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Combined Effect of Imposed Loads and Elevated Temperature on Normal Concrete and Concrete with Different Fibers

A Thesis

Submitted to the College of Engineering at University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of Engineering/ Civil Engineering/Construction Materials

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SUPERVISOR CERTIFICATION

I certify that the preparation of this thesis entitled " ***Combined Effect of Imposed Loads and Elevated Temperature on Normal Concrete and Concrete with Fibers Reinforcement*** " was prepared by " Maythem Shaker Lwaih " under my supervision at the department of Civil Engineering, College of Engineering, University of Babylon, as a partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Construction Materials).

SUPERVISORS

Signature:

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Date: / /

DEDICATION

This thesis is dedicated to:

My great wife, who never stop giving of herself in countless ways,

My little angle, my daughter Lujain

My beloved family; the symbol of love and giving,

My friends who encourage and support me,

Acknowledgements

In The Name of Allah, the Most Gracious, the Most Merciful

The writing this thesis has been fascinating and extremely rewarding. I would like to thank who have contributed to the final result in many different ways:

To commence with, I want to offer this endeavor to our **GOD**, the almighty to have bestowed me good health, courage, inspiration, zeal and the light to complete this research.

I would like to express my sincere gratitude to thank my thesis advisor: **Prof. Dr. Abbas AL-Ameeri**, he always accommodates and have a helping hand if I had question about my research or writing. He shows support in everything I do and teach me the right direction for my thesis writing. Deep sense of gratitude and respectful regards to my counsellor advisor **Prof. Haider Al-Bagdadi**, for the continuous support and valuable suggestions which have contributed greatly to the improvement of the thesis. I could not have imagined having better advisors and mentors for my study.

I would like to thank my **parents**, whose love and support are with me in whatever I pursue.

Maythem Shaker Lwaih

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Abstract

Reinforced concrete buildings and structures when being exposed to fire, the concrete qualities can vary in the case of an uncontrolled fire. It is essential to know how concrete's properties maybe change as a result of exposure to high temperatures and loading for normal concrete with / without fibers reinforcement. To understand the strength characteristics of concrete structures exposed to high temperatures is important. In order to predict how these structures will perform after exposure to this condition. Therefore, this study focuses on the investigation of the combined impact of loading and high temperature on the properties of concrete samples by testing the compressive strength, flexural strength, ultrasonic pulse velocity test (UPV) and rebound number of normal strength concrete (NSC) with/without steel fiber or basalt fiber. Two types of fibers were used in this study, steel and basalt fibers. The type of steel fiber employed in this investigation is hooked end steel fiber with 1% volume fraction of concrete while the type of basalt fiber is chopped fiber with 1% volume fraction. The concrete samples were subjected to three sustained load cases (20, 40, and 60) % of ultimate load and exposed to elevated temperatures (300 and 500) °C for about 2 hours. In addition, using unrestrictive test before and after loading and after heating. The results indicated that the loss in compressive strength is little where the percentage of reduction of compressive strength at 300° C was observed between (6-16%), (6-10%) and (16-19%). While, at 500° C temperature, the percentage of deterioration in compressive strength ranged (14-36%), (22-23%) and (17-22%) for mixes (NSC, Normal strength concrete with steel fiber (SF1) and normal strength concrete with basalt fiber (BF1)) respectively for all load cases. At 300° C temperature, the percentage of reduction of flexural strength between (14-18%), (6-9%) and (20-46%), while at 500 °C

temperature, the percentage of reduction of flexural strength between (30-36%), (23-27%) and (35-76%) for mixes (NSC, SF1 and BF1) respectively for all load cases. The results also indicated that cubes show no significant difference in ultrasonic pulse velocity for mixtures (NSC, SF1 and BF1) in all load cases at the 300 ^{O}C, whereas at 500 ^{O}C, NSC mix has a higher ultrasonic pulse velocity than SF1 and BF1 for (40% and 60%) of load. In addition, it was discovered that the percentage of rebound number reduction fell between (4-17%), (7-12%), and (4-7%) at 300 ° C, while at a temperature of 500° C, the percentage of rebound number reduction fell between (15-26%), (22-26%), and (14-18%) for mixes (NSC, SF1, and BF1), respectively. It was discovered that basalt fibers improved compressive strength at high temperatures and under all loading conditions, hence it is preferred to employ them in this field as opposed to improving flexural strength. In comparison with the use of other types of fibers, steel fiber performed well in flexural tests when it came to resisting loads and high temperatures.

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List of Abbreviations and Notation

C-S-H	Calcium silicate hydrate
CTE	Coefficients of thermal expansion
TTC	Transitory (or transitional) thermal creep
CMOD	Crack mouth opening displacement
UTM	Universal testing machine
NSC	The normal-strength concrete
BF1	Normal concret with basalt fibers
SF1	Normal concret with steel fibers
FRC	Fibre reinforced concrete
SCC	Self-compacting concrete
OMC	Ordinary micro concrete
VMA	Viscosity-modifying additives
SP	Superplasticizers
HRWR	High-range water-reducing

CHAPTER ONE

CHAPTER ONE

INTRODACTION

1.1 General

Despite the concrete has a very complicated internal composition, the normal-strength concrete (NSC) appears to be a very basic material. Concrete is the most widely used construction material in the world. These qualities, together with its adaptability, durability, and affordability, are seen in the range of constructions it is used for, including buildings, dams, bridges, and highways. NSC generally has a 45 MPa maximum compressive strength. The existing buildings and structures made of reinforced concrete are may be subjected to fire, and uncontrolled fires can change the concrete's properties. For normal concrete with (steel or basalt fibers) or without fiber reinforcing, Steel fiber reinforcing affects how cracks form in concrete and may provide increased fracture growth resistance, increase the roughness of individual crack surfaces, and increase the possibility of many cracks and crack branches forming, improving durability **(Banthia, 2010).** Another type of fibers that Basalt fibers resist high temperatures, impact, and chemicals well. Basalt fiber composites can be used in soil strengthening, industrial flooring, sound and heat insulation systems, and concrete structure restoration. Similar to how glass fibers are made, basalt fibers are made by crushing, washing, and melting rocks at a temperature of 1500 °C **(Kizilkanat et al., 2015).** It is critical to understand how the concrete's characteristics may alter as a result of exposure to high temperatures and loading. In order to forecast how these buildings will function after exposure to this situation, it is crucial to understand the strength characteristics of concrete structures exposed to high temperatures and stress.

1.2 Types of Fibers

Depending upon the material used for manufacturing fibers they can be broadly classified as;

1. Metallic fibers (e.g., low carbon steel, stainless steel, galvanized iron, aluminum).
2. Mineral fibers (basalt, carbon, glass, asbestos etc.).
3. Synthetic fibers (polypropylene, polyethylene, polyester, nylon etc.).
4. Natural fibers (bamboo, coir, jute, sisal, wood, sugarcane bagasse etc.).

Steel fiber makes a construction strong and durable by stopping the spread of shrinkage cracks that form during hydration. Additionally, when the loads applied on concrete approach the point of failure, cracks can sometimes appear quickly in addition to the action of fiber in halting the development of microcracks, which in effect increases the composite's strength.

When steel fiber used as reinforcement in concrete, steel fibers provide the following purposes:

1. To improve the tensile or flexural strength properties (including fatigue resistance).
2. To improve the impact resistance.
3. Using post-cracking ductility (in both tension and compression), one may control both cracking and the manner of failure. **(Lankard, 1984)**

Concrete's mechanical properties, which are greatly influenced by the type and quantity of fibers added, are affected. High aspect ratio fibers were discovered to be more effective **(Wafa, 1990).**

While basalt fibers were created by molding broken-down basalt volcanic rocks into long or short strands **(Kizilkanat et al., 2015).** Such fibers are Effectively resistant to impact, high temperatures, and chemical attack. are these fibers. Basalt fiber composites can be utilized for concrete structure restoration, industrial flooring, sound and heat insulation, and soil fortification. Basalt fibers are created by crushing, washing, and melting rocks at a temperature of 1500 °C, likes glass fibers. In order to reducing of concrete's brittleness and raise its fracture modulus, deformation resistance, toughness, and tensile strength, basalt fibers must be added **(Yildizel et al., 2020).**

1.3 Principal Problems of Concrete Exposed to High Temperatures.

Fire resistance and applied loads are the two most important parameters that directly affect the microstructure of concrete in the majority of civil engineering constructions. Compressive strength, flexural strength, ultrasonic pulse velocity, and rebound number are crucial factors to consider when assessing how concrete will behave after being subjected to high temperatures and loads. Concrete's constituents, including the fine and coarse aggregate and cement matrix, determine how it will behave thermally. Numerous publications have discussed how high temperatures and loads might cause concrete's behavior to vary. Temperature effects are brought on by important elements such as heating rate, exposure time, concrete grade, loading circumstances, etc. The inclusion of adequate high temperature safety measures for structural components and load capacity is one of the key safety requirements in building design. The rationale behind this criterion is that structural integrity is the last line of defense when other methods of limiting high temperatures and high load capacity fail. The strength and deformation properties of many structural elements, such as columns, beams, slabs, shear walls, etc., are significantly impacted by high temperatures caused by fire. Long-term exposure to high temperatures and stresses causes concrete to lose some of its mechanical qualities.

1.4 Research Significance

Normal strength concrete (NSC) is used in the construction of the majority of buildings. Researchers have recently proposed adding fibers, such as basalt or steel fibers, to normal concrete to improve its strength. The addition of fibers helps achieve objectives including the safety of the structure under loads, heat, and durability, therefore several types of fibers were employed to determine how much of an impact they would have on normal concrete under loads and heat. The impact of high temperatures on concrete and members made of reinforced concrete was extensively researched. They researched the deformation and strength characteristics at high temperatures. Such conditions simulate the real-world situation in which buildings are exposed to high temperatures while also being subjected to loads. The study aims to investigate the impact of temperatures when they penetrate deeper into concrete as a result of the presence of cracks. Therefore, the goal of this study is to improve the mechanical properties such as compressive strength and flexural strength of ordinary concrete with and without fibers by examining the combined effects of imposed load and increased temperature.

1.5 Objective and Scope

This Research aims to:

1- Study the combined effect of elevated temperature and imposed load on hardening properties such as: (compressive strength, flexural strength, ultrasonic pulse velocity and rebound number) of normal concrete reinforced by steel fiber or basalt and normal concrete without fibers.

2- Affect the imposed load on normal concrete with and without fibers (steel and basalt) for load cases of (20, 40, and 60 %) of ultimate load.

3- Specimens subjecting to imposed load (20, 40 and 60%) and temperatures (300 and 500 °C), with periods of exposure of (2 hours) the mechanical properties were measured.

1.6 Thesis Layout

In this study, the chapters are organized as follows:

Chapter one: provides an overview of the main research topic and the work's objectives.

Chapter two: a review of related previous research on normal strength concrete (NSC) with and without fibers (hooked end steel fiber and basalt), effect of elevated temperature on properties of concrete materials, durability of concrete and influence of loading during heating of concrete.

Chapter three: provides information about the components utilized, the ratio of the mix, and the tests performed during the experimental work.

Chapter four: this chapter discusses the results of the experimental tests.

Chapter five: is interested in the conclusions drawn from this work and suggestions for further research.

CHAPTER TWO

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Buildings and other types of construction generally utilize the material concrete. When being exposed to fire, the concrete qualities vary in the case of an uncontrolled fire. It is essential to know how concrete's properties change as a result of exposure to high temperatures and loading for normal concrete with / without fibers. The risk of exposing concrete to high temperatures rises as it is utilized for special purposes. Understanding the strength characteristics of concrete exposed to high temperatures is important in order to be able to predict how the building will react after exposure. Cracks form as a result of high temperatures exposure. Because the concrete is non-combustible and it has a relatively low thermal conductivity, structural components constructed of it which were traditionally made of NSC typically perform well in fire conditions **(Kodur and Banerji, (2021)).** Moreover, the heat transfers to the interior of a reinforced concrete element in a fire maybe gradually happen if the concrete cover stays during heating (there is no cover spalling) **(Kodur and Mcgrath, (2003))**. Therefore, it is a commonly held belief that concrete structures have inherent fire resistance.

Reviewing the components of concrete structures effects on the characteristics of both fresh and hardened properties of concrete will be dealt in this chapter.

2.2 Effect of Elevated Temperature on Properties of Concrete Materials:

For each experiment, a number of parameters should be taken into consideration in order to comprehend the behavior of concrete at high temperatures. The performance of concrete at high temperatures is influenced by a number of important factors, including the strength of the concrete, the type of cement **(Anand & Arulraj, 2011).** Therefore, the impact of high temperature on concrete materials will be presented in next sections.

2.2.1 Cement Past

Cement paste and aggregates are combined to form concrete. The fine and coarse aggregates are covered with a paste made concrete, cement serves as the glue that holds concrete together **(Weiss, 1999),** and as a result, it is crucial to the qualities of both freshly-poured concrete and concrete that has hardened.

