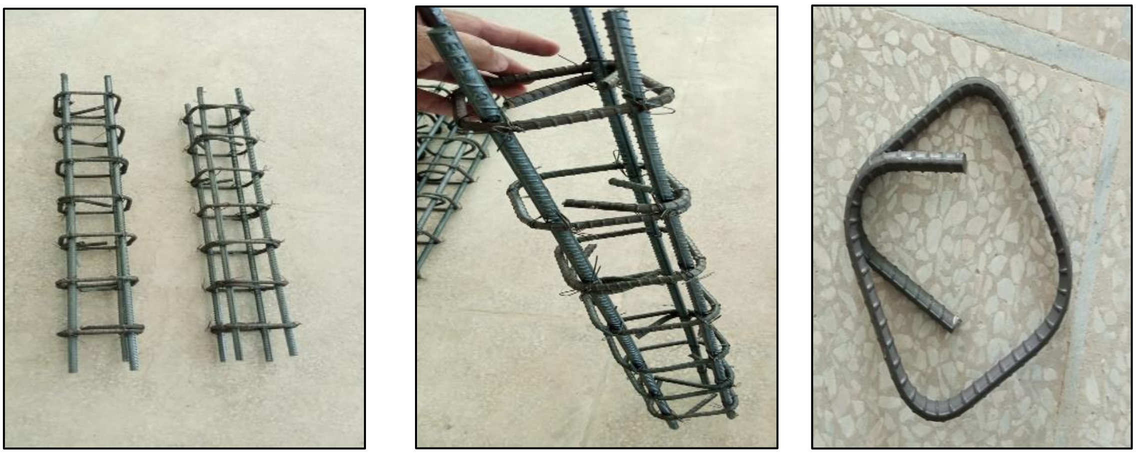
Table 1: Specimen Columns matrix

Sr no	**Material**	**Ambient Temp**	**Temperature(°C) Fire**				**Total**
			200	**400**	**600**	**800**	
1	Control Short Column	1	1	1	1	1	5
2	10 % CR-WMP in RCC-Columns	1	1	1	1	1	5
3	30% SRP-WMP	1	1	1	1	1	5
4	50% SRP-WMP	1	1	1	1	1	5
Total sample							20

3.5 Materials

3.5.1 Reinforced bars

The reinforcement enclosure consisted of four main reinforced bars of a 9 mm bar and 6 mm diameter bars as square stirrups with a minimum inside bend of 135° and having a consistent spacing of 100 mm C/C along the length of the columns, as depicted in Fig.13.



(a) (b) (c)

Figure 13: a,b = Reinforced bar of columns, c=ties

In addition to it, there is a concrete cover of 25 mm on all four sides. Bars measuring 6 mm and 9 mm had to yield strengths of 414 MPa. The flexural tensile strength was calculated for prisms with the following dimensions: (150 × 150 × 750) mm.

3.5.2 Cement

Using Ordinary Portland Cement (OPC), all columns were casted as standard ASTM C150. Cement is composed mainly of calcium oxide (CaO), aluminum oxide (Al_2O_3), and silicon dioxide (SiO_2).

Table 2: Ordinary Portland Cement content detail

Compound	OPC Percentage (Fauji cement)
CaO	64.0
SiO_2	21.80
Fe_2O_3	1.16
K_2O	0.22
Al_2O_3	13.80

3.5.3 Water

Pure drinkable water was used in this research for preparation and curing of specimen

3.5.4 Waste Marble Powder

During cutting sawing and polishing 40-45 % waste produced. Approximately 25% in foam of marble slurry and other is courser aggregate. Water is a crucial component needed throughout the whole marble making process. Groundwater, which is pumped out with the aid of water pumps and utilized in the creation of marble, is transformed into marble wastewater when it comes into touch with marble surfaces. Sedimentation tanks capture marble wastewater.

Wastewater that is collected in sedimentation tanks turns into marble slurry (white powder that is thick. The size of each sedimentation tank is 10 x 7 x 10. (ft). Height of the 10-foot sedimentation tank accumulates enough slurry that it must be frequently drained every week. The two waste products from the marble industry are slurry and marble wastewater. There are several uses for marble slurry in the building sector. Studies have been done to see if marble slurry may be used as a structural filler in road embankments, to make bricks instead of lime, to make ceramic tile raw materials, and to make hollow prefabricated construction blocks.

Although WMP has similar properties to cement, the WMP has a wider variety of particle sizes than the cement does (this indicates that some of the WMP particles are finer than the cement, while some are coarser). It could be due to marble's Mohs scale hardness, which indicates that it is not a particularly hard rock. During the polishing process, certain WMP particles are reduced to a finer size than cement. [32].

After being cut, polished, and resized from massive, hefty marble blocks, marble is a treated material. Large amounts of water are used during the cutting and shrinking of heavy, bulky stones into marble bits that may be used. After being processed, this water turns into marble effluent, which settles as a thick marble slurry and becomes a major source of pollution for the area around the marble plant. Large, heavy marble blocks are first removed from the quarry site using standard blasting techniques and explosives. Cranes are used to transport the cut blocks, which typically weigh 50–60 tones, from the quarry site to a storage yard. The steps of cutting and polishing marble stone are separated in the processing facilities that produce marble effluent.

The WMP was used in this research as a partial replacement cement in concrete and sand fine aggregate replacement of sand. This study used marble powder found in the Mardan marble industries of the zone, Kpk, Pakistan and collected in the form of slurry, which heating in an oven shows powder form. Then it was passed from sieve #100 to get the fine powder material. To determine the oxide composition of the marble powder XRF test was conducted, and the results are shown in Table 3.

Table 3: Chemically composition of Waste Marble Powder

Compound	Percentage (%)
CaO	56.16
SiO_2	1.28
Fe_2O_3	0.34
K_2O	0.10
LOI	41.8

The table shows that waste marble powder has calcium oxide approximately equal to cement. Waste marble powder has binding properties.

3.5.5 Fine aggregates

The study employed locally accessible Lawrencepur area sand with a Fineness Modulus (F.M) of 2.64. The sand was clean and free of organic contaminants, and it was employed in a saturated surface dry state. Table 4 lists some of its most important physical features as determined by laboratory studies. Also, the result for the gradation and standard gradation is given in Table 4 below.

Table 4: Gradation of fine aggregates and comparison with ASTM Limits

Sieve Number	Sieve Size	Weight Retained (grams)	% Retained	Cumulative % Retained	% Passing	ASTM Lower Limit	ASTM Upper Limit
	(mm)		(%)	(%)	(%)		
#4	4.75	25	1.44	1.44	98.56	95	100
#8	2.36	60	3.45	4.89	95.11	80	100
#16	1.18	410	23.59	28.48	71.52	50	85
#30	0.6	360.5	20.74	49.22	50.78	25	60
#50	0.3	610	35.10	84.32	15.68	5	30
#100	0.15	202	11.62	95.94	4.06	0	10
#200	0.075	45	2.59	98.53	1.47	0	3
Pan	0	20.85	1.20	99.70	0.0	0	0.00
Total		1738					

Total cumulative % = 264.03

Fineness Modulus (F.M) = 264.03/100

F.M = 2.64

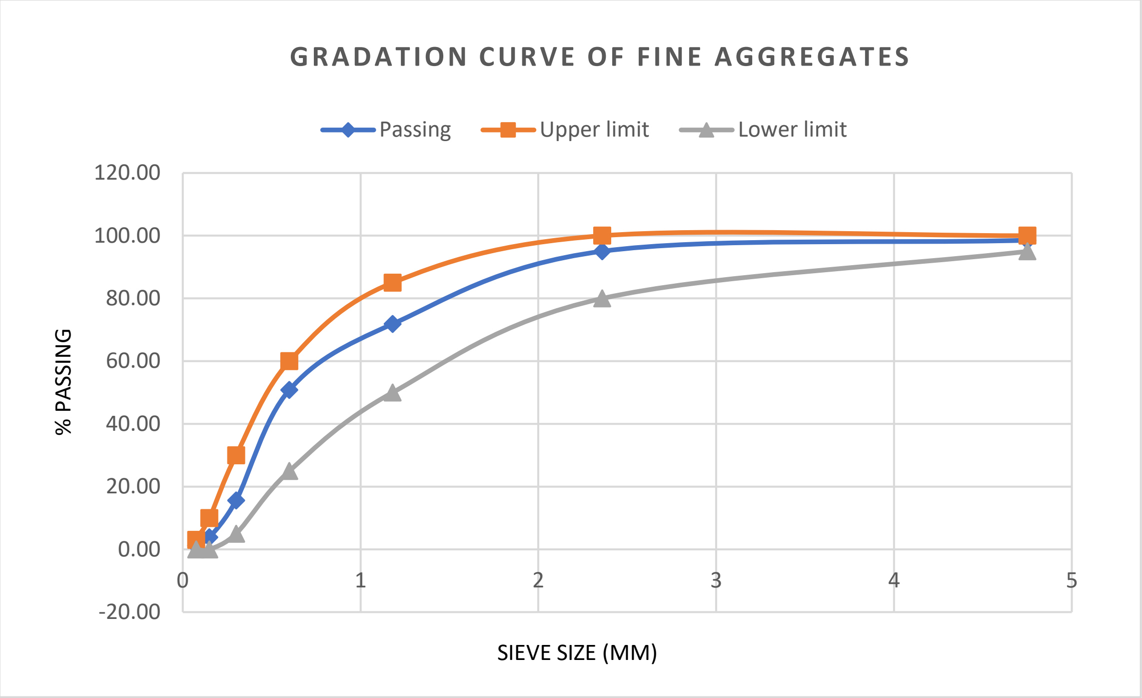


Figure 14: Fineness modulus of sand

3.5.6 Fineness modulus of combine sand and WMP

In mortar replacement of 30% and 50% so combine fineness modulus calculated which is given below

3.5.6.1 Fineness modulus of 50 % WMP

In mortar replacement of 50% WMP and 50% is sand by volume was combine fineness modulus calculated which is given below table and graph.