Javidan et. al. (2014), Tran et. al. (2011) explored that the progression of damage caused by elevated temperature can be summarized as starting at around 110°C, the cement paste begins to dehydrate where the chemically bound water is released from the calcium silicate hydrate (C-S-H). In the range of 400 − 800°C, calcium hydroxide decomposes into calcium oxide and water, causing the major strength reduction. Consequently, the deterioration of concrete's strength is caused by more than only the breakdown of cement hydration products. It is also influenced by the microcracks that form as a result of the disparity in the paste's and the aggregates' coefficients of thermal expansion (CTE).

The fluctuations of CTE for cement and binder samples as the temperature rises from ambient temperature to 500°C were examined by **Fu et al. (2004).** The CTE of mortar samples is rather consistent over this range, according to their findings.

In addition, experiments on cement paste conducted by **Odelson et al. (2007)** showed the stiffness deterioration occurs predominantly before the temperature reaches 200°C, leading them to the conclusion that microcracking is the main mechanism causing this drop. They asserted that after these microcracks have formed, the impact of chemical deterioration is negligible and that this microcracking is a result of water expansion and evaporation.

Several models have been put out to simulate how elevated temperature affects concrete materials, each of which focuses on a particular component of temperature effects. **Tenchev and Purnell, (2005)** suggested a damage constitute model and mimic the behavior of concrete at high temperatures. In these simulations, their model took into account the impact of transient creep, heat transmission, and pore pressure by fusing the plasticity and damage theories. In the same line, **Gernay et al., (2013)** developed a 3-dimensional thermomechanical model for concrete. The significance of various parameters was investigated by **Gawin et al., (2011)** in the modeling of a concrete wall subjected to elevated temperatures. At the mesoscale, it is possible to gain a deeper comprehension of the macroscopic constitutive behavior of concrete **(Contri, 1984)** where emphasis is given to the effects of pores and inclusions (aggregates), model of the interactions between aggregates and the hydrated cement paste was developed by **Xotta et al., (2015)** using the finite element approach. They investigated the progression of concrete deterioration under high temperatures using their model.

Several studies have highlighted the significance of the thermal expansion coefficient in relation to how concrete loses strength in high temperatures **(Arioz, 2007; Gernay et al., 2013).** The amount of the harm brought on by what is referred to as "thermal incompatibility" between the various elements of concrete material is still unknown, though. Temperatures between 204 and 871°C caused cement paste to shrink; this mitigated the expansion of the cement paste matrix at high temperatures. For a range of temperatures, the typical coefficients of expansion are given for the tested materials. Devices designed to automatically regulate heating rate and record strain **(Cruz & Gillen, 1980).**

Phan and Phan, (1996) investigated how high temperature exposure affected cement paste, mortar, concrete samples, and reinforced concrete members. The findings of research served as the scientific foundation for several codes' requirements and suggestions for measuring the concrete strength at elevated temperatures. Using design curves outlined in the codes **(Abrams, 1971; Finland., 1991)**, it is possible to determine the mechanical properties of concrete at high temperatures for design purposes.

2.2.2 Coarse and Fine Aggregate

The aggregates typically have a high level of fire resistance **(Biró and Lublóy, 2021).** The outcomes, however, demonstrate that the type of aggregate used in the concrete mixture has an impact on how much degradation maybe occur. This properly is the result of both the aggregates' thermal expansion and their mineral composition. In fact, it is thought that one of the key factors causing degradation at high temperatures is the thermal instability of the aggregates **(Hertz, 2005; Yoon et al., 2015).**

To understand the behavior of concrete at high temperatures, a variety of parameters should be considered for each experiment. The type of aggregate used in concrete has a significant impact on its performance at high temperatures **(Anand and Arulraj, 2011).**

The performance of concrete at high temperatures is significantly influenced by the type of aggregates used in its production. **Fintel,**

(1974) asserted that carbonate aggregates outperform siliceous aggregates in high temperatures. At 570°C, siliceous aggregates rapidly start to grow and break apart.

According to **Yoon et al., (2015),** the strength degradation of concrete produced from lightweight aggregate is lower than that of concrete made from regular aggregate. Because the typical aggregate has a larger thermal expansion coefficient than light-weight aggregate.

2.2.3 Admixture Materials

Some substances or a combination of organic and inorganic compounds are known as superplasticizers (SP) or high-range water-reducing (HRWR) and are used in change the characteristics of concrete or mortar to improve their suitability **(CAA, 2006).** The majority of admixture producers will offer a variety of superplasticizing admixtures that are suited to particular user needs and the impacts of other mix constituents **(EFNARC, 2005).**

These admixtures are used in concrete for the following purposes: Increasing viscosity and thixotropic characteristics, reducing bleeding and segregation for fluid mixes, improving stability during transit, installing enhanced pumping, and dimensional stability allows for flexibility in mixture proportioning, improved finishing, and less drooping **(CAA, 2006).** In order to prevent segregation, the mix's rheology maybe need to be changed in a way that increases the plasticity while maintaining fluidity and compactability, viscosity-modifying additives (VMA) are employed **(CAA, 2006).** To create a high fluid, viscosity modifying admixtures are frequently employed in conjunction with high range water reduction agents.

Concrete's primary constituents that can easily flow into reduce water dilution, increase the degree of suspension of different solids, and ensure that there is little separation between the various elements of varying densities **(Khayat, 1998).**

2.2.4 Steel Fibers

Similar conclusions have been achieved by other researchers, who found that adding steel fibers at random to concrete can greatly increase the material's strength, ductility, and impact resistance **(Abdallah et al., 2016; Zhang et al., 2020).** As fiber-reinforced concrete has been developed and used, **Kearsley and Wainwright, (2002)** demonstrated that the compressive strength of the material diminishes exponentially as density decreases. Experimental studies on the mechanical characteristics of normal concrete following the application of high temperatures were done by **Al-Ameeri, (2013), Ismail et al., (2011).** The compressive strength of high-temperature concrete altered little or even improved when the temperature does not rise above 300 C. The compressive strength of concrete progressively reduced as the temperature increased. The concrete essentially lost its ability to support weight around 800 °C.

These compounds also include steel fibers, which are now frequently used in concrete. Fiber-concrete production aims to improve the material's toughness, resistance to impact effects, flexural strength, and other mechanical qualities. The use areas for concretes with fiber are more varied. as compared to normal concretes, such as field concrete, paving, industrial constructions, slope stabilization and retaining wall construction, hydraulics, and construction buildings **(Ahmad et al., 1988; Altun et al., 2006).**

Consequently, the density of fiber-reinforced concrete maybe causes the compressive strength to go down exponentially **(Ismail et al., 2011)**

In particular, airport aprons, industrial grounds and chimneys running at high temperatures, and facilities producing chemical ingredients with a significant fire risk show the effects of high temperatures.

According to the degree of the temperature and the duration of the heating process, damages in burned constructions can be seen mainly on concrete bearings from the outside to the interior. Measuring results showed that, a component that it is referred to as a shell form as the loss of strength in reinforced concrete bearings decreases from the outside to the inside (**Düğenci et al., 2015).** While core concrete will suffer fewer strength losses than shell concrete, the contribution of adding steel fiber to the compressive strength should not be disregarded. Because it is believed that by preventing the development of cracks, it will make a significant contribution.

Steel fibers were employed to decrease the cracking, spalling, and damage that high temperatures caused in self-compacting concrete (SCC). This could be explained by the fact that mechanical anchoring or surface roughness may improve their attachment to the matrix **(Al-Ameeri, 2013).**

2.2.5 Basalt Fibres

Basalt fibers are made of broken-down basalt volcanic rocks, which were then molded into continuous or chopped fibers **(Kizilkanat et al., 2015).** These fibers are effectively resistant to high temperatures, impact, and chemicals attack. Basalt fiber composites can be used in soil strengthening, industrial flooring, sound and heat insulation systems, and concrete structure restoration. Similar to how glass fibers are made, basalt fibers are made by crushing, washing, and melting rocks at a temperature of 1500 °C. The addition of basalt fibers is crucial in lower the brittleness of concrete and increase its fracture modulus, deformation resistance, toughness, and tensile strength **(Hu & Shen, 2005; Serbescu et al.,**

2015; Yildizel et al., 2020). In compared to carbon and glass fibers, basalt fibers display higher strength to tensile actions, impact loads, fatigue, thermal instability, corrosion, and water penetration **(Lu et al., 2015)**. Additional researches of **(Kabay, 2014; Sim & Park, 2005)** looked at the insulation properties, thermal resistance, and durability of concrete reinforced with basalt fibers. The addition of basalt fibers significantly improves these properties of concrete. When the temperature was raised to 500 °C, the basalt fibre self-compacting concrete (SCC), the compressive strength decreased by 28%, as shown in **Figure (2-1) (Haido et al., 2021).**

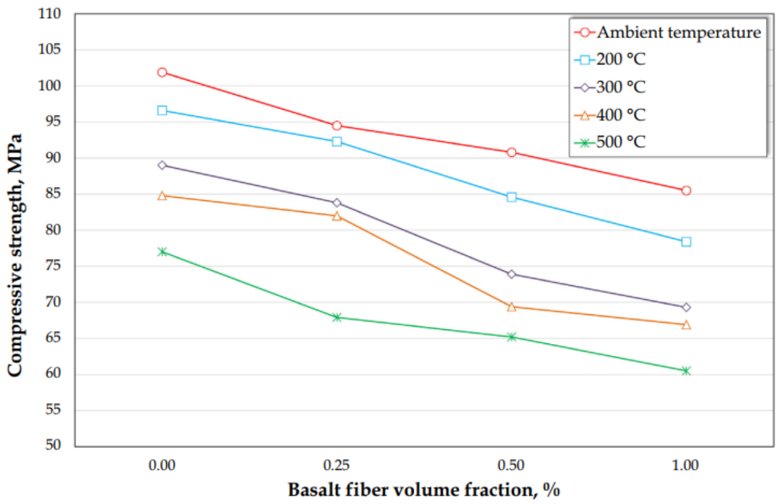

Figure (2-1): *Elevated temperature and fibre content effect on the compressive strength of the basalt fibre SCC mixtures.*

According to **(Ren et al., 2016),** basalt fiber-reinforced concrete's dynamic strength and impact toughness often decrease with increasing temperature for a given impact velocity while increasing with impact velocity for a given temperature.

2.2.6 Reinforced Steel Bar

Compared to concrete, the performance of steel during a fire is well understood, and the strength of steel at a given temperature can be anticipated reasonably well **(Fletcher et al., 2007).** Because low carbon steels are known to display blue brittleness between 200 and 300°C, it is commonly accepted that steel reinforcing bars need to be protected from exposure to temperatures above 250–300°C. At temperatures up to 400°C, steel and concrete both experience similar thermal expansion. The load-bearing capacity of the steel reinforcement will be decreased to around 20% of its design value if temperatures on the order of 700°C are reached, while greater temperatures will result in little expansion of the steel relative to the concrete **(Fletcher et al., 2007).**

Topçu and Karakurt, (2008) studied the steel reinforcing bars' mechanical characteristics following exposure to high temperatures. For three hours each, specimens of plain steel, reinforcing steel bars embedded in a mortar, and plain mortar were manufactured and exposed to the various fire temperatures (20, 100, 200, 300, 500, 800, and 950°C). A 25 mm thick concrete cap protects against temperatures as high as 400°C. When the reinforcing steel with the 25mm cover was exposed to a temperature 250°C above the exposure temperature of plain steel, the properties of the high temperature exposed plain steel and the steel with the cover are the same.

Mamillapalli, (2009) heated the reinforcement steel bars to temperatures of (100, 300, 600, and 900°C) allowed researchers to examine the effects of the high temperatures on the bars. By quenching in water and typically by air-cooling, the hot samples were quickly cooled. Using the universal testing machine (UTM), the variations in the mechanical properties were investigated. On the reinforcing bars, the effect of elevated temperature exceeding 900°C was seen. Rapid quenching cooling resulted in a considerable loss of ductility. In the same situation, the impact of temperature on ductility was not significant while cooling under typical air circumstances.

Topçu and IşIkdağ, (2008) examined the mechanical characteristics of steel reinforcing bars after being exposed to high temperatures. The B16 mm-ribbed steel bars were utilized to create specimens that were (56 x 56 x 290 mm), (76 x 76 x 310 mm), (96 x 96 x 330 mm), and (116 x 116 x 350 mm) against increased temperatures up to 800°C. The specimens were subjected to (20, 100, 200, 300, 500, and 800°C) after the reinforcement steel bars were inserted in mortars. The samples underwent chilling before being cured for 28 days. At the conclusion of the studies, the ultimate tensile strength, yield strength, and elongation of mortar specimens at various temperatures were measured. The mechanical tests were performed on cooled specimens. The findings showed that rebar was protected from high temperatures by covers with a thickness of 20, 30, 40, and 50 mm. Rebar with the cover has a 15% better strength than rebar without it and has less yield and tensile strength loss. A rebar with a cover had the same yield and tensile strengths in exposure to high temperatures for temperatures up to 300°C as a rebar without a cover. Nevertheless, when the temperature reached 800 °C, the rebars with covers maybe a 20% loss in strength on average, compared to 80% loss for rebars without covers. There was a finding that. The mechanical characteristics of rebars were not adequately protected when exposed to temperatures exceeding 500°C by cover thicknesses of 20, 30, 40, and 50 mm.

2.3 Effect of Elevated Temperature on Properties of Concrete

2.3.1 Compressive Strength

Numerous researches have noted that strength declines with exposure temperature rises. Under high temperatures, the strength degradation is not uniform. The kind of aggregates used, the heating and cooling schedule, the presence of pozzolanas, fibers, etc. All have a role in this **(Fintel, 1974).** The residual compressive strength increased by 110% when the test temperature was 200 ˚C, **(Wu & Wu, 2014).** The reduction in residual compressive strength is particularly pronounced between 400 ˚C and 600 C, with values ranging from 97% to 71% at 400 ˚C and falling to 30% at 600 ˚C as shown in **Figure (2-2)**. The residual compressive strength continues to decline to 9% between 600 ˚C and 1000 ˚C. The compressive strength of concrete begins to decline at a temperature of 200 ˚C, according to **Zhai et al., (2014)** After firing at 1000 ˚C, the compressive strength value lowers significantly to 21.3% when compared to specimens that were not fired **(Zhai et al., 2014)** studied the influence of specimen size and found that larger size specimens perform better and suffer from reduced strength loss. Therefore, it is necessary to look into really large specimens.

Depending on the temperature, there are different relationships between residual strength and high temperature strength. According to reports, up to a temperature of 400 C, strength at low temperatures is greater than strength at rest. The residual strength, on the other hand, is measured to be lowerthan the strength at high temperature as the exposure.

For unsealed concrete, compressive strength decreases from ambient to a minimum at 80 ° C. It is believed that this 'apparent' strength loss, which is mainly reversible upon cooling, is caused by the physical Van der Waals forces becoming weaker as the expanding water molecules push the C-S-H layers apart. So, when the "residual" strength is calculated after cooling and plotted against the initial temperature, this minimum does not show up. The 'hot' strength is frequently observed to peak at a temperature that is 200–300°C higher than the original strength before heating. However, it also depends on the type of cement and aggregate mixture utilized in the mixture. By using wise mix design, the concrete performance between 300 and 600 °C can be improved.

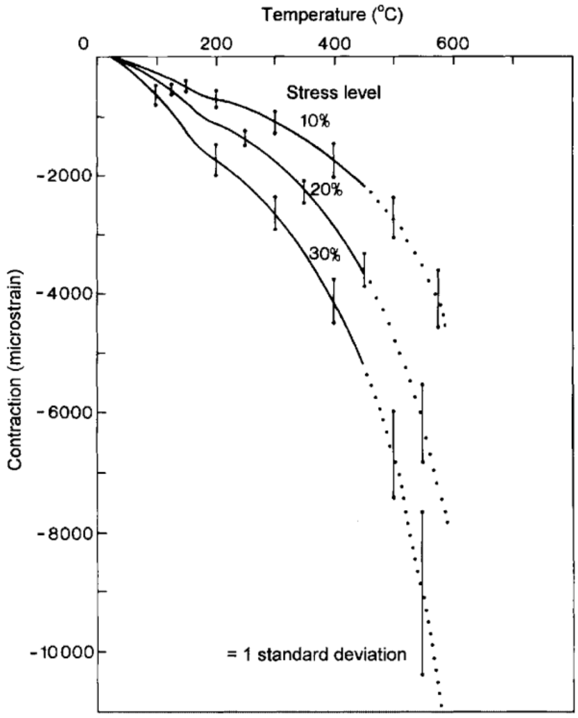

Figure (2-2): *Concrete under compressive loads up to 30% of its unheated strength while heating at 1 °C min^{-1} to 600 °C; heating was delayed to reduce "structural" effects.*

A few researchers have studied into the mechanical changes that concrete goes through when temperatures rise. According to **Wu, (2014)** and **Zhai et al., (2014)** up to 600°C and during a period of 1-6 hours, the extent of strength deterioration is essentially independent of the exposure time. **Ergün et al., (2013)** claimed that the cement dosage utilized in the mix design has no bearing on the strength reduction brought on by high temperature.

2.3.2 Flexural Strength

In order to represent the residual post-cracking, **(Jeng et al., 2002)** presented a relative residual account of the peak flexural tensile strength or the mechanical behavior of the FRC specimens up to that point.

Flexural tensile strength under particular control of the crack mouth opening displacement (CMOD), as demonstrated by **Mindess et al., (1994) and Barr et al., (1996)**, the deflection control causes challenges in many circumstances while forming fibre reinforced concrete (FRC), calling into question the applicable standard's processes for identifying the first crack. Concretes with steel fiber reinforcement have greater flexural strength than concretes without steel fiber reinforcement. This is mostly owing to the composite's increased crack resistance and the fibers' resilience. Also, it was discovered that as fiber content grew, so the proportion of the rise maybe increase in flexural strength. This characteristic is mostly related to steel fibers' ability to release fracture energy at crack tips, which is necessary for the crack to spread by moving from one side to another **(Jenq and Shah, 1986).** As a result, there are numerous microcracks created in the specimens' interior structures between the aggregate and cement paste and as a result of these expanding cracks, the specimens explode due to its lower permeability and greater moisture content compared with normal concrete (NC), self-compact concrete (SCC) is likely to fracture more frequently **(Anagnostopoulos et al., 2009).**

As a result of the drying shrinkage of concrete, which results in the dissolution of cement compounds and a drop in flexural strengths at high temperatures, specimens have internal cracks that lower their flexural strengths **(Neville, 1995).**

More than compressive and splitting tensile strength, steel fibers are observed to be helpful in reduce the damage effect of high temperature for ST1 (SSC with steel fibers 0.5%) and ST2 (SSC with steel fibers 1%) blends. In comparison to compressive and splitting tensile strength, steel fibers were typically more successful in enhance the flexural strength. For all ages and exposure times, some specimens' flexural strength increased by up to more than 100% when compared to specimens without steel fiber. That might be because steel fiber changes how fractures form in concrete by enhancing crack growth resistance and strengthening the link between steel fibers and concrete **(Ahmed, 2013).**

2.3.3 Ultrasonic Pulse Velocity

The integrity of concrete heated to high temperatures was assessed using the ultrasonic pulse velocity method, this technique has a lot of benefits, including little influence on the tested structure, a simple evaluation process, and the capacity to assess changes in the internal structure of concrete.

The compressive strength of concrete can be estimated using formulae, and concrete integrity can be assessed using criteria such as monitoring the ultrasonic pulse velocity in concrete **(Gucunski et al., 2009; Hong & Cho, 2011).** Furthermore, **Yang et al., (2009); AL-Ameeri (2014)** calculated and predicted the compressive strength of concrete exposed to high temperatures took into account different compressive concrete design strengths and types. Similar to this, **(Benedetti, 1998); (Lie et al., 1986)** assessed the integrity and remaining mechanical properties of concrete exposed to fire conditions. In recent years, concrete degradation has been assessed using ultrasonic pulse parameters such propagation duration and amplitude. **Shah and Ribakov, (2009); Shah et al., (2009)** investigated the formation of harmonic waves during loading in concrete specimens with conventional and 150 mm cubic sizes. Moreover, **Pahlavan et al., (2018)** investigated cracks in concrete buildings by interacting with ultrasonic pulses when concrete degradation had already started, the ultrasonic pulse velocity and mechanical qualities of the concrete were assessed. It is essential to evaluate the integrity of the concrete during the heating, nevertheless, because concrete is continuously degrading during high-temperature heating. It is also essential to evaluate the ultrasonic pulse velocity both before and after the degradation has advanced in order to understand the relationship between that quantity and the mechanical characteristics of concrete.

2.4 Effect of Elevated Temperature on Durability of Concrete

Fire poses a major threat to the lives of the building's residents since it has detrimental long- and short-term impacts on the structure. Numerous studies have assessed the behaviors of concrete in these circumstances while taking into consideration the significance of its fire performance. The residual strength and durability of concrete structures, as well as their safety and usable lifespan after being exposed to fire, are crucial issues.

Concrete's performance in terms of its physical, mechanical, and durability is negatively and permanently impacted by fire exposure. Investigating how concrete performs after being subjected to fire is important. According to research was done thus far, environmental and mechanical elements are the two main ones that can affect how long cementitious matrices last **(Poon et al., 2003).** High temperatures brought on by a fire maybe reduce the strength and durability of structures. The type of aggregate and cement used, its composition, the temperature and duration of the fire, the sizes of the structure's elements, and the concrete's moisture content, all have an effect on the fire resistance of concrete **(Noumowe et al., 1994; Phan et al., 2001).** Mineral aggregates are the main component of the composite material known as concrete, which is held together by a matrix of hydrated cement paste. Unless properly dried, the very porous matrix holds a sizable amount of free water. Concrete changes chemically, physically, and in terms of water content when subjected to high temperatures. In untreated settings, these modifications primarily affect the hardened cement paste. The physical and mechanical characteristics of concrete that are affected by temperature increase reflect these changes. There are two ways that concrete can collapse in high temperatures **(Lublóy & Balazs, 2012).**

1) Little flaws (cracks) in the material's structure as shown in **Figure (2-3)**.

2) Worldwide harm leading to the collapse of the element as shown in **Figure (2-4).**

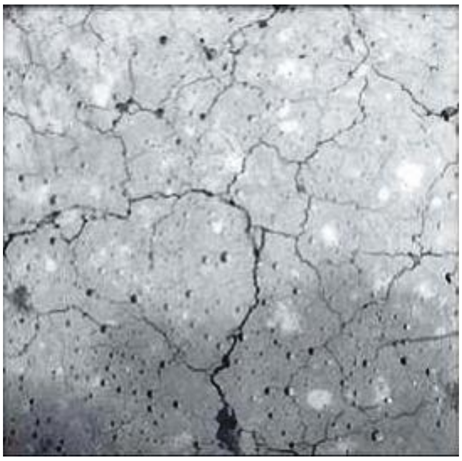

Figure (2-3)*: Cracking of the surface as a result of high temperatures* ***(Lublóy, 2010)***

Figure (2-4): *Building collapse* ***(Lublóy & Balazs, 2012).***

Cracks form as a result of effect of high temperature concrete properties. The effect of temperature on fractures distributions of concrete members in a fire is the subject of research **(Wu et al., 2014).** Similar to other cracks, these cracks could eventually result in a loss of structural integrity and a reduction in service life **(Kulkarni & Patil, 2011),**

The reinforcement of concrete by steel fiber affects how the cracks to form in concrete and maybe enhance the resistance to crack growth, increase surface roughness of individual cracks, and increase the possibility of break branching and multiple crack development **(ACI-544.5R, 2010).** Concrete's permeability can be considerably reduced using steel fiber reinforcing, increasing the material's durability **(Banthia, 2010).** For each experiment, a number of parameters should be taken into consideration in order to comprehend the behavior of concrete at high temperatures. The performance of concrete at high temperatures is influenced by a number of important factors, including the strength of the concrete, the type of cement, the type of aggregate, the water cement ratio, the density of the concrete, the percentage of reinforcement, the cover-to-reinforcement ratio, etc **(Anand & Arulraj, 2011)**. As a building material, concrete typically has an acceptable level of fire resistance. The impact of exposure temperature (300-700 °C) and exposure period (1–9 h) on the remaining mechanical strength of concrete were also studied. The most glaring tendency regarding exposure temperature was the decline in residual compressive strength with an increase in intended exposure temperature. Additionally, it was noted that regardless of the exposure temperature, extending the exposure period has a negative impact on the residual performance of concretes, particularly the compressive strength **(Toumi et al., 2009).**

2.5 Influence of Loading during Heating of Concrete

Malhotra, (1956) published the first tests on heated concrete under stress. The strength of specimens heated under constant stress was found to be higher than that of specimens heated without load by about 0.2 *fc* (where *fc* is the uniaxial compressive strength at air temperature). When the temperature is increased, the disparity grew from 4% at 200 °C to 21% at 500°C. **Abrams, (1971)** investigated the combined effect of load and high temperature on the strength of concrete. Six different concretes specimens were tested to peak stress in uniaxial compression after being heated to 204 °C, 482 °C, and 704 °C and loaded in uniaxial compression to 0.25, 0.40, and 0.55 of compressive strength *fc*, respectively.

It was concluded that no matter the aggregate type, mix proportions, compressive strength at air temperature, specimen heating temperature, or degree of tension during heating, the results showed 5-25% higher hot strengths than the companion specimens heated without stress in all experiments.