Table 5: For mortar fineness modulus of 50% WMP and 50% Sand

Sieve Number	Sieve Size	Weight Retained	Percent Retained	Cumulative Percent Retained	Percent Passing
	(mm)	(grams)	(%)	(%)	(%)
#4	4.75	0	0.00	0.00	100.00
#8	2.36	0	0.00	0.00	100.00
#16	1.18	14	1.27	1.27	98.73
#30	0.6	61	5.52	6.79	93.21
#50	0.3	325	29.42	36.20	63.80
#100	0.15	475	42.99	79.20	20.80
#200	0.075	203	18.37	97.57	2.43
Pan	0	26.85	2.43	99.7	0.30
Total		1105			
			total %	123.46	
			F.M	**1.23**	

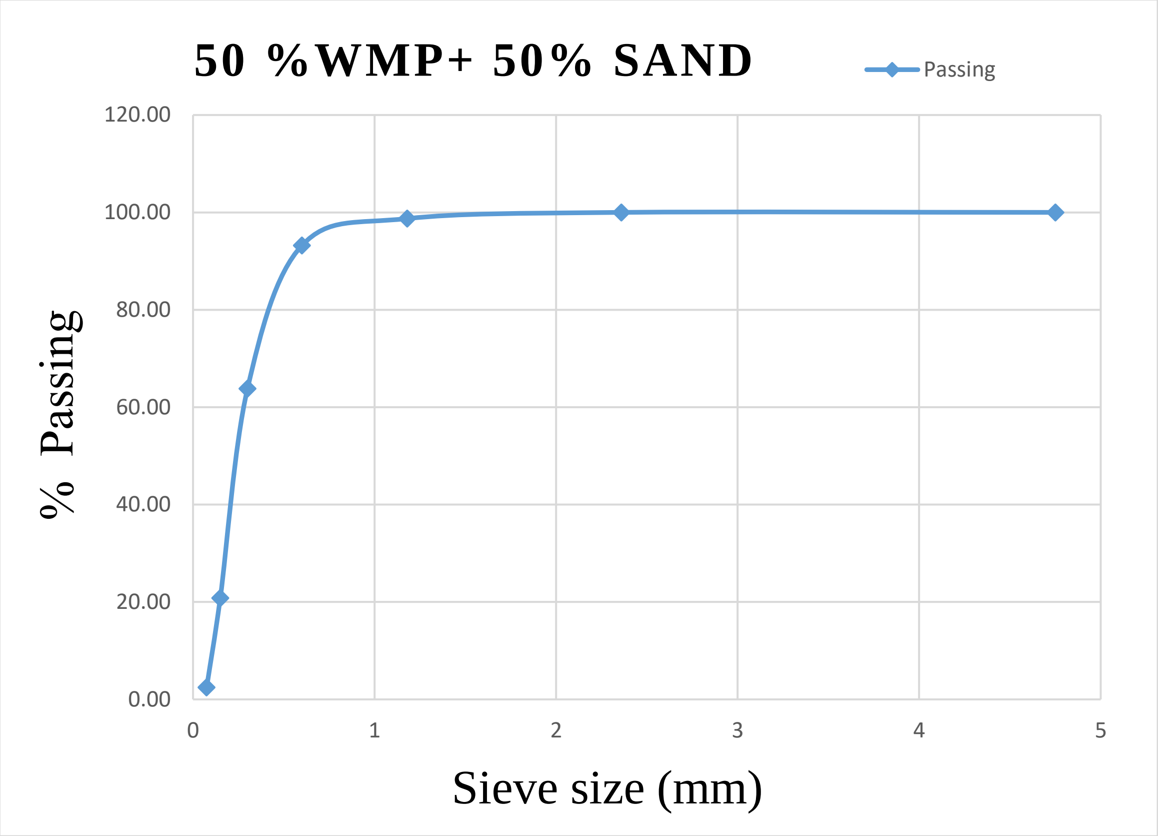


Figure 15: For mortar fineness modulus of 50% WMP and 50% Sand

3.5.6.2 Fineness modulus of 30 % WMP

In mortar replacement of 30% and 70% is sand by volume was combine and fineness modulus calculated which is given below

Table 6: For mortar fineness modulus of 30% WMP and 70% Sand

Sieve Number	Sieve Size	Weight Retained (grams)	Percent Retained	Cumulative Percent Retained	Percent Passing
	(mm)		(%)	(%)	(%)
#4	4.75	0	0.00	0.00	100.00
#8	2.36	0	0.00	0.00	100.00
#16	1.18	10.3	1.33	1.33	98.67
#30	0.6	46.5	6.02	7.35	92.65
#50	0.3	310.6	40.18	47.53	52.47
#100	0.15	333	43.08	90.60	9.40
#200	0.075	51.8	6.70	97.30	2.70
Pan	0	20.85	2.70	99.7	0.30
Total		773			
			total %	146.81	
			F.M	1.46	

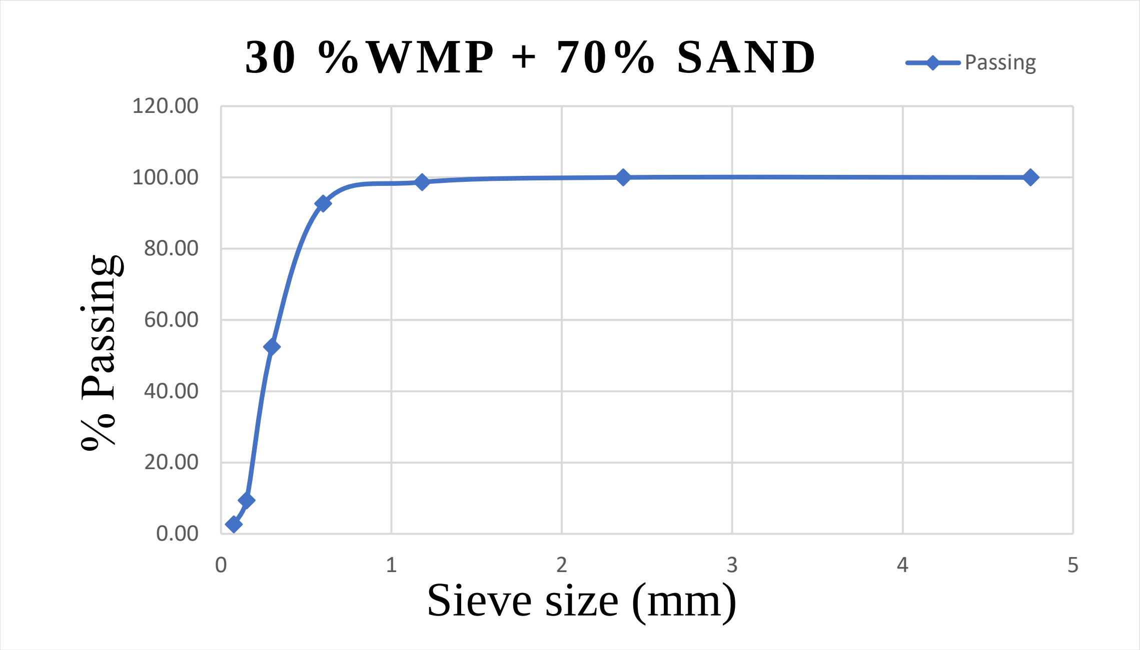


Figure 16:For mortar fineness modulus of 30% WMP and 70% Sand

3.5.7 Coarse Aggregates

For the current investigation, Khairtabad crush delivered normal-weight aggregates of crushed angular stone. In a saturated surface dry condition, coarse aggregates with a maximum size of 12.5mm according to ASTM C33 (C33 200) and a specific gravity of 2.68 were used (SSD).

(a) (b) (c)

Figure 17: Coarse aggregate Impact Value (b) Coarse aggregate (c) Coarse aggrege

Khairabad crushing provided the coarse aggregates used in this study. The greatest size employed in this investigation was 12.5 mm, and the Margalla crush is limestone-based. The gradation is generated from a mixture of different sizes in accordance with ASTM C-33. The resulting mix met all of ASTM C-33's requirements. Figure 14 depicts the final blended gradation of coarse particles employed. As determined by lab tests, some of its physical characteristics are listed in Table 7.

Table 7: Physical properties of coarse aggregate

Sr. No	Properties	Results
4	Impact Value of Coarse Aggregates (%)	6.38%
5	Specific Gravity of Coarse Aggregates (SSD)	2.68
6	Crushing Value of Coarse Aggreagte (%)	17%

3.5.8 Superplasticizer

Normally, these are used for water-reducing agents in HSC. As early told that waste marble powder has a high density and a tiny average particle size, resulting in a better microstructure in the concretes. A superplasticizer Chemical (BASF 8591) was used to prepare a workable concrete mix at a very low (0.28) water-cement ratio. The commercial name of the superplasticizer is Master Glenium sky 8591.

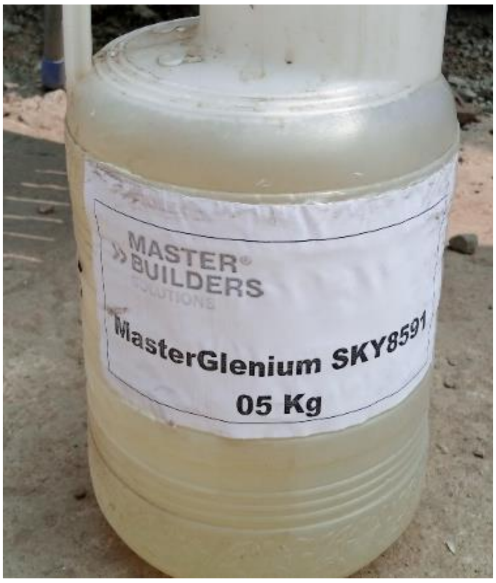


Figure 18: Superplasticizer (BASF-8591)

3.6 Mix proportion

The mix proportion of Concrete M40 target strength 40 MPa of columns ratios was used 1:1.27: 2.33, and a water-to-cement ratio of 0.28 were used in RCC short columns. To make the optimal mixes proportions. Casting was done in two stages: the first stage consisted of a short column with a cross-section of (150 mm x 150 mm x 750 mm) and included both control column mixes and column mixtures in which 10 % of the volume of the cement was replaced with waste marble powder. In the second stage, ten columns were built the same manner as the control sample and allowed to cure for twenty-eight days. However, five of the samples were plastered with 12.5 mm mortar that contained 30 % SRP-WMP, and the remaining five were plastered with 12.5 mm mortar that contained 50 % SRP-WMP. These samples underwent a second round of curing that lasted for another 28 days. Tables 7 (without plastering) and 8 (with plastering) show the mixed design below.