Hansen and Eriksson, (1966) found that specimens of cement and mortar heated under load deformed more than specimens heated first and then loaded. Furthermore, this very large additional strain known as transitory (or transitional) thermal creep (TTC) was only noticed during the initial heating to a certain temperature. In the past 40 years, TTC has been studied in trials on various types of concrete that have been heated at various rates to temperatures as high as 600 °C while being subjected to various (moderate) uniaxial **(Anderberg and Thelandersson, 1976; Khoury et al., 1985)** and biaxial **(Ehm and Schneider, 1985)** stress levels. The temperature-strain connections, as well as the material and ambient conditions that affected them, were the main topics of this experimental study. **Khoury et al., (1985)** heated concrete specimens in one of their test programs to 600 °C under uniaxial compression of (10, 20, and 30) % of *fc*, then cooled them and tested them at room temperature **(Khoury et al., 1986).** They discovered that the residual strength reached its maximum at stresses between 20% and 30% of *fc*, much higher than that of the control specimens (heated without load). The authors made the assumption that "densification of the cement paste" and "reduction of tensile stresses during cooling" were the main causes of the increased strength. For concrete tested at temperatures between 150 °C and 750 °C, **Ulrich, (1988)** provided the results demonstrating an increase in modulus of elasticity when the specimens were heated under tension between 0 and 0.30 f_t, but very little change for stresses between 0.3 and 0.5 f_t. He stated that it was "clear that the strained strength is higher than unstressed strength However, some experimental data do not support the generalization that adding load while concrete is heating increases its strength. Heating under loads between 0.1 *fc* and 0.45 *fc* increased significantly the modulus of elasticity, decreased the ultimate strain (strain at peak load), but had almost little impact on the hot compressive strength **(Anderberg and Thelandersson, 1976)**

Sarshar & Khoury, (1993) studied specimens made from five different mixes were heated to temperatures up to 600 °C at rates of 1 °C per minute and 3 °C per minute while being subjected to 0.1 *fc* and 0.15 *fc* stress. The specimens were then tested to peak stress immediately following the peak temperature, after a period of constant temperature, and after cooling. They discovered that while the concrete with Lytag aggregates showed no difference, the concrete with firebrick aggregates heated under 0.15 *fc* stress had a little higher hot strength than the control specimens. The cement paste specimens heated under load, in contrast to the behavior of the concrete, developed cracks after cooling in the direction of the load. Compared to specimens heated without stress, their residual strength was significantly reduced. Other than making the assumption that aggregates prevented this behavior in concrete specimens, the authors provided no explanation for this. Another finding **(Sarshar & Khoury, 1993)** was that the strength of their cement paste specimens was also affected by the heating rates, with OPC specimens heated faster (3 °C min^{-1}) showing lower strength at 300 °C, but similar strength at 500 °C. The silica fume when heated at 3 °C min^{-1} to 520 °C, paste specimens exhibited the reverse behavior, maintaining a similar strength at 300 °C but completely disintegrating. However, as the heating rate was raised, the strength of the concrete specimens rose, supporting the results of past investigations **(Khoury et al., 1986; Mohamedbhai, 1986).** This result of many research focus on the result of the material deteriorating from prolonged exposure to high temperatures. And the tests on sealed and unsealed specimens, heated without load to temperatures as high as 260 °C, were conducted by **Lankard et al., (1971)** to determine the effects of moisture content. They discovered that heating unsealed specimens caused only minor losses in elasticity and uniaxial compressive strength. However, heating sealed specimens caused a loss of strength of around 50% and a fall in modulus of elasticity of almost 70%. Limestone concrete's unsealed-hot and sealed-residual characteristics were compared by **(Callahan et al., 1978)**. At 250 °C, they discovered that (i) unsealed-hot strength was 35% greater than sealed-residual strength and (ii) modulus of elasticity was comparable for the two test circumstances despite being drastically reduced by high temperatures. According to **Callahan et al., (1978),** data from unsealed despite the fact that structural concrete is generally subjected to multiaxial stress conditions, practically all experimental research has been carried out on specimens loaded in uniaxial compression. The experimental investigation of concrete under biaxial compression at elevated temperature was carried out by researchers at the University of Braunschweig **(Ehm & Schneider, 1985).** They heated unstressed specimens to different temperatures (up to 600 °C, at 2 °C min^{-1}) and then loaded in biaxial compression at a range of 1/2 ratios until peak stress was reached. The outcomes display various forms of biaxial strength envelopes captured at various temperatures. The triaxial torsional ring at Northwestern University was used to conduct the sole multiaxial compression testing at high temperatures **(Baẑant & Prasannan, 1986).** The main objective of this work was to investigate stresses under multiaxial compression at high temperatures and under regulated hygrometric settings. The experiments were primarily restricted to low stress levels, and the strength or stress-strain behavior at high stress levels was not examined.

Thorough experimental analysis of the impacts of various heat-load regimes on the thermal and hygroscopic characteristics of Portland cement mortar was investigated. When heated to 800 °C at a rather high rate of 6.7 °C min^{-1}, specimens loaded to 0.9 *fc* were compared to specimens heated without load. It was discovered that specimens heated without load had a moisture diffusivity that was ten times higher than specimens heated with weight. The load applied before heating induced cracks that prevented the growth in pore pressures, explosive pore failures were thought to be caused by the build-up of pore pressures during heating of unstressed specimens **(Baẑant & Prasannan, 1986)**.

Researchers are still very interested in the strength of concrete at high temperatures. The impact of various material parameters on the residual strength of unstressed concrete heated to high temperatures were the main focus on the experimental research conducted in the previous more than 16 years ago **(Arioz, 2007; Xu et al., 2001).** According to a review of the research on concrete at high temperatures done in China between 1990 and 2001, **(Xiao & König, 2004),** there has also been a lot of attention paid to the residual, uniaxial compression strength of unsealed specimens heated without load. The tests were conducted under biaxial compression and the specimens were heated under stress.

This analysis demonstrates that the majority of studies on concrete at high temperatures has used relatively small, unsealed, unstressed specimens heated at relatively modest heating rates before being loaded to their maximum stress in uniaxial compression. These studies' findings are not readily transferable to scenarios in which concrete structures are exposed to fire or other high temperatures. In actuality, under various multiaxial stress levels, the majority of the material in structural concrete elements are partially sealed and heated.

The beneficial influence of loading, which puts the substance into compression, compacts the concrete during heating, and prevents cracking is another benefit of concrete at high temperatures. Again, the practicing engineer does not completely understand this influence, and the rules and standards do not adequately address it. **Figure (2-5)** illustrates this phenomenon by comparing the stress-strain relation for concrete heated under 20% load and without load at high temperature levels of 20 to 700 °C. Temperature effects can be significantly reduced, when the concrete heated under load, both the compressive strength and elastic modulus decrease as the temperature rises **(Khoury, 2000)**. Nonetheless, experiments consistently demonstrate that for concrete heated without load, the modulus of elasticity decreases with an increase in temperature by a greater percentage of the beginning value than the compressive strength **(Khoury & Algar, 1998).**

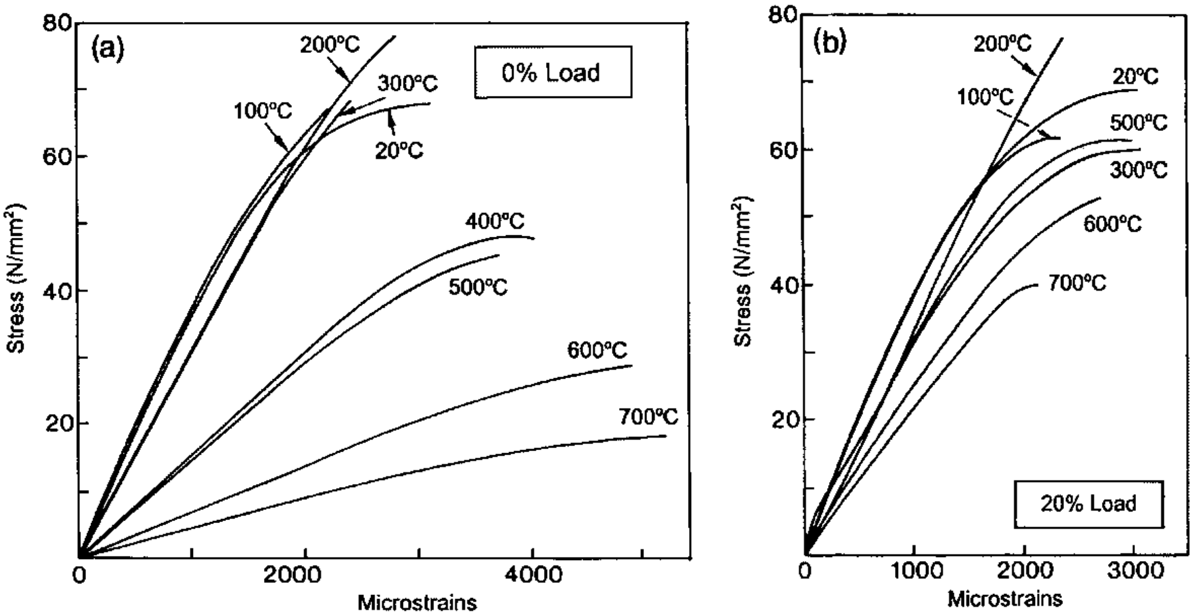

Figure (2-5)**: Heating-up effects of temperature and load level on the residual stress-strain relation in uniaxial compression of cylindrical* ***(Khoury, 2000).

High-temperature stressed tests entail simultaneously heating and loading the sample. In these tests, the samples are loaded to a small portion of their nominal strength, heated while the load is maintained, and then the test is repeated. The current load is increased till failure once the temperature reaches the desired value. High-temperature unstressed tests are comparable to stressed testing but do not include the starting load. Tests under stress and tests without stress are frequently conducted in tandem **(Petkovski, 2010).** The results show that stressed samples generally experience less strength loss than unstressed ones, despite the fact that the presence of stress during heating causes intricate micro-mechanical during residual tests following exposure to high temperature, as opposed to stressed and unstressed tests at high temperatures, the sample is allowed to cool down to room temperature before being put under load **(Wu & Wu, 2014).**

2.6 Effect of Temperature and Method of Cooling on Compressive Strength of Concrete

The residual compressive strength is also influenced by how the hot concrete is cooled. A thermal shock results from the rapid cooling of a heated concrete surface using water, which results in a slight worsening of concrete strength. **Janotka & Nürnbergerová, (2005)** claimed that the quick cooling of heated concrete surfaces exposed to 1000 °C and 2000°C is just as detrimental for structural quality deterioration as temperature increases.

Arioz, (2007) noted a considerable fall in relative strength after 600 °C and a sharp reduction in residual strength up to that point (residual strength 90% for carbonate aggregates and 50% for river gravel). According to test results, ordinary micro concrete (OMC) loses 12% of its compressive strength when heated to 400°C and cooled in air, and 29% in water. Samples heated to 600 °C and cooled in air lose 27%, whereas samples cooled in water lose 44% of their compressive strength, it is a downward trend with rising temperature. The strength loss curves for conventional concrete derived from this work show the same trend as those from **(Abrams, 1971; Lee et al., 2008; Morita et al., 1992).**

The properties of the materials used in produce the concrete, the rate at which it heated up, the maximum temperature to which it was exposed and how long it was exposed to it, the method used to cool the concrete after it reached its maximum temperature, and the loading level at the time of cooling are just a few environmental factors that affect how concrete will actually behave when exposed to high temperatures **(Crook and Murray, 1970; Düğenci et al., 2015).**After being subjected to the effects of various temperatures, OMC cooled in air has a lower flexural strength than the reference samples: 21% for 200°C, 33% for 400°C, 58% for 600°C, and 63% for 800°C. OMC's flexural strength is also lower than that of reference samples after being subjected to the effects of various temperatures: 22%, 36%, 68% and 84% for 200°C, 400°C ,600°C and 800°C respectively **(Husem, 2006).**

2.7 Chemical Changes in Concrete during Fire Exposure

The apparent degradation at some temperatures is primarily brought on by the dehydration of the C-S-H gel and rising pore water pressure **(Chan et al., 1999).** The chemical make-up and physical structure of concrete are significantly altered by high temperatures. Above a temperature of around 110°C, the dehydration, such as the release of chemically bonded water from the calcium silicate hydrate (C-S-H), becomes considerable **(Khoury et al., 2002).** Internal stresses are increased by the dehydration of the hydrated calcium silicate and the aggregate's thermal expansion, which causes at 300 °C micro cracks to be produced throughout the material **(Hertz, 2005).**

Figure (2-6) shows a summary of **(Khoury, 2000)** results on the behavior of reinforced concrete during the fire and the intensity of the effects. After an hour of exposure, concrete members start to cracking at each degree of heating as the temperature rises. This damage is brought on by a combination of gases released by burning materials, as well as flames and hot air.

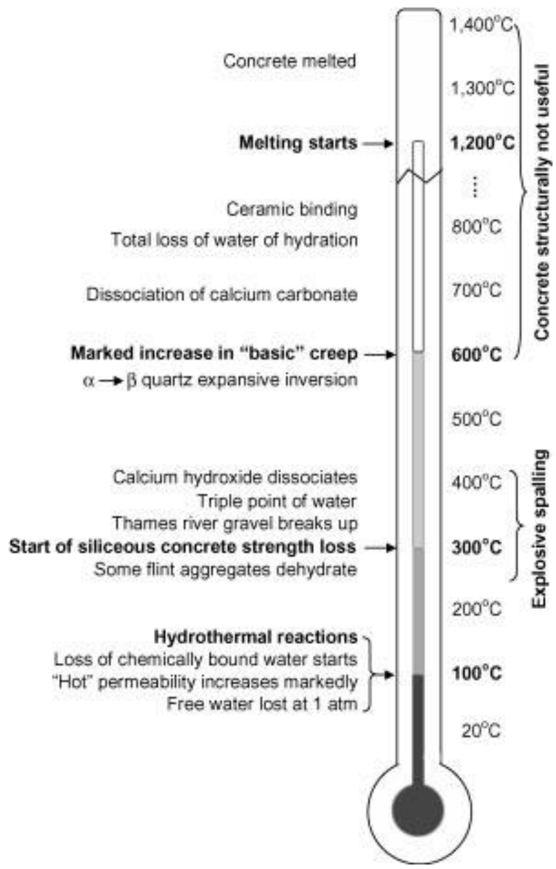

Figure (2-6): *The physiochemical process for an hour was reproduced from concrete in the fire* ***(Khoury, 2000).***

The following physical and chemical changes can be seen when the temperature rises **(Bilow & Kamara, 2008).**

1) The weight loss at about 100°C denotes water evaporation from the micro pores. Ettringite ($3CaOAl_2O_3.3CaSO_4.31H_2O$) maybe dehydrate between (50 and 110°C).
2) The both free and bound water in C-S-H gel can evaporate in the temperature range (100-300°C). A strength loss of between 15 and 40% occurs above 300 °C.
3) When the temperature exceeds 500°C, the effects of high heat become more obvious. At this temperature, most changes that occur to concrete are thought to be permanent. The dihydroxylation of $Ca(OH)_2$ and a loss in strength in the range of 57%–70% both occur at 550°C. Internal strains and microcracks caused by the cementing material are

exacerbated by the dehydration of calcium silicate hydrated and thermal expansion. Concrete cracks and crumbles when fire is extinguished out by water, as CaO transforms into $Ca(OH)_2$.

4) At a temperature of 700 °C, calcium silicate hydrates were observed to dehydrate and de-composite.
5) Concrete typically crumbles at 800 ° C, and this stage of concrete is marked by the collapse of its structural integrity, exposing residual compressive strength **(Bilow & Kamara, 2008)** temperature climbs over 400°C.

2.8 Conclusion Remark

Researchers have studied the behavior of NSC structures with and without fiber under heating and loading exposure at the same time in many studies, but the behavior of NSC concrete with and without fiber under loading effect before heating has rarely been studied, according to a previous review of the literature in the area of the effect of imposed load and elevated temperature on concrete structures. As a result, the following is a summary of the literature review's findings.

- According to research, carbonate aggregates perform better than siliceous aggregates at high temperatures. A number of significant aspects, including the strength of the concrete, the type of cement, and the aggregate, all have an impact on how well concrete performs in extreme temperatures. Siliceous aggregates begin to rapidly develop and disintegrate at 570°C.

- When the temperature does not exceed 300 °C, there is minimal change in the compressive strength of high-temperature concrete.

- Demonstrated cement and mortar samples heated while under load distorted more than samples heated before being loaded.

- The compressive strength and flexural strength of heated concrete drop significantly less as the temperature rises while the concrete is under load.
- Damages in burned constructions are primarily visible on concrete bearings from the exterior to the interior, depending on the temperature and length of the heating process.
- Basalt fibers can be used in soil stabilization, commercial flooring, sound and heat insulation systems, and concrete structure restoration since they are very resistant to high temperatures, impact, and chemicals.
- Concretes reinforced by steel fibers have higher flexural strength than concretes without steel fibers.
- Evaluated the structural soundness and residual mechanical characteristics of concrete that have been exposed to fire can be evaluated nondestructive tests such as ultrasonic pulse. Ultrasonic pulse properties including propagation duration of damage have recently been used to measure concrete degradation.

The reviewed literature shows that there have only been a few investigations into the physical and mechanical properties of regular concrete, both with and without fibers. Further work in this area should concentrate on creating details.

CHAPTER THREE

CHAPTER THREE

EXPERIMENTAL PROGRAMME

3.1 Introduction

In this chapter, the details of the experimental programme are presented. It elaborates the research methodology adopted in achieve the objectives mentioned in chapter one, details of the materials used, cement, sand, coarse aggregate, steel fiber, basalt fibre, mineral and chemical admixtures, mixture proportions, preparation, mixing, casting procedures, curing, and testing programme of specimens. The aim and objective of the experimental investigations are undertaken in order to study the effect of imposed load with elevated temperature on normal concrete specimens with /without fibers. The experimental variables will investigate for the specimens are listed below:

i. Type of concrete normal with and without fiber;

ii. Type of fibers (hooked end steel fiber and basalt fiber);

iii. Imposed load at (20, 40, and 60) % of ultimate load; and

iv. Elevated temperature at (300, and 500) ^{o}C.

Test of fresh concrete (slump flow) that have in this chapter and used destructive and nondestructive tests for hardened concrete (compressive strength, flexural strength, ultrasonic test and rebound hammer test). The necessary tests were conducted at University of Babylon, College of Engineering, Civil Engineering Department laboratories.

3.2 Flow Chart of the Research

The experimental programme is presented in **Figure (3-1).**

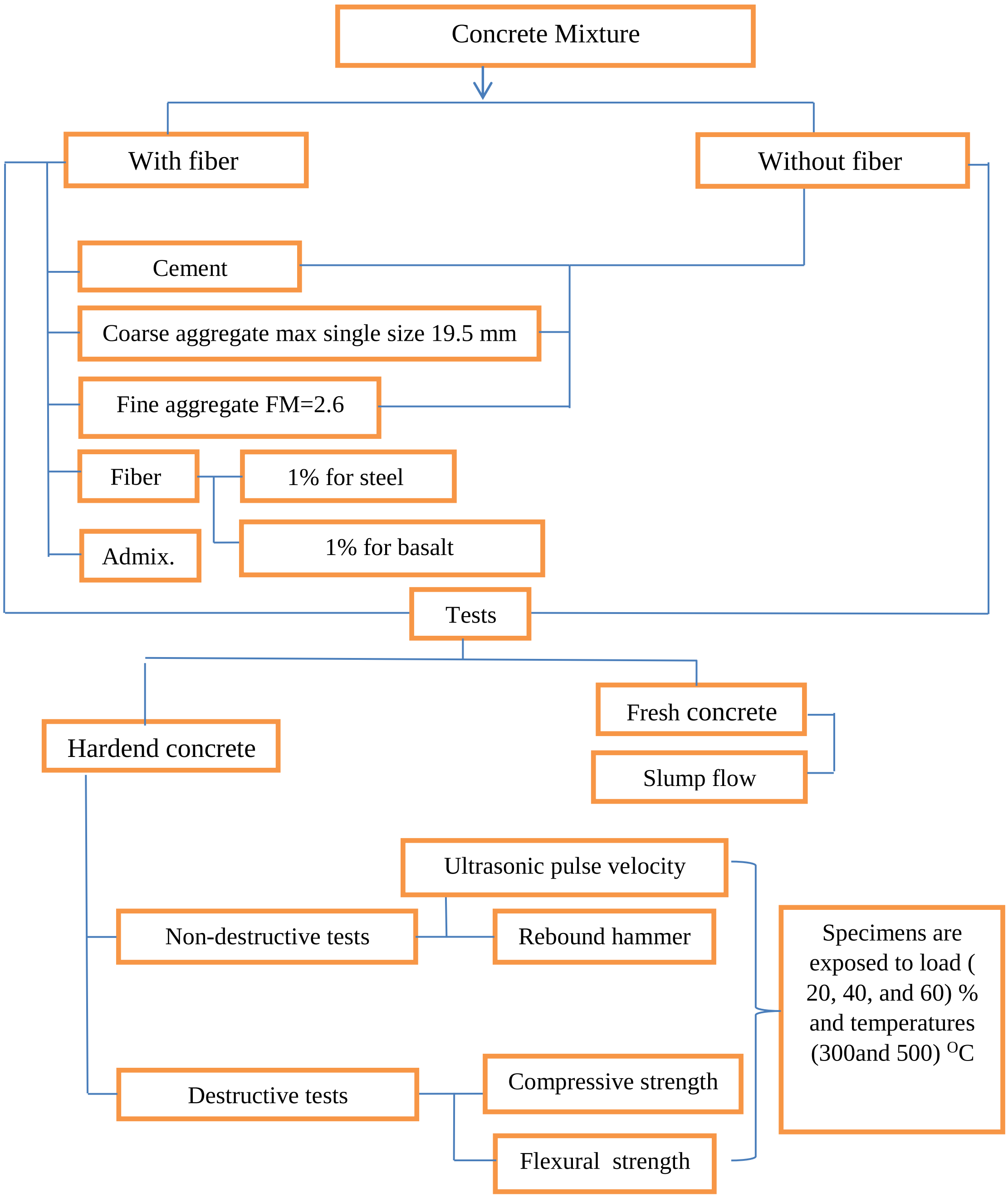

Figure (3-1): *The research plan's flowchart.*

3.3 Materials

3.3.1 Cement

In this study, Ordinary Portland Cement **(CEM I/A-L 42.5 R)** was employed. It was produced in the Bazian and Tasluja plants near Slemani**,** located in the Kurdistan region- Iraq by the Lafarge Company and is marketed as "Karasta". To protect it from exposure to various atmospheric conditions, it was housed in a dry location. The employed cement's chemical analysis and physical tests are shown in **Tables (3-1)** and **(3-2)** respectively. This cement satisfied the requirements of **(I.Q.S.NO.5/2019).**

Table (3-1): *Main components and chemical composition of Karasta cement.*

Compound Composition	**Oxide**	**Test Result**	**Limit according to I.Q.S. 5/2019**	**Conformed to I.Q.S**
Lime Oxide	CaO %	62.43	--------------	
Silica Dioxide	SiO2 %	19.44	--------------	
Alumina Oxide	Al2O3 %	4.98	--------------	
Iron Oxide	Fe2O3 %	3.4	--------------	
Magnesia Oxide Contino	MgO %	2.57	≤ 5%	OK
Sulfate Trioxide	SO3 %	2.41	≤2.5%ifC3A< 5% ≤2.8%ifC3A> 5%	OK
Free Lime	F.L. %	1.18	1% - 2%	
Loss on Ignition	L.O.I. %	4.0	≤4%	OK
Insoluble Resdue	I. R. %	1.25	≤1.5 %	OK
Lime Saturation Factor	L.S.F	0.95	0.66-1.02	OK
	M.S	2.32	---------------------	
	M.A	1.46	---------------------	
	Total	99.22		

Table (3-1): *continue*		
C3S	Tricalcium Silicate	65.8
C2S	Dicalcium Silicate	2.56
C3A	Tricalcium Aluminate	7.45
C4AF	Tetracalcium Alumino ferrite	10.34

Key Compounds Percentage by Weight of Cement (Bogue's Equation)

Table (3-2): *Physical properties of Karasta cement.*

Physical properties	Test result	Limit of IQS 5/2019
Fineness using blains air permeabillity apparatus (cm^2 /gm)	3100	>2500
Soundness using autoclave method	0.19%	<0.8%
Setting time using vicats instrument initial (minite) Final (hours)	198 4.5	> 45 min ≤ 10 hrs
Compressive strength 2 days (MPa) 28 days (MPa)	 18.4 43.75	 ≥10 ≥42.5

*Physical tests are conducted in Construction Materials Laboratory of College of Engineering in Babylon University

3.3.2 Fine Aggregate

The natural washed fine aggregate from the nearby (Al-Ekhaidhir) quarry in Iraq is the fine aggregate utilized in the mixtures. After being speared on the ground for 48 hours even if it is dry, a sample of sand was subjected to a sieve examination in accordance with Iraqi specification. The limitations of grading, physical and chemical properties for the fine aggregate utilized in this investigation are shown in **Table (3-3), Table (3-4) and Figure (3-2)**. These results are in accordance with **(IQSNO.45:1984).**

Table (3-3): *The original fine aggregate (sand) grading compared with the requirements of* ***(IQSNO.45:1984).***

Size of the sieve (mm)	Cumulative passing	Limits of IQS No.45:1984 (Zone 2)
10	100	100
4.75	92	90-100
2.36	81	75-100
1.18	73	55-90
0.60	55	35-59
0.30	24	8-30
0.15	7	0-10

Table (3-4): *The physical and chemical properties of fine aggregate.*

Physical Properties		
Properties	Test results	Iraqi specification No. 45:1984
Specific gravity	2.65	---
Absorption	0.94%	---
Fine material passing from sieve (75 μm)	3%	Max ≤ 5.0%
Fineness modulus	2.6	---
Chemical properties		
Sulfate content	0.344%	Max ≤ 0.5%

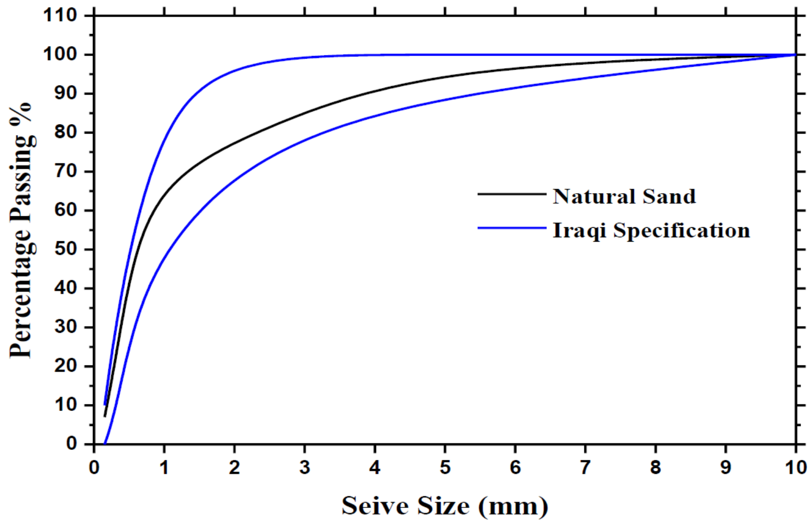

Figure (3-2): *Grading curves for fine aggregate compared with requirements of **(IQSNO.45:1984).***

3.3.3 Coarse Aggregate (Gravel)

Rounded gravel from the (AL-Nibaey) region, with a maximum size of 19mm, was utilized for this investigation. This rounded gravel was cleaned, placed in the air to dry on the surface, and then placed in containers to dry completely before use. The grading, physical and chemical properties of this aggregate and the acceptance limit of Iraqi standard **IQS NO.45:1984** are shown in **Table (3-5)** and **(3-6)**.