Table 8: Mix proportions obtained from mix design

Components	**HSC**
Ordinary Portland Cement (Kg/m3)	520
Fine Aggregate (Kg/m3)	660
Coarse Aggregate (Kg/m3)	1211
w/cm ratio	0.28
Super Plasticizer % of cement	0.9
Slump (mm)	80-100

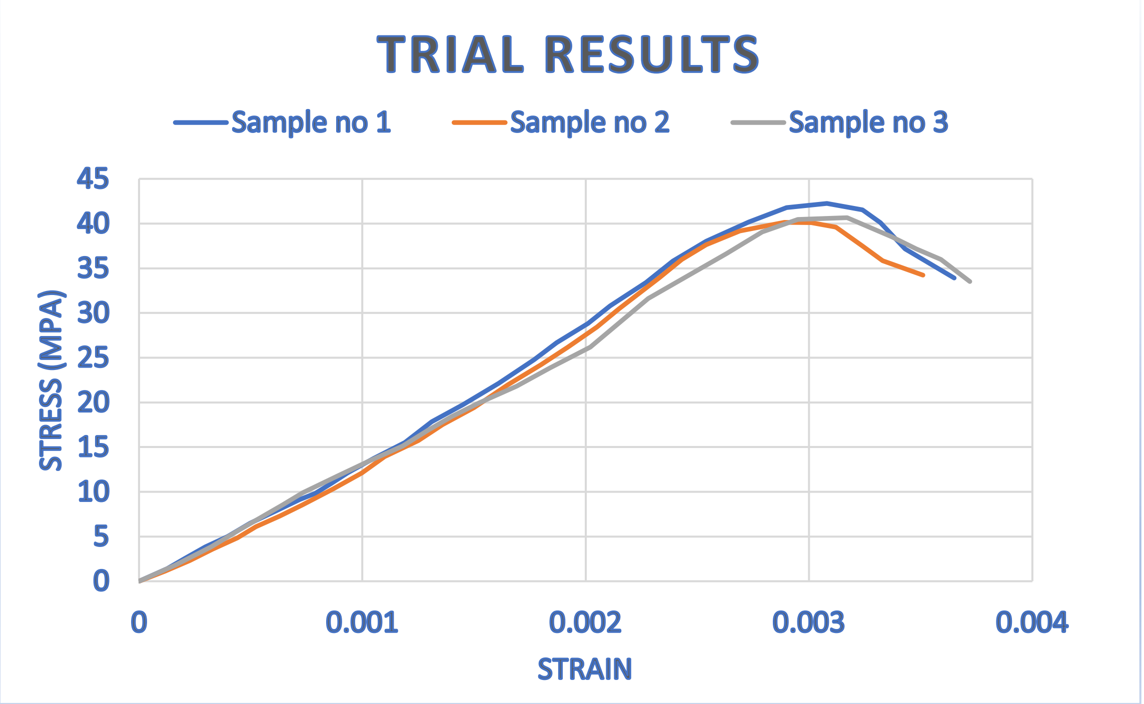


Figure 19: Mix Design trails before casting of columns

Table 9: Mix-Design of many formulations Kg/m^3

Mix Id	**Description**	**Cement (Kg/m^3)**	**Sand (Kg/m^3)**	**Coarse Agg (Kg/m^3)**	**Marble powder (Kg/m^3)**	**Water (Lit)**	**Super-plasticizer (g/m^3)**
10%CR-WMP	Cement replacement	538	731	1317	43.48	22.23	6.16
Control Columns	control	685	731	1317	0	22.23	6.16

Table 10: Mix-Design of different formulations in Kg/m3

Mix Id	**Cement**		**Sand**		**Coarse Agg**	**Marble**	**Water**	**Super-plasticizer**
	In concrete	In mortar	In concrete	In mortar	In concrete	In mortar	In concrete	In concrete
30% SRP-WMP	685	787	731	1391	1317	472.5	192	6.16
50% SRP-WMP	685	787	731	993	1317	787.5	192	6.16

Table 11: All concrete ingredient's summaries values

Sr. No	Properties	Results
1	Max Coarse Aggregates Size	12.5mm
2	Fineness Modulus (sand)	2.6
3	Specific Gravity of Fine Aggregates (SSD)	2.6
4	Impact Value of Coarse Aggregates (%)	6.38%
5	Specific Gravity of Coarse Aggregates (SSD)	2.68
6	Crushing Value of Coarse Aggregate (%)	17%

3.7 Mixing of concrete ingredient

The mixing of all the proportioned ingredients was done in mixer Fig 14 below. First, coarse aggregates are added to the horizontal drum mixer with 25% of the mixing water added. After mixing for 1-minute, clear fine aggregates were added and again the ingredient is allowed to mix for 2minutes. Then OPC was added to the horizontal mixer and 50% of the mixing water is also added and these are allowed to mix completely. After the thorough mixing of all the ingredients took place, remaining 25% of the mixing water left is added in which superplasticizer was pre-mixed. This mixing was carried out according to (ASTMC 192/192M-13 2013).

Figure 20: Concrete mixer machine

(a) (b)

Figure 21: (a) casting of concrete (b) 20 columns before curing

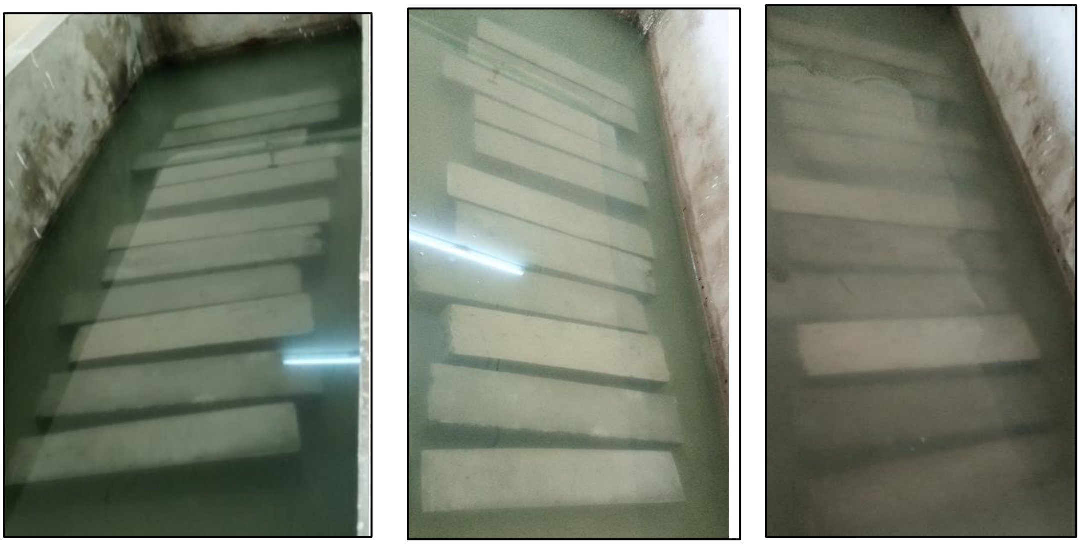
(a) (b)

Figure 22: (a) WMP mixing in mortar (b)Plastering 30 % and 50 % of columns

The column specimens were removed from the curing tank after 28 days and placed in a dry area at room temperature. The Ten columns further (30%, 50%) Sand replacement in plastered with waste marble powder after 28 days of concrete casting and curing for 28 days again. Figure 16 shows freshly poured concrete specimens in molds and concrete specimens in the hardened stage.

3.8 Specimen preparation and curing details

All the test specimens' columns are 6 inches by 6 inches (150mm * 150mm). After 24 hours, the specimens were removed from foam work and placed in a water tank to cure at room temperature (23 to 27°C) (ASTM C192 / C192M 2016) 2016.



(a) (b) (c)

Figure 23: All columns cured 28 days

Figure 24: Sulphur capped all columns

3.9 Capping ends of concrete's columns

Concrete's columns specimen has one smooth end which is formed on the base plate of the mold and other rough end. Non formed (rough) ends of all the specimens intended to be used for compressive testing were capped with the help of sulfur capping to bring them well within the permissible tolerances of (ASTM C39 / C39M 2016). Figure 21 shows the Sulphur capping used for the purpose of smooth end of a specimen.

3.10 Experimental Test procedure

3.10.1 Heating oven

All the columns were target temperatures 23°C, 200°C, 400°C, 600°C and 800°C selected for unstress-residual test conditions. The electric furnace named Protherm Electric Furnace, which had a temperature range of up to 1200 ºC, imitated the condition of a real fire. When concrete is heated in a furnace, it causes the air within the furnace to rise consistently, and temperatures at the column surface and core rise more gradually than the atmosphere of the furnace.

Table 12: Columns matrix heating temperature

Mix Type	Exposure Temperature (°C)	No of specimen	Remarks
CONTROL	23	1	Residual Test Conditions
	200	1	
	400	1	
	600	1	
	800	1	
10 % CR-WMP	23	1	Residual Test Conditions
	200	1	
	400	1	
	600	1	
	800	1	
30 % SRP-WMP 60SP-HSC	23	1	Residual Test Conditions
	200	1	
	400	1	
	600	1	
	800	1	
50 % SRP-WMP 60SP-HSC	23	1	Residual Test Conditions
	200	1	
	400	1	
	600	1	
	800	1	

In conclusion, the air temperature extends the desired temperature a great deal sooner than the temperature of the columns does. It is required to keep the furnace temperature at the desired degree for an extended period. This time is referred to as the hold time. A previous investigation led to the development of the method for estimating hold time [28]. The temperature record was kept using two different thermocouples, one placed inside the core and the other on the surface. In this experiment, thermocouples of type-K were employed. After drilling a hole in the top center of column, a thermocouple was installed, and then cement paste was plastered into the hole before the column was allowed to heat. After that, the information about their body temperatures was recorded using a digital data logger equipped with a thermocouple.

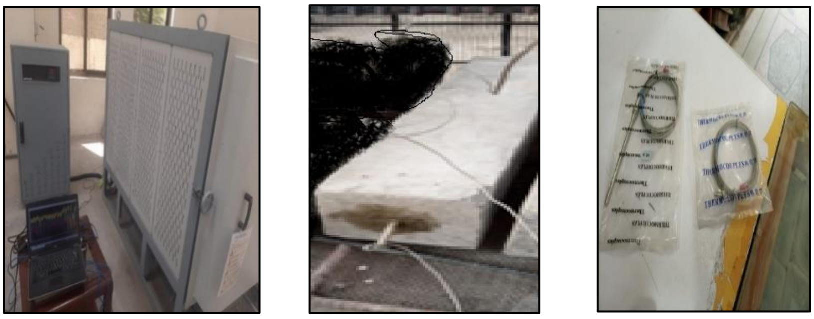

(a) (b) (c)

Figure 25: (a)oven (b)Columns top end thermocouple (c) type-k thermocouple

3.10.2 Heating rate

The heating rate is directly associated with the spalling behavior of HSC specimens. The usual heating rate used by researcher is (2°C – 5°C)/min. But to the study, the spalling behavior of concrete specimens a bit higher heating rate was selected which was 5°C/min. A target temperature of 800 °C was set for the test specimens in the electric furnace. The RILEM test methods were followed, including hold duration, loading, and heating conditions.

The residual test technique was used in this study to assess the material's characteristics at increased temperatures, as illustrated in Figure 23.

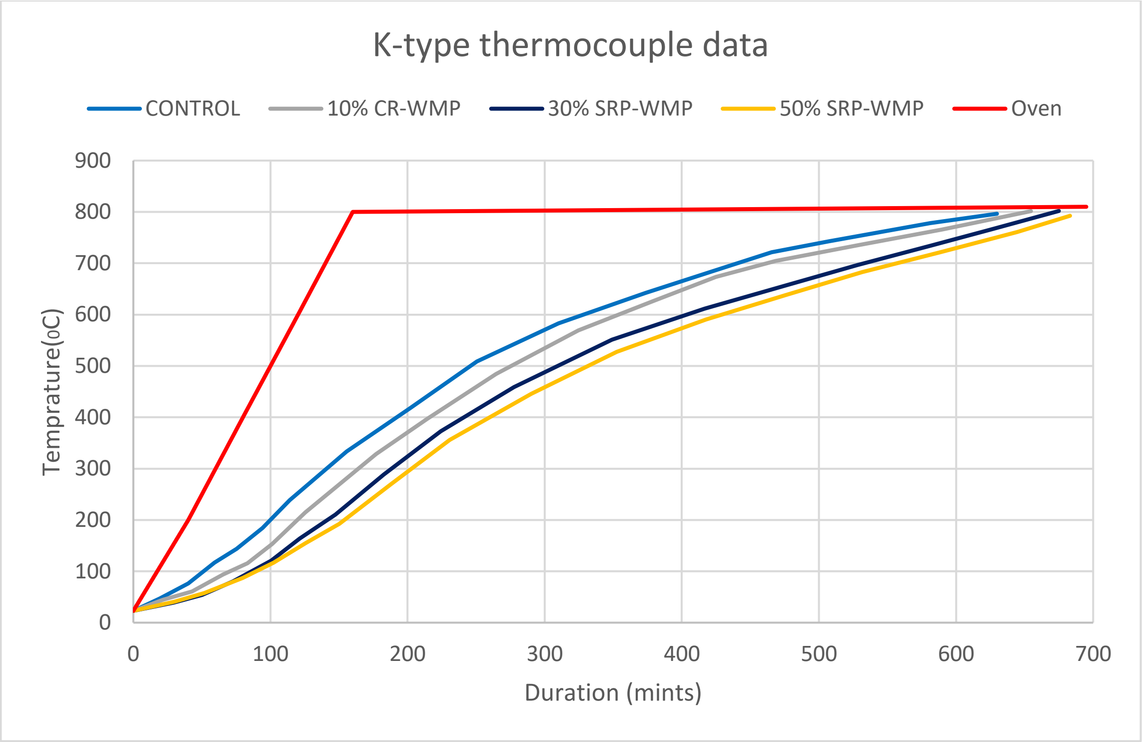


Figure 26: Thermocouple data obtain

The top-surface thermocouple-embedded columns were then put inside the furnace chamber and heated at a rate of 5 ºC/min to the appropriate temperature (23, 200, 400, 600, and 800) ºC. The temperature history of 0, 10, waste marble powder high-strength concrete was used to calculate the hold duration for heated specimens. As indicated in Fig.10, 30% SRP-WMP and 50% SRP-WMP mortar high-strength concrete were used for plastering. The time it takes for the concrete core to achieve the correct temperature increases when the proportion of WMP is increased, indicating that WMP samples have lower thermal conductivity than control columns.

Keeping a minimum hold period of two hours is necessary because concrete's limited thermal conductivity slows the temperature increase within the specimen compared to the surface and furnace temperature [49]. To get the samples into a state of thermal equilibrium at all the desired temperatures & the hold duration was kept constant at all goal temperatures attained to verify that the temperature within the columns was stable (thermal equilibrium). Specimens were put on a digital scale with a minimum of 0.01 grams to assess the loss amount of mass. To determine the amount of relative mass loss, divide the mass at the target temperature by the mass when it was at the surrounding temperature.

3.11 Compressive strength test

For the compressive strength test, hydraulic Compression Testing Machine (CTM) with a capacity of 3000 KN and 100 mm linear variable displacement transducers (LVDTs. All the specimens had Sulphur caps placed on them to distribute the load equally. The control loading rate of the machine was set at a loading rate was 1KN/sec. The material property concrete columns and modified WMP concrete columns were tested according to the residual test conditions [7], [28].


(a) (b)

Figure 27: (a) Compression testing machine setup (b) Sample during testing in CTM

The goal of this study is to see how waste marble powder admixtures affect concrete's performance when subjected to high temperatures.

3.12 Mass Loss

To carry out the mass loss of concrete specimen, they were weighed before heating and after that specimen were heated to a targeted elevated temperature and then were allowed to cool down to room temperature. After that specimen were again weighed on a weighing balance having least count of 0.1 grams. Relative mass loss measured at a targeted temperature was calculated from the following relationship.

$$Mass\ Loss = \frac{M_T}{M}$$

Where:

M_T = Mass at target temperature

M = Mass at room temperature

Chapter 4

4 Results and Discussions

4.1 General

In this part, the findings of Load deformation, failure modes, stiffness, ductility, energy absorptions, toughness index, and mass loss tests on control short column specimens and modified short columns are presented. Visual assessment is also included in this section. Along with checking the mechanical qualities, visual observations were taken to determine how the color and spalling behavior of all samples changed after they were removed from the electric furnace. The resulting mechanical properties data both modified and control with and without plaster are used to construct relationships for various material properties as a function of temperature spanning from 23 to 800 °C.