Table (3-5): *Grading of natural coarse aggregate.*

Sieve Size (mm)	Percentage Passing %	Limits of IQS No.45:1984
37.5	100	100
25	100	90-100
19	82	40-85
12.5	13	10-40
9.5	10	0-15
4.75	0	0-5

Table (3-6): *Physical and chemical properties of coarse aggregate*

Properties	Test result	Limits of (IQS No.45/1984)
Specific gravity	2.66	-
Sulfate content SO_3	0.03 %	≤ 0.1%
Absorption	0.05 %	-
Clay content	0.30 %	≤ 2%

* This test was conducted in the laboratories of Al-musaib technical institute.

3.3.4 High Range Water Reducing Admixture (HRWRA)

A high performance concrete super-plasticizer based on polycarboxylic technology, also known as High Range Water Reduction Agent HRWRA and marketed as Hyperplast PC200, was utilized. According to **(ASTMC494TypeF, 2017)** it is made by BASF Company. **Table (3-7)** lists its characteristics.

Table (3-7): *Technical description of Hyperplast PC200**

Chemical basis	Aqueous Solution of Modified Polycarboxylate
Freezing point	≈ -3 °C
Color	Light yellow liquid
Specific gravity	1.05 ± 0.02
Air entrainment	Typically less than 2% additional air is entrained above control mix at regular dosages.
Chloride content	None
Toxicity	Not classified as hazardous material.
Storage	Stored at temperatures between 2 °C and 50 °C.
Fire	Nonflammable

*Manufacturer Properties.

3.3.5 Water

Water used in mixtures for casting and curing was potable water from water-supply network system; so, it was free from suspended solids and organic materials, which might have affected the properties of fresh and hardened concrete.

3.3.6 Steel Fibers

In this study, a hooked end steel fibres were used. The hooked fiber was supplied by the Chinese company called HEBEL YUSEN METAL WIRE MESH followed the standard **(ASTMA820-05, 1996).** The hooked fibers used in the current experiment are depicted in **Figure (3-3)**. The technical characteristics of the steel fibers employed, as disclosed by the producer company, are shown in **Tables (3–8)**.

Table (3-8): *Properties of hooked end steel fiber.*

Property	Results of hooked end steel fiber
Description	Deformed shape hooked end
Appearance	Bright and clean wire
Length (l), mm	35
Diameter (d), mm	0.55
Aspect ratio(l/d)	63.6
Density (kg/m^3)	7800
Tensile strength (MPa)	1100

*Manufacturer Properties.

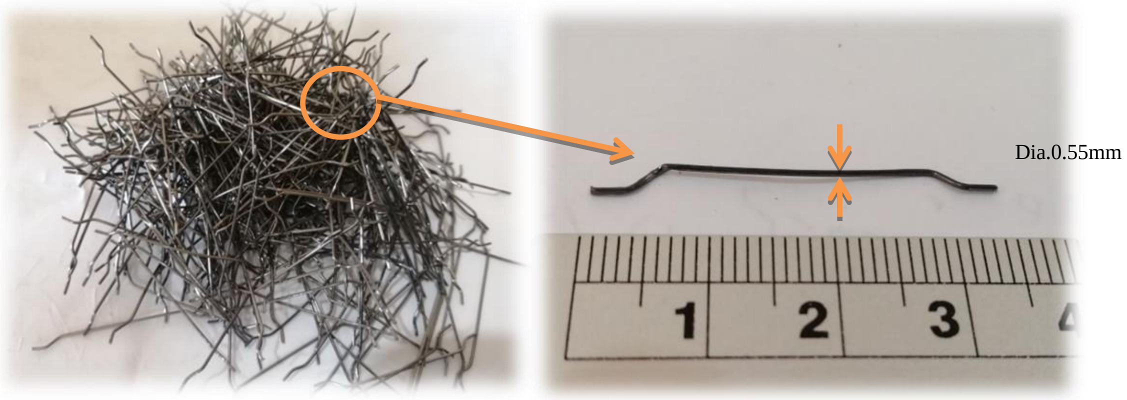

Figure (3-3): *steel fiber's geometrical configuration.*

3.3.7 Basalt Fibers

By pultruding volcanic rocks that have been melted in blast furnaces, basalt fiber is created which followed the standard **(ASTMD8448/D8448M-22).** This fiber is depicted in **Figure (3-4)**. A continuous fiber may be produced using this method, and basalt fiber has superior physical and mechanical properties are shown in **Table (3-9)**.

Table (3-9): *Properties of basalt fiber.*

Property	Value
Tensile strength	2.8–3.1 GPa
Elastic modulus	85–87 GPa
Elongation at break	3.15%
Density	2.67 g/cm^3
Max Operating Temp.	600
Max Peak Temperature	700 – 1,095*
Diameter (μm)	17
Length (mm)	19

*Most product made of basalt fibers can withstand up to 700 °C; however, basalt tapes can withstand up to 1,095 °C due to their fabrication.

Figure (3-4): *Basalt fibers used.*

3.4 Preparation of Concrete Mixes.

Due to the significance of the necessity to overfill gaps between aggregate particles, mix designers frequently consider volumes as a significant parameter in their work **(ACI211.1, 1991). Table (3-10)** provides information on the mixtures that were used (Normal strength concrete (**NSC**), Normal concrete with steel fibers (**SF1**) and Normal concrete with basalt fibers (**BF1**).

Table (3-10): *Mix Proportions.*

Mix symbol	Cement (kg/m^3)	Sand (kg/m^3)	Gravil (kg/m^3)	w/c	S.P (kg/m^3)	V_f (%)
NSC	400	675	1100	0.5	-------	---
SF1	400	675	1100	0.5	1.2	1
BF1	400	675	1100	0.5	4	1

3.5 Mixing procedure

A laboratory drum mixer with capacity of 0.09 m^3 was used for the mixing operation to blend the materials for the concrete; it was clean and moist. The steps used in blend the mixtures were as follows:

- To achieve a uniform mix, the dry aggregates (sand and gravel) were thoroughly mixed for two minutes.
- Sand and gravel were added to the dry cement, and the mixture was mixed for about one minute.
- Add half of the water to the mixture, then add the remaining liquid (water plus HRWR) after mixing for about a minute.
- Add half of the steel fiber content to the mixer gradually after about two minutes of mixing.
- Add all of the steel fibers slowly to the mixer after a minute of blending.
- Immediately after the addition of all the fibers, mix for an additional three minutes. Subsequently, the mixture is prepared for pouring.

For basalt fiber, the same procedures are used, but with longer times for mixing, briefly as follows:

- Sand and gravel are mixed for two minutes.
- Add dry cement to aggregates and blend them in a rotary mixer for one minute.
- Pour half of the water content into the mixture and then the remaining water and HRWR.
- Add half of the basalt fiber content to the mixer after approximately two minutes of mixing.
- Add all of the basalt fibers gradually to the mixer after about three minutes of mixing.
- After all the fibers have been added, keep mixing for about five minutes.

To prevent adhesion with concrete once it hardened, oil was applied to the interior surfaces of all steel molds before they were ready for mixing. When the steel molds are full, the mixtures are poured into them and compacted using vibration table. After 24 hours, all specimens were demolded and put in water tank for curing at various curing ages (28, 56, and 90) days.

3.6 Heating Procedure

Specimens are exposed to different temperatures in an electrical furnace after loading of specimens as shown in **Figure (3-5)**.

The dimensions of inside furnace are (50×50×50) cm, heating and cooling programme are shown in **Figure (3-6)**, the specimens were exposed to elevated temperature at the ages of (28, 56 and 90 days). Three temperature levels of (300 and 500) ºC were exposed duration of (2) hours. After heating, the concrete specimens were allowed to cool inside the electrical furnace for 2 hours after end of the heating see **Figure (3-5)** and stored in a laboratory environment about 24 hours.

***Figure (3-5)**: Electrical furnace*

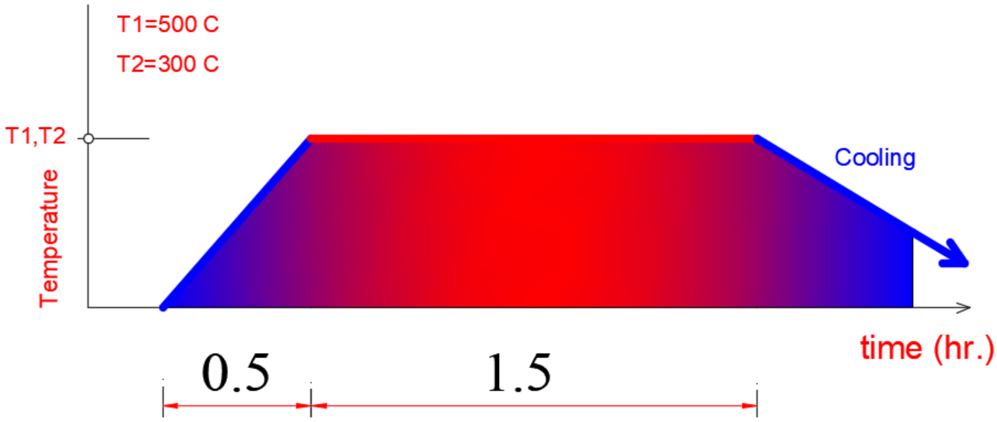

Figure (3-6): *Heating and cooling program for electrical furnace*

3.7 Fresh test

3.7.1 Slump Test for Fresh Concrete

A truncated cone and a tamping rod used as the testing instruments for the slump test. The truncated cone is 30 cm tall and 10 cm diameter at the top and 20 cm at the bottom. It is filled with concrete in three equal layers, each of which is slowly lifted after being uniformly stroked 25 times by a steel rod. The slump is the height difference between the top of the mold and the average level of the concrete after it has slumped down under its own weight. The slump values on **Figure (3–7)** ranged from (110–130) mm, as intended.

Figure (3–7)*: Fresh concrete slump test.*

3.8 Hardened Testing

After 24 hours, all specimens were demolded, marked, and cured in water at roughly 20 ±5 °C before being tested for age. NSC, SF1 and BF1 are tested using destructive and non-destructive testing after being hardened.

3.8.1 Destructive Tests

3.8.1.1 Compressive Strength Test

The results of the compression test were calculated using **(Referenceguide, No.348/1992).** The samples were demolded one day after being cast in (100x100x100mm) cubes in the lab. A hydraulic compression machine with a 1900 kN load capacity is used to test the specimens at a loading rate of 3 kN/sec. There were 324 cubes tested in all. At each test, an average of three cubes were adopted. The tests were done at (28, 56, and 90) days age. **Figure (3-8)** shows the testing machine for compressive strength.

Figure (3-8): *Compressive strength testing machine.*

3.8.1.2 Flexural Strength Test

The findings of a basic beam with two-point loading test performed in accordance with **(ASTMC78-02, 2002).** Were used to compute the flexural strength, represented as modulus of rupture, as illustrated in **Figure (3- 9)** and **Figure (3-10)**. Prisms mold dimension (100×100×400) mm. There were 216 prisms tested in total. Each test is consisted of the average of three prisms. The test was conducted using loading rate of 0.5 kN/sec. The following equation was used to determine the flexural strength:

$$\boldsymbol{fr} = \frac{\boldsymbol{PL}}{\boldsymbol{bd^2}} \qquad ------(\mathbf{3-2})$$

<u>Where:</u>

$\boldsymbol{fr}$: modulus of rupture (MPa).

P: maximum applied load indicated by the testing machine (N).

L: span length = 300 mm.

b*:* average width of specimen =100 mm.

d*:* average depth of specimen =100 mm.

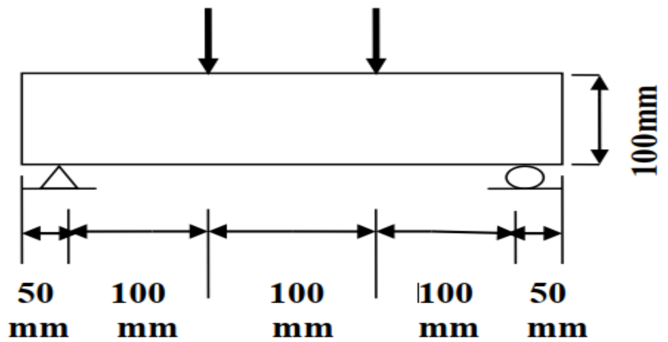

Figure (3-9): *Two-point load flexural strength test.*

Figure (3-10): *flexural machine.*

3.8.2 Non-destructive Tests

3.8.2.1 Ultrasonic Pulse Velocity Test Procedure

This test has been done according to **(ASTMC597, 2009),** on cubic specimens and prisms as shown in **Figure (3-11)**. Ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse, passing through concrete to be tested. The pulse generator circuit consists of an electronic circuit for generating pulses and transducer for transforming these electronic pulses into mechanical energy having vibration frequency. The time of travel between initial onset and the reception of pulse was measured electronically. A path length between transducers, divided by a time of travel, gives the average velocity of wave propagation at accuracy 0.1s and 50 kHz:

V =L / T ---------- (3-1)

where: -

V = Ultrasonic pulse velocity (km/sec).