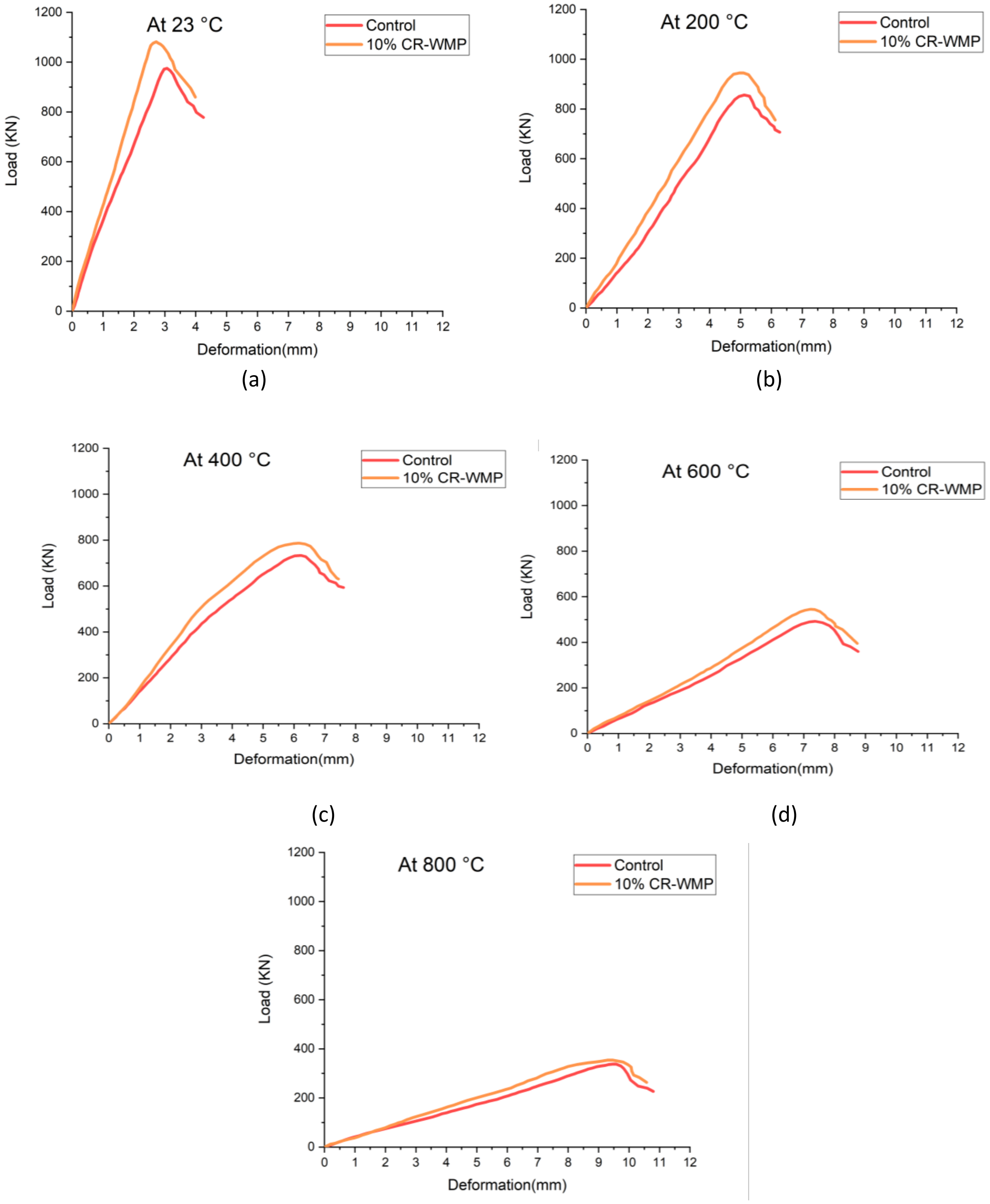
4.2 Mechanical properties

Different properties are discussed below

4.2.1 Load deformation

The Load vs deformation of the control columns and the 10 % CR-WMP column was evaluated from the test. Fig. 25 illustrates how these load deformation curves have been plotted against temperatures for the residual test circumstances. All the specimens demonstrate that as the temperature increased from 23 to 800 ºC, the peak load values reduced while the associated displacements was also increased.

The sample with 10 % CR-WMP modified has a of 1081 KN with 10 % higher than the control which is 975 KN at ambient temperature. This increased load is the result of WMP-modified samples having a higher packing density when analyzed at normal temperature. This pattern was also seen with a temperature of 200 ºC. At a temperature of 200 ºC the control column, and 10% CR-WMP columns has load is 944 KN but control peak load carrying was 856 KN. The load carrying of the modified sample at 400 ºC is 8.91 % greater than the control sample. Further, increase in temperature to 600 ºC, the peak load value of control was 524KN with a deformation value of 8mm and the value of the modified sample was 492KN with a deformation value is 8.13mm. Further increase temperature to 800 ºC, the load value of control column was 316KN with a deformation value of 10.42mm and the value of the modified sample was 354KN with 10.58mm deformation. So, modified shows significantly increase due to smaller particle size than cement particle.



(a) (b)

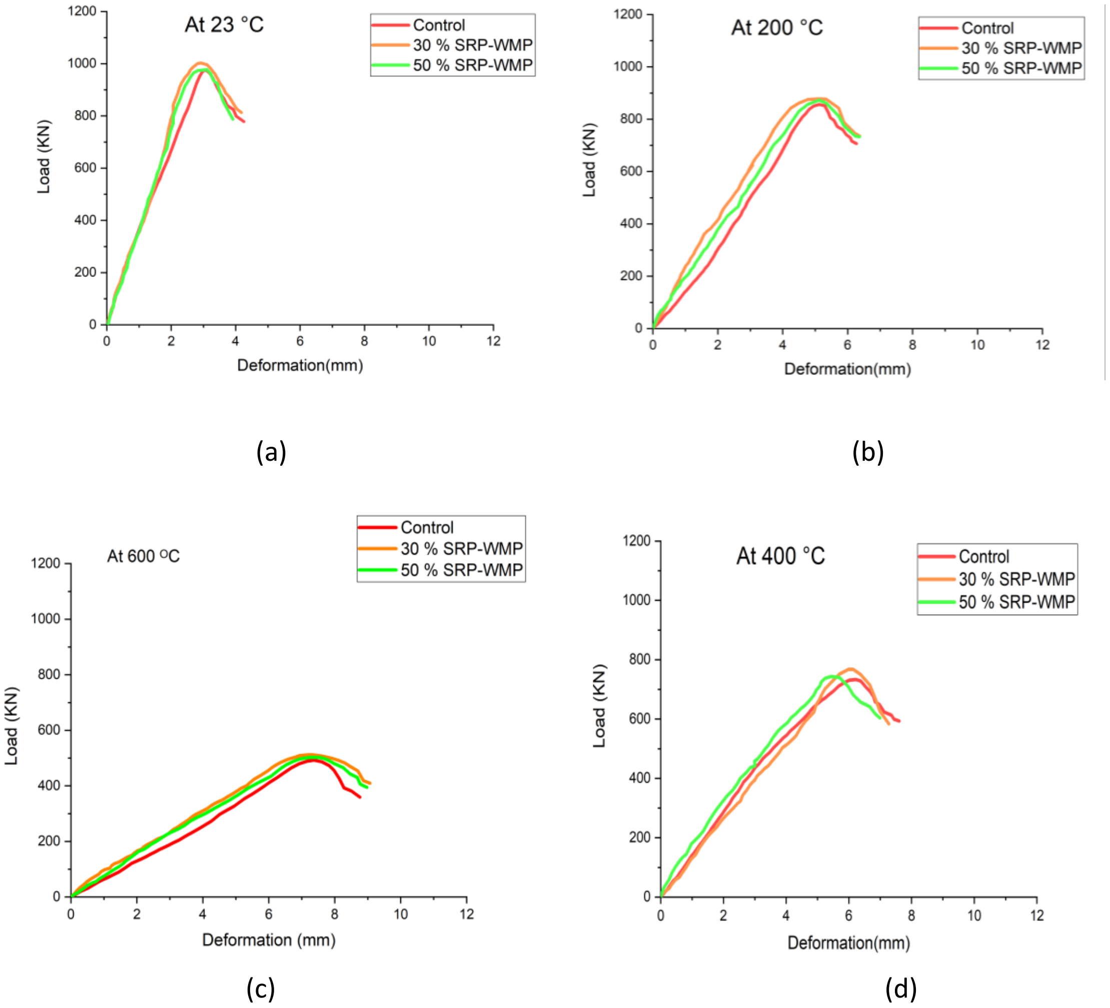
(c) (d)

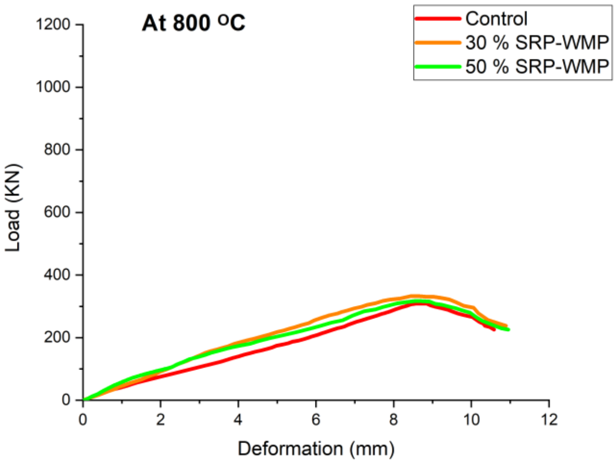
(e)

Figure 28: Load vs deformation of Control and CR-WMP samples at different temperature (a=23, b=200, c=400, d=600, e=800) ºC

Now discuss when sand replacement in mortar. 30 % SRP-WMP load carrying capacity was (1001, 877,767,511,337) KN at 23 ºC, 200 ºC, 400 ºC, 600 ºC, and 800 ºC respectively. Which shows slightly greater than the control specimen. Because surface coating and smaller size use as filler material that is why temperature of coating sample better load carrying capacity.

Load value of 50 % SRP-WMP (978, 872, 743, 502, 332) KN at 23 ºC, 200 ºC, 400 ºC, 600 ºC, and 800 ºC respectively. As the temperature rises from 23 to 800 ºC, the load drops, and the final deformation rises in proportion. 50 % SRP-WMP also show quit batter than control ones.





(e)

Figure 29: Columns load deformation curve Load deformation curve for both Control and SRP-WMP (a=23, b=200, c=400, d=600, e=800) ºC

4.2.2 Visual assessment

Visual inspection is important for establishing the use of fire-damaged concrete. At high temperatures, Color variations might be a clearer perspective exposed to cracking [22], [50]**.** Increased temperatures in concrete result in cracking due to evaporation, paste drying, and microstructure damage [34]. Above the temperature of 200 ºC, there is a noticeable shift in the color of the RCC short column samples that have been exposed to light. At temperatures of 200 ºC, these samples are a light grey color, while temperatures of 400 ºC give them gray color, and at 600 ºC these samples are light pink. As the process progressed, surface samples exhibited a little amount of spalling as the temperature went from 600 to 800 ºC.

10% CR-WMP concrete shows light grey color when heated to 200 ºC. At the very end, the color had almost completely lost its brightness. At 600 ºC, the surface of the modified concrete became a pink tint, and there were no fractures that could be seen. At a temperature of 800 ºC, the modified columns’ concrete had become white and had obvious surface cracks at incorporation. When the temperature increased from 600 to 800 ºC, the concrete that contained 10 % CR-WMP was spalling at the edges. However, at 600 ºC no spalling was seen in any of the plaster samples. 800°C, both 30, and 50 % SRP coating approximately 35-40 % layer spall. The modified samples show significantly fewer fractures than the control columns.

According to the published research, the spalling of samples begins at temperatures higher than 600 ºC [38]. Because the concrete matrix has a deep microstructure and there is a lot of pore pressure in it, the specimens disintegrate apart and spall the columns. The presence of these pores may help bring down the heat conductivity of the concrete [44]. The spalling of concrete occurs above 600 ◦C, which is consistent with the literature [38].