L = Path length (km).

T = transit time (sec).

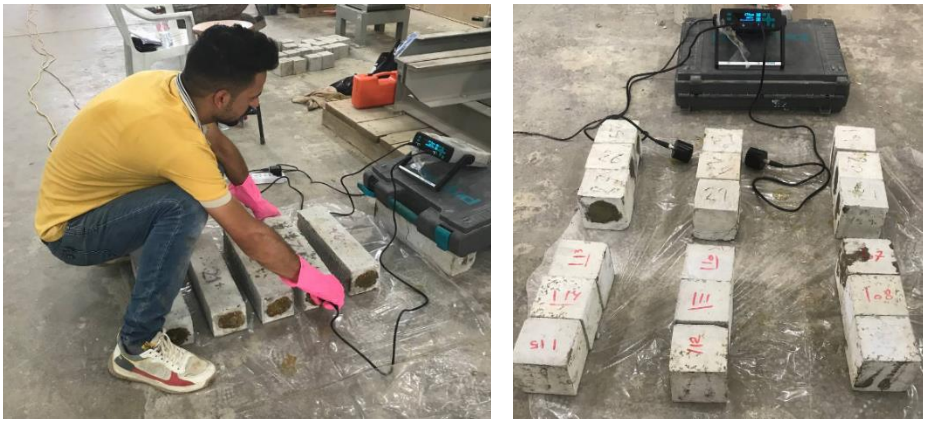

Figure (3-11): *Ultrasonic Pulse Velocity Test for cubes and prisms.*

3.8.2.2 Schmidt Rebound Hammer Test Procedure.

This test had been done according to **(Referenceguide, No.325/1993).** On cubic specimens of (100) mm which have been fixed by applying 20kN, in a compression machine to avoid any movement during this test, is shown in **Figure (3-12)**.

Figure (3-12): *Schmidt rebound hammer test.*

CHAPTER FOUR

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The major goal of study is to conduct an experimental investigation of the impact of imposed load and elevated temperature on concrete with and without fibers. The specimens included prisms and cubes of the same mixture with steel fibers, basalt fibers as well as reference concrete mixture exposed to various load scenarios and temperatures. Comparing the results to assess the significance of the experimental variables. The load rates were (20, 40, and 60 %) of total load and exposed temperature degrees to samples were (300, and 500) °C. The used fibers were hooked end steel fiber and basalt and assessed experimental factors outcomes. The effect of elevated temperature on the mechanical characteristics of concrete samples, compressive strength and flexural strength is also covered in this chapter. Moreover, the non-destructive tests, such as the ultrasound pulse velocity test and rebound number were employed to evaluate the exposure effects on properties of concrete. Finally, the results of tested cube and prism specimens will be presented and discussed in this chapter.

4.2 The Results of Tested Concrete of Mixture and Specimen

4.2.1 Slump Test for Fresh Concrete

A concrete slump test evaluates mixture of concrete's consistency to determine how will easily it flow. The test does not only check the uniformity between mixtures but also detect flaws in a mixture, allowing the operator to fix the mixture before it is poured samples. The slump for each mixture was the same and varied between (110-130 mm). With the addition of fibers to mixtures, a significant reduction in slump flow has been observed. Due to increase of the interlock and friction between the fibers and aggregate, added fibers increased flow resistance and decreased flowability **(Almusawee, 2012).** To achieve equal workability for all mixtures, plasticizers were added to the mixtures containing fiber.

4.2.2 Hardened Concrete Tests

After being hardened concrete, NSC, SF1, and BF1 were subjected to destructive and non-destructive testing. After 24 hours, all specimens were demolded, marked, and cured in water at 25°C for period of testing (28, 56 and 90) days.

4.2.2.1 Destructive Tests

This section shows the results of compressive strength and flexural strength under the effects of load and elevated temperature at (28, 56, and 90) days curing ages.

4.2.2.1.1 Results of Compressive Strength

The one of the most crucial characteristics of concrete that has been hardened is compressive strength. The purpose of this study is to determine how high temperatures and loads affect compressive strength of NSC with and without fibers, the results are reported in Table (4-1). The results indicate that all specimens' compressive strength of every specimen increased continuously with progress in age. because the hydration process continues and creates a fresh hydration product within the mass of concrete, the compressive strength of concrete increases with age **(Neville, 2010).** Compressive strength of concrete samples decreased with increasing exposure temperature, which was attributed to the breakdown of the interfacial bond caused by an incompatible volume change between the cement paste and the aggregate during heating and cooling **(Xu et al., 2003).**

Table (4-1): *Test results of compressive strength (f_{cu}) of NSC, SF1 and BF1*

Type	Temperature °C	Compressive Strength (MPa) at											
		28 days				56 days				90 days			
		Load (%)				Load (%)				Load (%)			
		0	20	40	60	0	20	40	60	0	20	40	60
NSC	25 (R)	30.3	30.3	30.0	27.0	31.5	31.4	31.2	28.8	33.0	32.9	32.1	28.9
	300 (a)	28.6	28.1	27.2	24.0	28.9	28.4	27.5	24.2	30.2	29.8	28.7	24.7
	500 (b)	26.1	25.8	23.8	18.0	26.6	26.3	24.3	18.4	27.0	26.7	24.6	18.6
SF1	25 (R)	28.6	28.0	26.8	26.2	31.5	30.6	29.3	28.0	31.8	31.1	29.8	28.5
	300 (a)	26.9	26.1	24.7	24.3	28.9	28.1	26.8	25.5	29.2	28.4	27.1	25.8
	500 (b)	22.0	21.8	20.6	20.0	24.2	23.4	22.3	21.1	24.5	24.2	22.9	21.4
BF1	25 (R)	23	21	19	17.7	23.9	21	20	18	24.3	21.82	19.75	18.1
	300 (a)	19	17.4	15.6	14.3	20	17.7	16.7	14.5	20.7	18.8	16.4	14.6
	500 (b)	18.8	17	15.4	14.1	19.9	17.2	16	14.3	20.3	18.4	16	14.1

Figures (4-1) through (4-3) show the relation between compressive strengths and elevated temperature for all load cases of specimens. While Table (4-2) and Figures (4-4) through (4-6), show the reduction in compressive strength values for all mixes (NSC, SF1 and BF1), exposed to elevated temperature (300 and 500° C) at ages (28, 56 and 90 days). It was found that the NSC has a higher compressive strength than SF1and BF1 since the fiber addition increased the amount of trapped air, which decreased the compressive strength at 25 ºC and without pre-loading **(Almusawee, 2012).** For period of exposure (2 hours) and at 300° C temperature, the loss in compressive strength is little where the percentage of reduction of compressive strength was observed between (6-16%), (6-10%) and (16-19%) for concrete mixes.

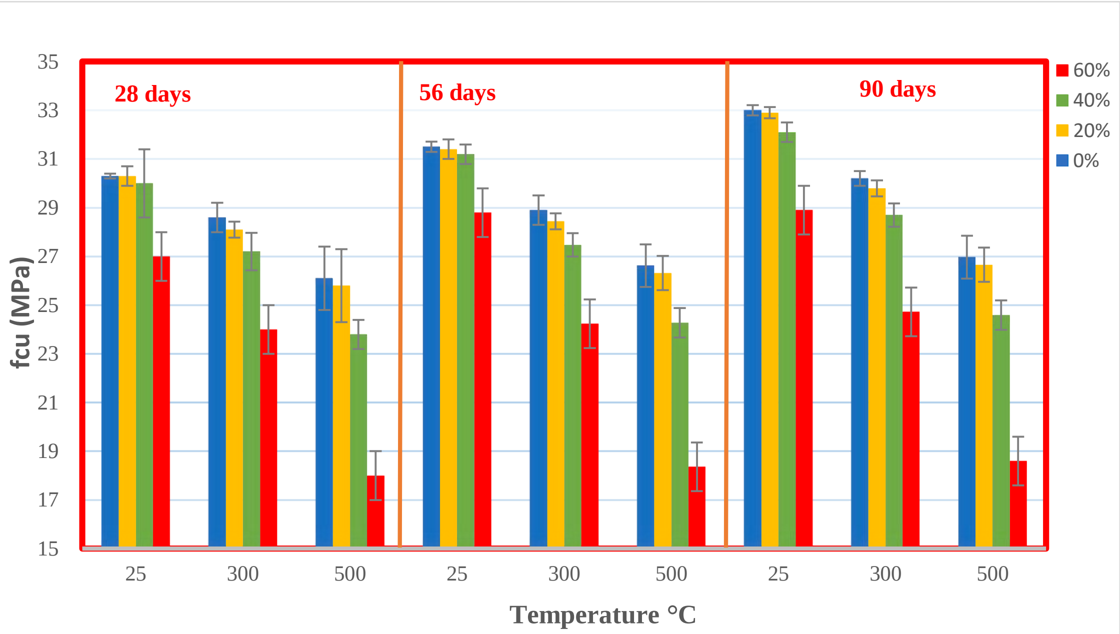

Fig.(4-1): *Compressive strength of NSC under the effect of imposed load and elevated temperature.*

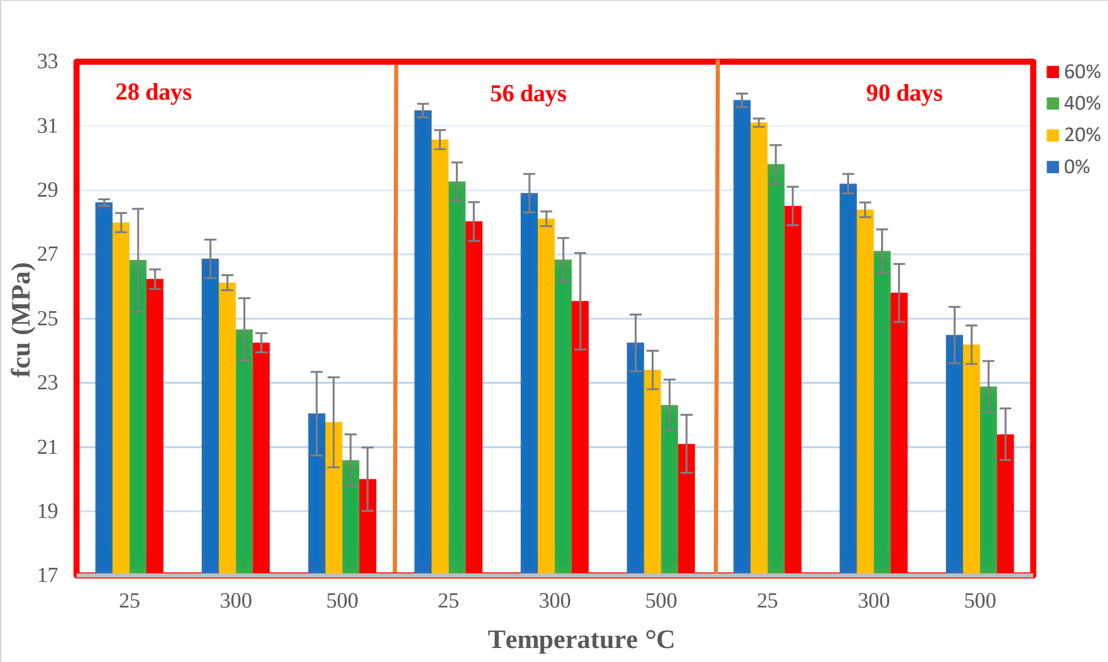

Fig.(4-2): *Compressive strength of SF1 under the effect of imposed load and elevated temperature.*