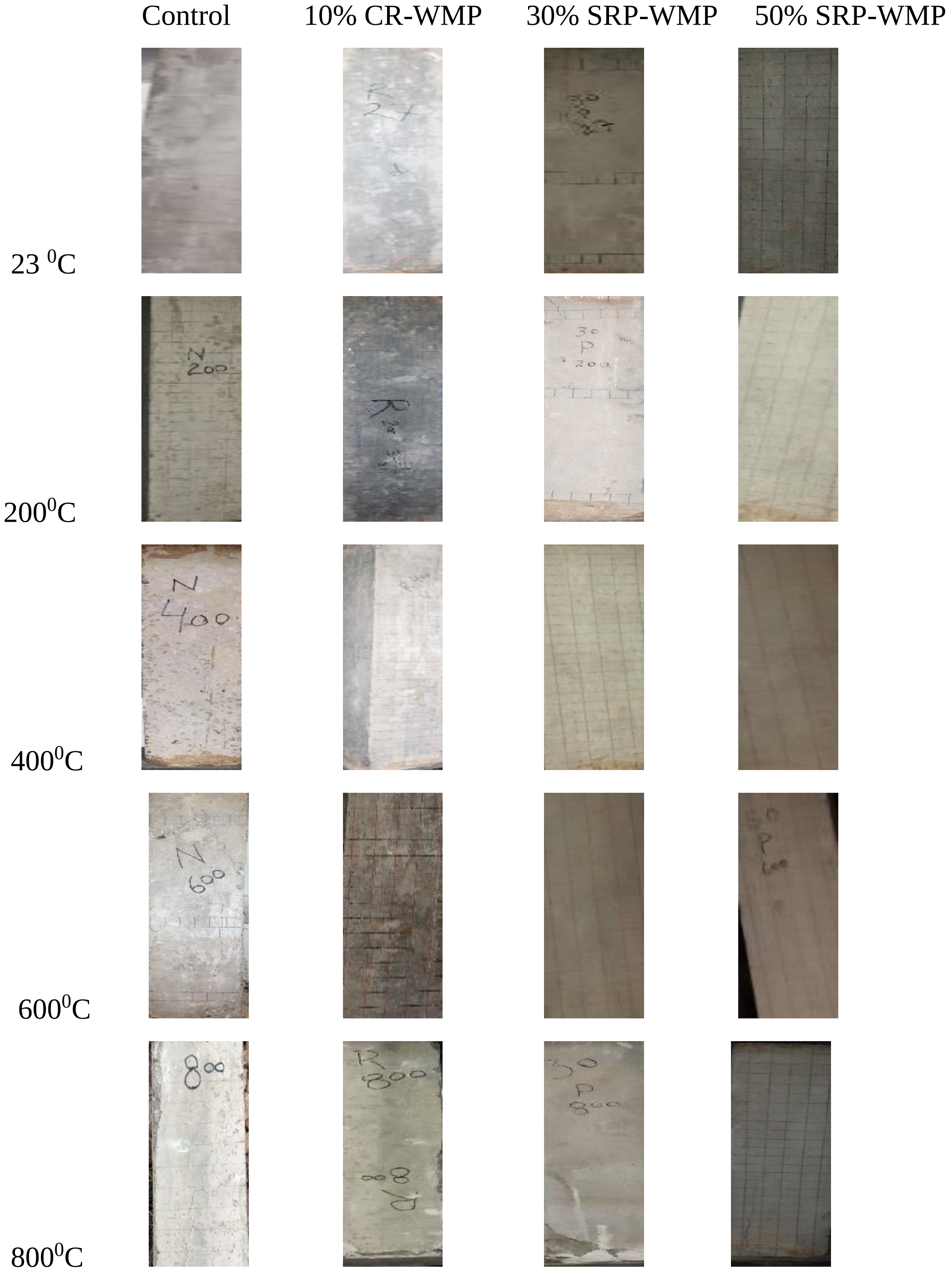


Figure 30: All sample visual assessments after elevated temperature

The above figures show the physical condition of the concrete, CR-WMP, SRP-WMP columns (Control, 10% WMP in concrete and 30% Sand replacement in Plastering -WMP and 50% Sand replacement in Plastering WMP) mixes exposed (23, 200, 400, 600 and 800) ºC. After fired, all samples are cooled at room temperature. [16].

At increased temperatures, thermal cracking in concrete is due to water loss, which causes the paste to dry up and the microstructure to deteriorate. The spalling of concrete at temperatures exceeding 600 ºC is in agreement with the literature [38].

4.2.3 Mass loss

Various types of moisture in concrete, including free water, adsorbed capillary water, interlayer water, and chemically mixed moisture, play a crucial role in mass loss because moisture evaporates at elevated temperatures. To calculate mass loss in all the samples either control or modified columns, mass at target temperature to mass at ambient temperature (M_T/M). The changed sample, as seen in Fig. 26, has a greater mass loss. Up to 100 ºC, moisture undergoes a phase shift from liquid to vapor. In the temperature range of 200-800°C, there is a larger loss of mass in modified columns than in control columns. This is because the disintegration of WMP at high temperatures generates matrix pores. *Mass loss* of control sample at 200, 400, 600, and 800°C was, 2.72, 8.86, 11.43 and 16.47 % respectively. And 10% CR-WMP had mass loss values amounted to 4.8, 9.18, 13.18, 17.49 % respectively which is show that modified sample mass loss slightly higher as compared to modified samples.

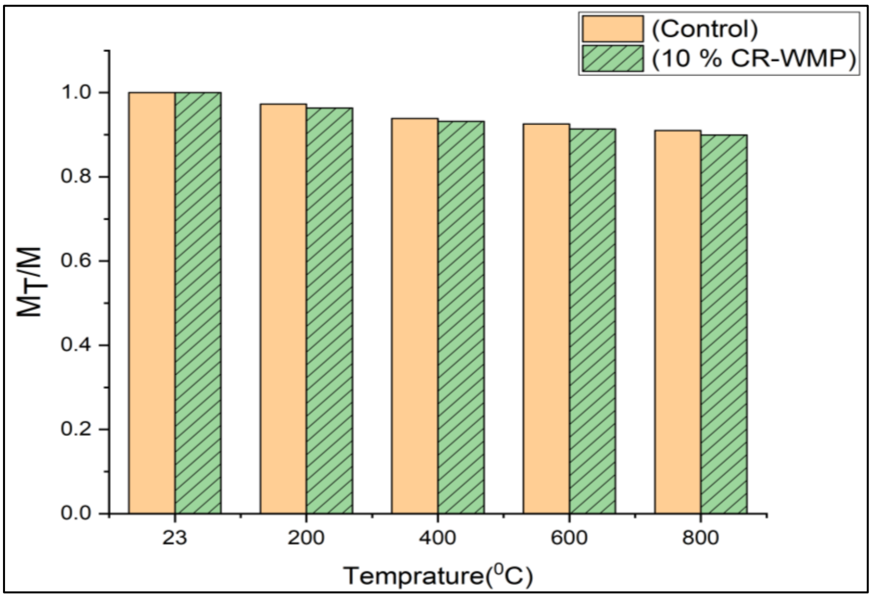


Figure 31: Mass losses in control and modified in concrete

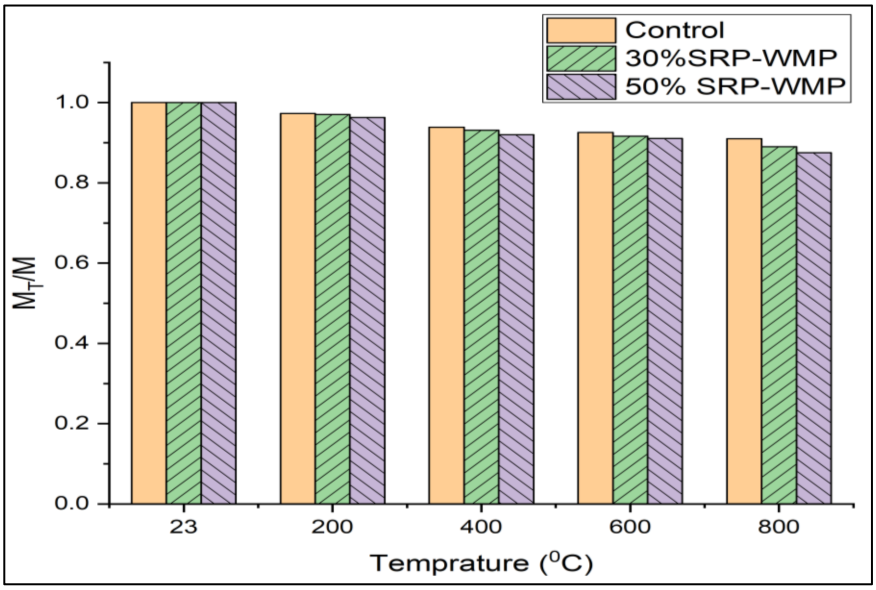


Figure 32: Mass losses in control and plastering modified

The value of mass loss for 30 % SRP-WMP sample (3.92, 7.17,11.51, 16.96) % at (200, 400, 600, 800) ºC respectively. The value of mass loss for 50 % SRP-WMP mass loss values were (3.98, 7.40,12.17, 18.71) % at (23, 200, 400, 600, 800) ºC respectively. In above results shows 50 % grater mass losses as compared to the control specimen. Only 800 ºC sample lesser mass as compared to the control due to plastering coating 35-40 % damage.

This is because of smaller size of waste marble powder so, workability is decrease when at elevated temperature water evaporate garter as compared to control so,

4.2.4 Failure mode

At a room temperature of 23 ^{O}C, each specimen exhibits a brittle failure. At room temperature, the modified columns exhibited a behavior that was more brittle than the control columns because of the denser microstructure of the modified columns. When the temperature rises, the brittle character of the sample gradually transforms into a ductile state up to a certain degree. The cracks were proportionately increased when the temperature was higher, up to 600 ^{O}C. At a temperature of 800 ^{O}C, the exterior surface of 10% CR-WMP began to degrade at the edges. At the same time, the compound itself dissolved entirely as the breakdown of the samples generated voids and lessened the brittleness character of concrete samples. Notably, WMP modified samples subjected to temperatures over 200 ^{O}C had fewer cracks.

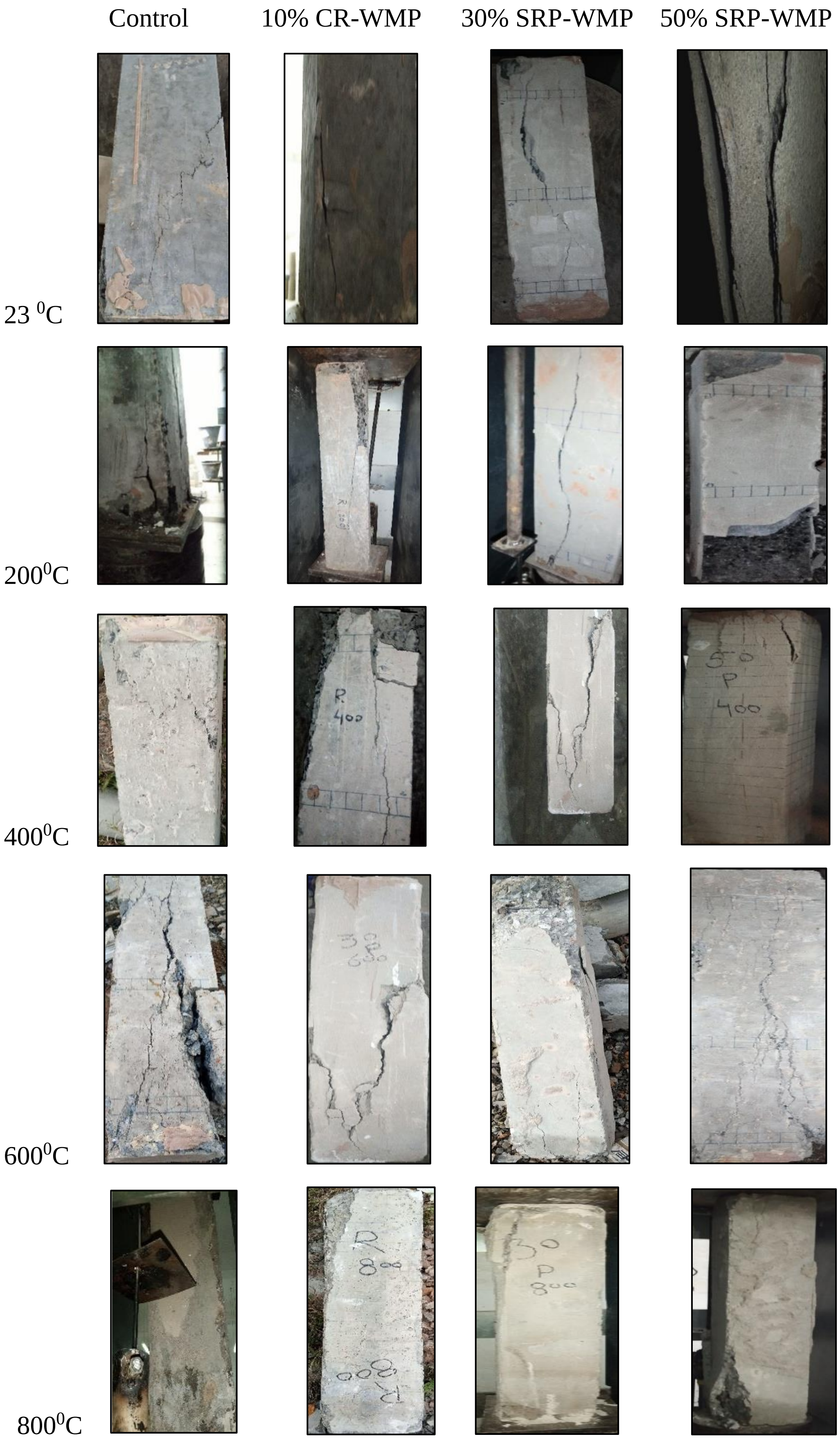


Figure 33: Failure mode of all samples

shows the physical condition of concrete and modified RCC- columns (Control, 10% CR-WMP and 30% Sand replacement in Plastering -WMP and 50% Sand replacement in Plastering WMP) formulations exposed to various target temperatures.

4.2.5 Stiffness

There are two techniques to find stiffness, one is initial & the other is Secant stiffness. The sample stiffer means failure is catastrophic and brittle failure occurs. As temperature increases, deformation values increase, which shows that the behavior of specimen stiffness reduces, and its brittle failure changes into ductile failure.

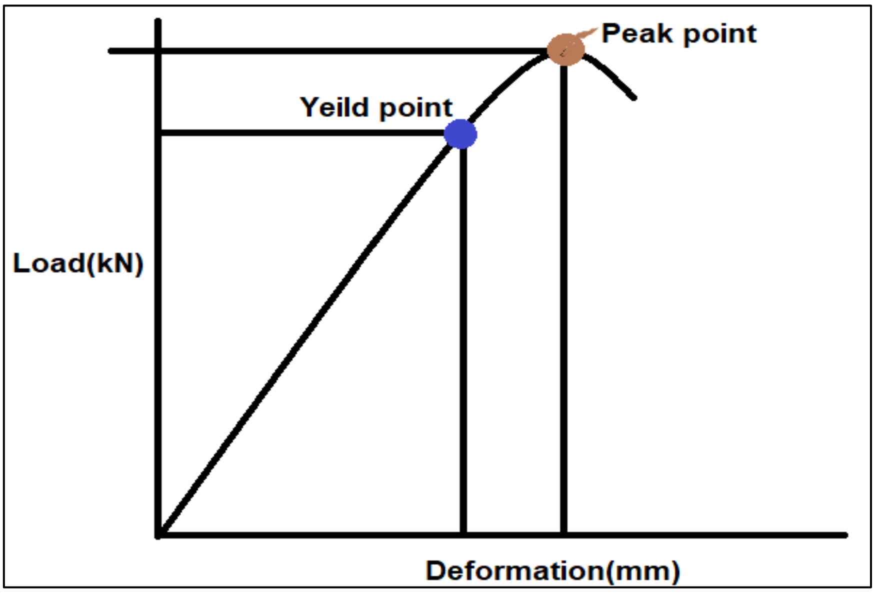


Figure 34: Stiffness diagram

4.2.6 Secant Stiffness/Effective Stiffness

It is defined that “the ratio of load and deformation at peak point” from this we are saying the load capacity of columns. If a column is stiffer then the load carrying capacity is too high. So, stiffness is very important to calculate and failure of columns.

Effective stiffness is also called secant stiffness.

Secant Stiffness = (Load / deformation) at peak point

The value modified 10 %CR-WMP at (23, 200, 400, 600, 800) was increase (25.2, 14.11, 13.8, 12.9, 6.71) % respectively as compared to control sample

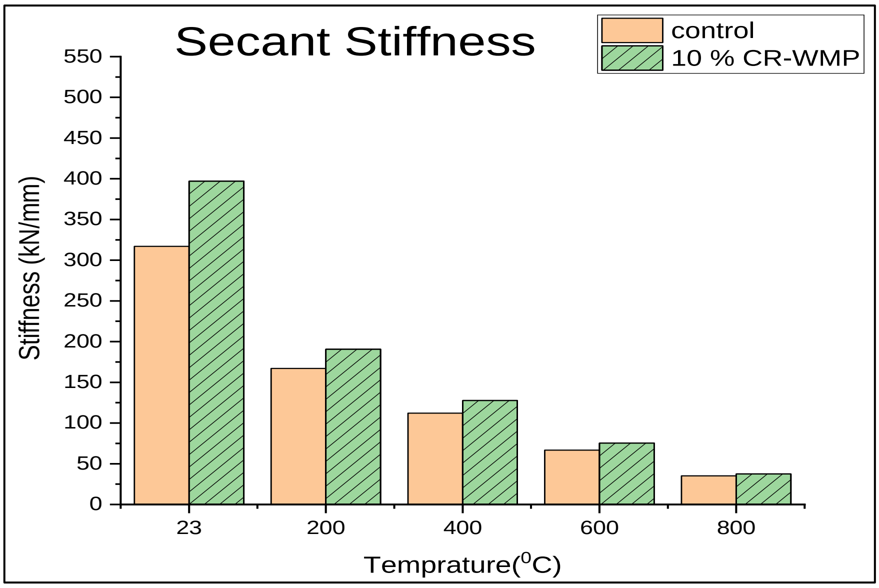


Figure 35: Effective stiffness control and modified columns

4.2.7 Initial Stiffness

It is defined that "the ratio of load value and deformation at yield point"

Initial Stiffness = (Load / displacement) at yield point

The value modified 10 %CR-WMP at (23, 200, 400, 600, 800) ºC was increasing (27, 14.5, 14.1.06, 12.7, 12.50,) % respectively as compared to control sample

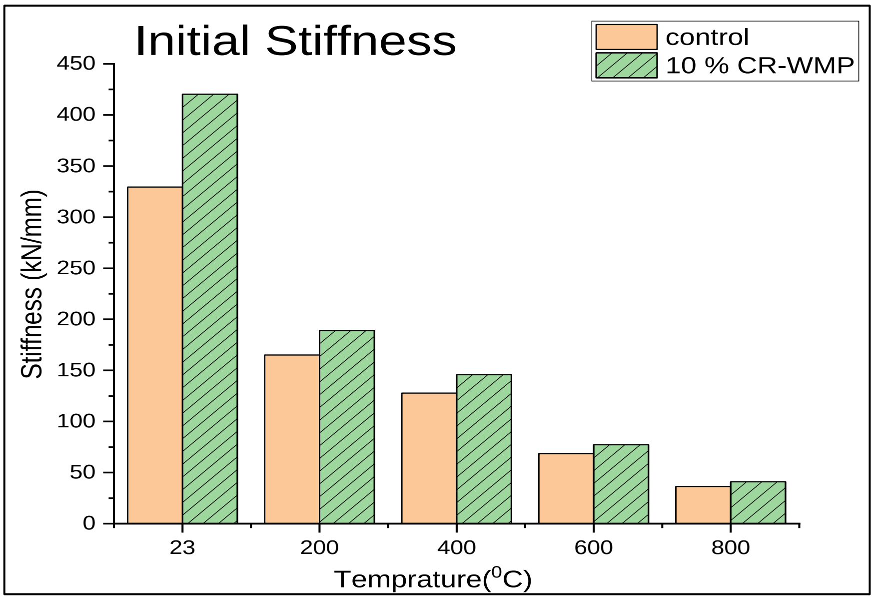


Figure 36: Initial stiffness comparison of control and modified columns

4.2.8 Displacement Ductility index

As shown fig. 34 displacement ductility is defined as the ratio between the displacement at peak load (Δu) and the displacement at yield (Δy).

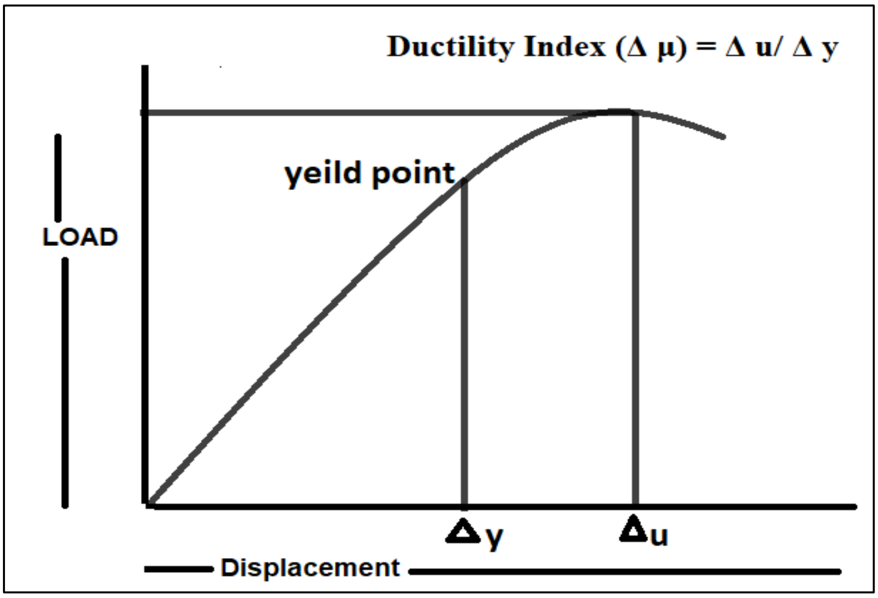


Figure 37: formula ductility index

The load and deformation curve were shown flatten when temperature is increase. Due to reinforcement in columns, indicating a softer behavior despite the sharp drop in load-bearing capability at elevated temperature. The displacement ductility index did not distinguish between modified columns and control columns with high load carrying capacity or not, because displacement ductility index calculated only from deformation value. The value modified specimen at (23, 200, 400, 600, 800) °C was greater (0.19, 0.59, 2.45, 3.27, 4.28) as compared to control columns, which show that slightly large displacement ductility value.

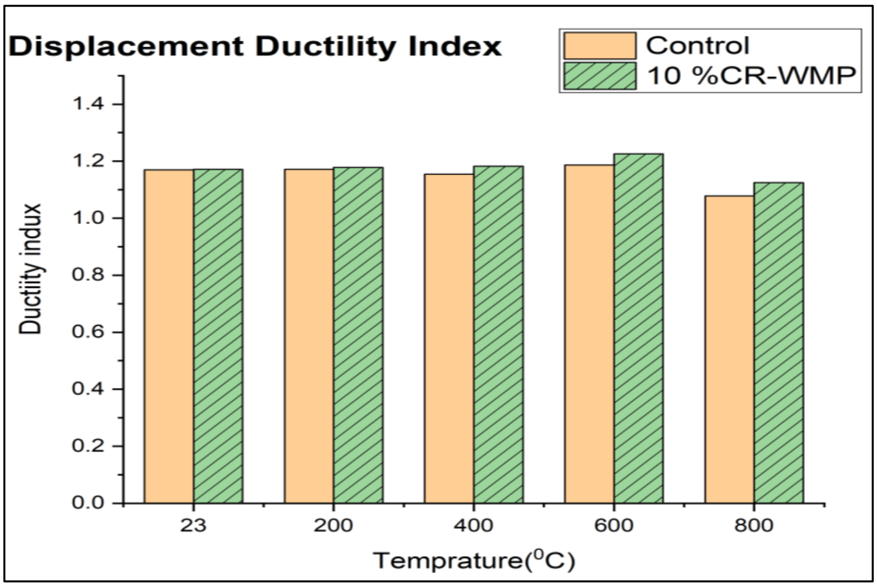


Figure 38: Ductility index control and modified column

4.2.9 Total crack energy in compression (TEC):

Concrete's total energy-absorbing capacity and its ability to sustain deformation under service load are its compressive toughness, often called "Total Crack Energy (TEC)”.

The total area below the curve from start point to peak point of the Load and deformation ". The load deformation curve will calculate the compressive toughness of both the control and WMP modified columns.

Based on the load deformation graph, the CR-WMP samples had higher Cracking energy than the control samples. TEC of 10 % CR-WMP achieved 11.42%, 10.06%, 5.36%, 2.877%, and 3.73 % increment as compared to control samples at (23 ºC - 800 ºC) respectively.

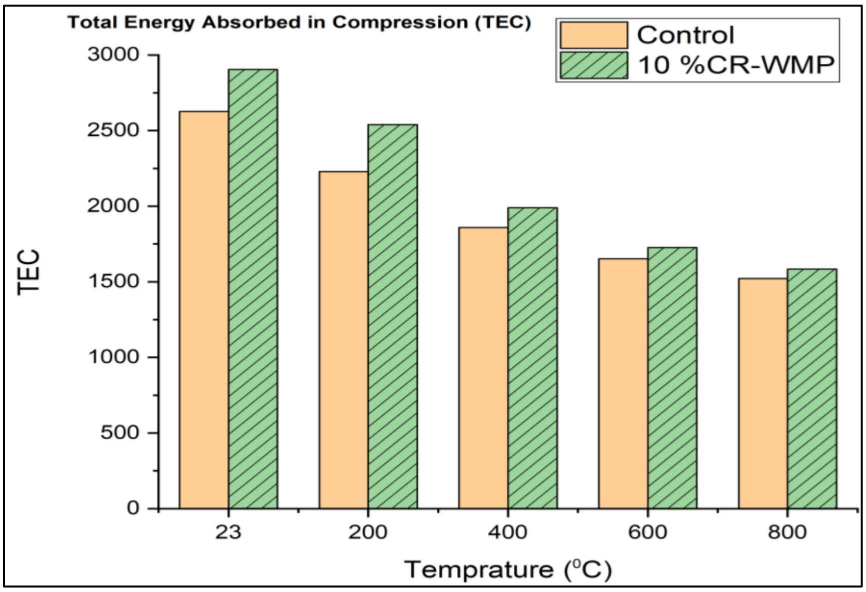


Figure 39: Total Energy Absorbed in Compression

Chapter 5

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This study discusses the mechanical properties of high strength concrete (HSC) short columns made with Waste Marble Powder (WMP) and comparison with HSC control columns. The mechanical properties of both the concretes are studied at elevated temperatures of (23, 100, 200, 400, 600 and 800) °C under both unstressed and residual test conditions. In addition to mechanical properties, the cracking analysis and visual assessment different elevated temperatures were also studied. After careful analysis, the results obtained from the experimental work done conclusions are made which are presented below. Future recommendation for research on this topic is also discussed at the end.

5.2 Conclusion

The reinforced concrete structure suffers a loss in strength and durability after being exposed to fire. When evaluating a structure that has been exposed to fire may be utilized for its deliberate purpose, mapping the damage produced by the fire is of the utmost importance. This study provides a concise overview of the structural member column evaluation against fire.

For all experiments ranging from 23 ^{O}C to 800 ^{O}C, below are the results of each column's experimental analysis.

- In visual inspection, the samples at 600°C and 800°C for both controls and 10% CR-WMP samples had surface cracks. Deterioration of the physical properties, notably at 800 °C.
- According to a visual inspection of 30% SRP-WMP and 50SRP-WMP plastering specimens, there were lesser cracks on the column than on the control samples.
- Mass losses control sample at (23, 200, 400, 600, 800) °C was (0,3.63,7.79,9.84,13.41) % and CR-WMP mass loss values was (0, 4.81, 8.86, 11.41, 16.47) % respectively. Which shows that mass loss modified sample slightly larger as compared to control sample.
    - A flatter load vs displacement curve is shown when the axial load is subjected to high temperatures, indicating a softer response in the control or modified sample.

- Load carrying capacity of modified columns 10% CR-WMP are higher due to particle of marble powder is smaller as compared to cement. So, the sample was dense and compacted. Eventually, fire resistance was improved at elevated temperatures.
- The Load deformation curve of columns with WMP alterations is considerably better than those of the control specimen when subjected to higher temperatures. According to the findings, the 800 ºC elevated temperature system caused the disintegration of waste marble powder, and 5% higher load carrying capacity as compared to control columns. There are direct correlations between cracks and the increase in the deformation as the temperature of the concrete increases.
- At room temperature, brittle failure is seen in all samples, whether control or modified WMP samples. But when temperatures increase (200,400,600 and 800) °C, the displacement value increase and failure was ductile.
- Furthermore, the experiment showed that the stiffness (initial and secant) values reduced as the temperature increased, demonstrating that all the samples' brittle behavior changed to ductility at higher temperatures. 10%CR-WMP stiffness value high as compared to the control sample because finer particle of waste marble powder very compacted and dense material so better stiffer and better load carrying capacity.
- Samples with temperatures between 23 ºC and 800 ºC show higher deformation values caused by vapor pressure development and columns was become porous, resulting in substantial degradation.

5.3 Recommendation

Further study can be done to achieve an optimum percentage of WMP in concrete HSC short columns under cyclic test loading for ambient as well as at elevated temperatures. Study the effect of thermal and mechanical properties of waste marble powder inducement in high-strength concrete short columns in both unstressed and stressed conditions. Dynamic behavior of concrete at elevated temperature by using various percentages of WMP can be evaluated.

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