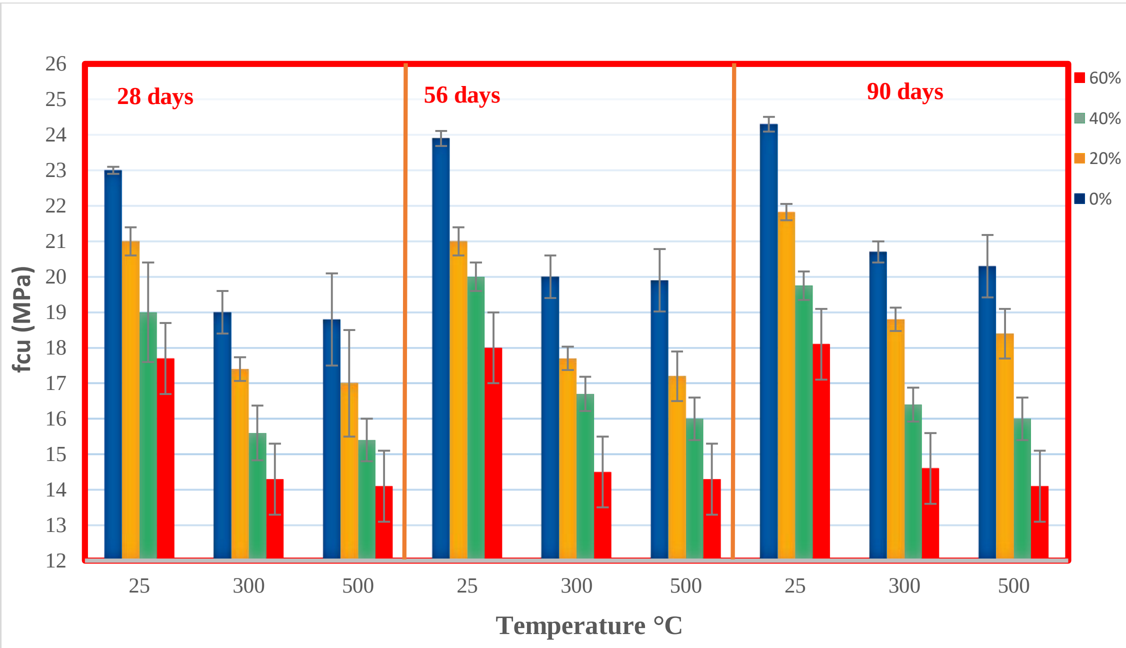

Fig. (4-3): *Compressive strength of BF1 under the effect of imposed load and elevated temperature.*

While, at 500°C temperature, the percentage of deterioration in compressive strength ranged (14-36%), (22-23%) and (17-22%) for mixes (NSC, SF1 and BF1) respectively for all load cases because the cement's calcium hydroxide could start to dehydrate, producing more water vapor while also significantly reducing the compressive strength **(Kulkarni & Patil, 2011).**

In addition, all specimens at ages (28, 56 and 90 days), the reduction of compressive strength of NSC at 500° C is clear at 60% of ultimate load as shown in Figure (4-4), that's due to a high ratio of load, physical and chemical changes in concrete. The results also indicate that for all load and temperature cases at ages (28, 56 and 90 days) the compressive strength of SF1 is slightly decline as shown in Figure (4-5). It is important to take into consideration how steel fibers affect compressive strength. Because it is thought that preventing cracks would significantly contribute to the situation **(Al-Ameeri, 2013).** The compressive strength of BF1 decreased as the volume fraction of fiber increased, and this decrease was noticeably less than control mix samples (which had no fiber) **(Ayub et al., 2014).**

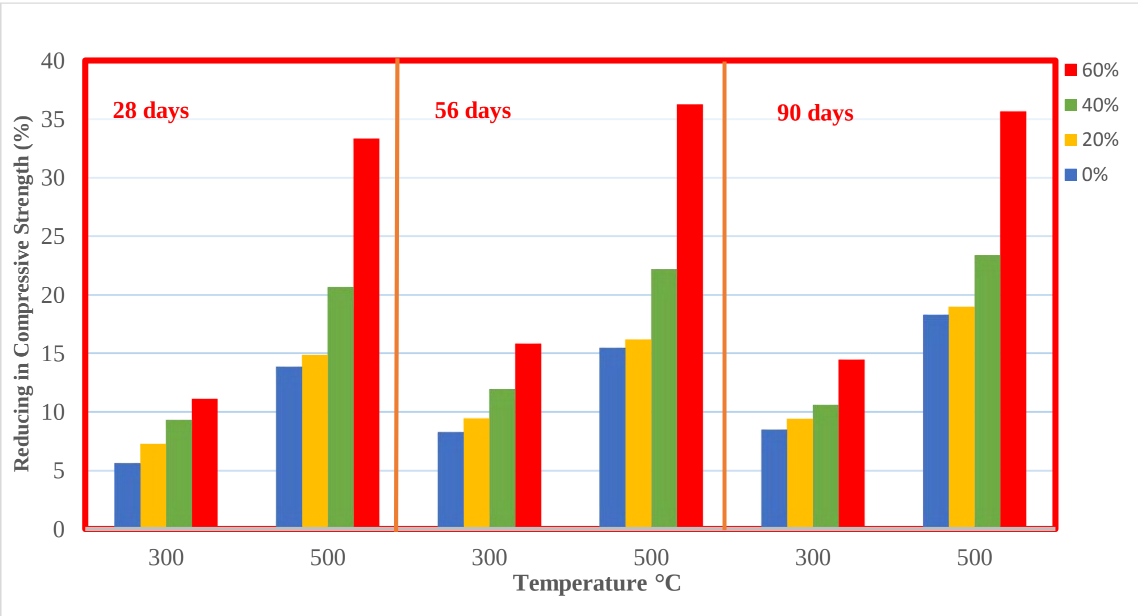

Fig. (4-4): *Reduction in Compressive Strength of NSC.*

The compressive strength decrease of BF1 mixture is less than NSC and SF1 mixtures at 500° C as shown in Figure (4-6). The addition of basalt fibers inhibits heat transfer and preserves the concrete's structure, preventing spalling and degradation **(Hu & Shen, 2005; Serbescu et al., 2015; Yildizel et al., 2020).**

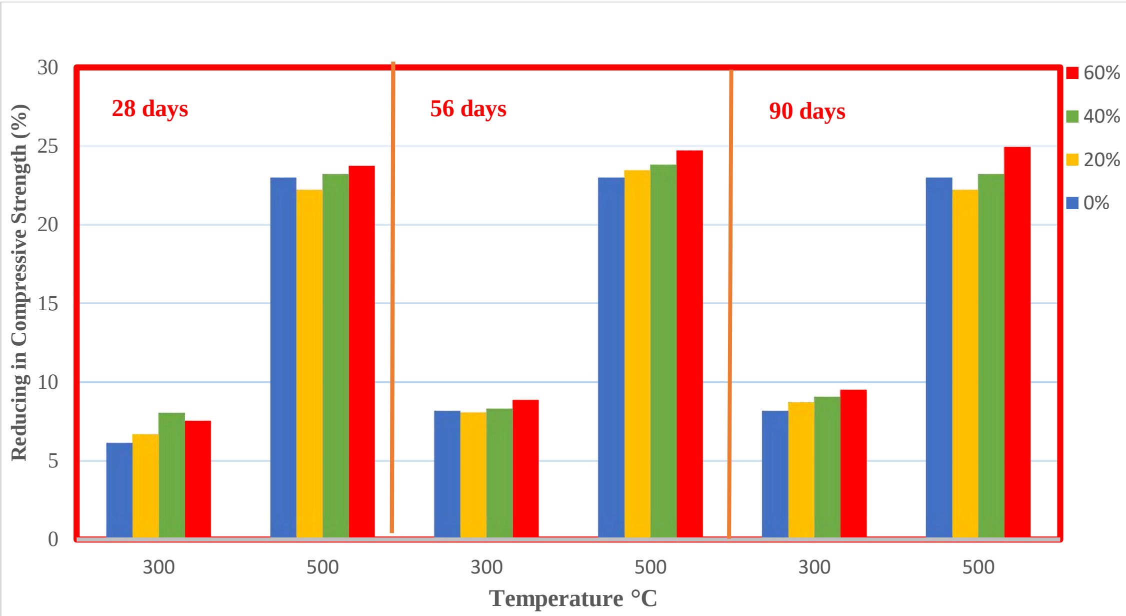

Fig. (4-5): *Reduction in Compressive Strength of SF1.*

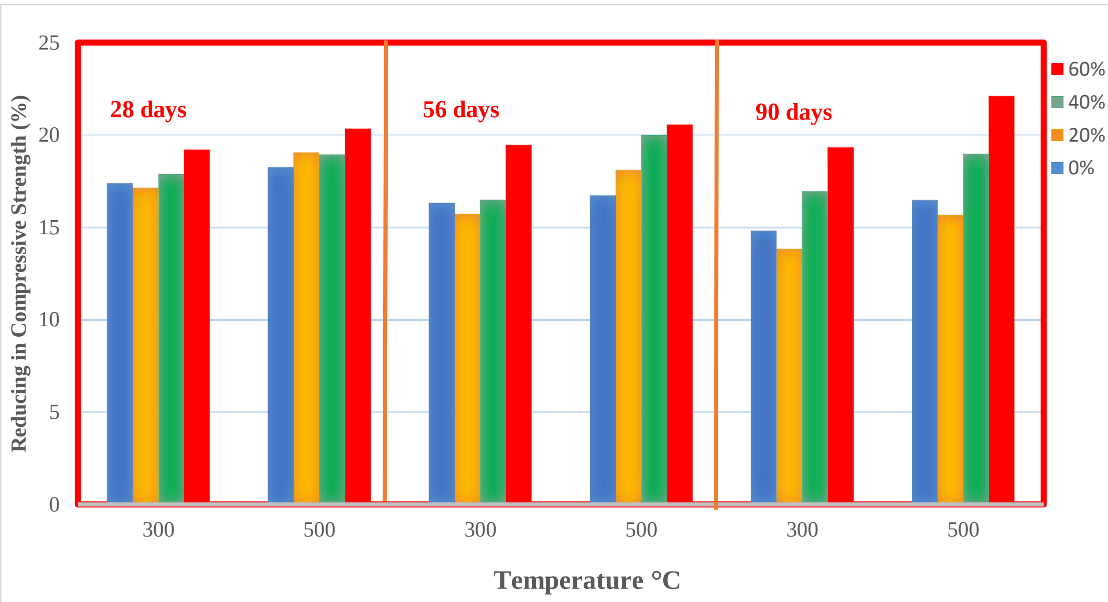

Fig. (4-6): *Reduction in Compressive Strength of BF.*

Table (4-2): *Percentage reduction of compressive strength for NSC, SF1 and BF1*

Type	**Change in (fcu) %**	**Temperature °C**	**The percentage of change in compressive strength (fcu) % (Reduction)**											
			28 days				**56 days**				**90 days**			
			Load (%)				**Load (%)**				**Load (%)**			
			0	**20**	**40**	**60**	**0**	**20**	**40**	**60**	**0**	**20**	**40**	**60**
NSC	(a-R)/(R)%	300	6	7	9	11	8	9	12	16	8	9	11	14
	(b-R)/(R)%	500	14	15	21	33	15	16	22	36	18	19	23	36
SF1	(a-R)/(R)%	300	6	7	8	8	8	8	8	9	8	9	9	10
	(b-R)/(R)%	500	23	22	23	24	23	23	24	25	23	22	23	25
BF1	(a-R)/(R)%	300	17	17	18	19	16	16	17	19	15	14	17	19
	(b-R)/(R)%	500	18	19	19	20	17	18	20	21	16	16	19	22

4.2.2.1.2 Flexural Strength

The findings show that, like concrete's compressive strengths, flexural strengths increased steadily with age in all specimens. Flexural strength reduced for all specimens with rising temperatures and loads, as can be shown in Table (4-3) and Figures (4-7) through (4-9). this can be attributed to the dry shrinkage of concrete, which results in the breakdown of cement compounds and the development of cracks inside specimens, the flexural strengths are decreased When the load is increased, the flexural strength decreases because the crack width widens, allowing heat to quickly enter the sample and exposing the interior skeleton of the specimen **(Neville, 2010).** The reduction in flexural strength is summarized in Table (4-4) and Figures (4-10) through (4-12), for mixes (NSC, SF1 and BF1), exposed to high elevated temperature (300 and 500° C) at ages (28, 56 and 90 days). It was found that for period of exposure (2 hours) and at 300° C temperature, the percentage of reduction of flexural strength between (14-18%), (6-9%) and (20-46%), while at 500 °C temperature, the percentage of reduction of flexural strength between (30-36%), (23-27%) and (35-76%) for mixes (NSC, SF1 and BF1) respectively for all load cases. Normal concrete mixture at all ages has clear effects of load and high temperature, but symbols that contain steel fibers exhibit only a little influence of load at the same temperature as shown in Figures (4-10) and (4-11) because compared to unreinforced concrete, concrete with steel fibers has greater flexural strength. The ability of fibers to resist cracking and the composite's increased fracture resistance are the key causes of this. Once the concrete matrix has crumbled. This tendency is mostly related to steel fibers' function in releasing fracture energy at crack tips, which is necessary to extend crack growth by moving it from one side to another **(Alubaidi, Banthia; 2011).**

Table (4-3): *Test results of Flexural strength (fr) for NSC, SF1 and BF1.*

Flexural Strength (MPa)													
Type	**Temperature °C**	**28 days**				**56 days**				**90 days**			
		Load (%)				**Load (%)**				**Load (%)**			
		0	**20**	**40**	**60**	**0**	**20**	**40**	**60**	**0**	**20**	**40**	**60**
NSC	25 (R)	3.63	3.60	3.20	2.97	3.72	3.69	3.27	3.03	3.94	3.80	3.30	3.00
	300 (a)	2.96	2.93	2.55	2.10	3.10	3.00	2.61	2.14	3.30	3.20	2.68	2.20
	500 (b)	2.46	2.41	2.05	1.82	2.55	2.47	2.10	1.86	2.75	2.65	2.16	1.90
SF1	25 (R)	5.63	5.50	5.35	5.20	5.77	5.60	5.45	5.31	5.92	5.74	5.61	5.44
	300 (a)	5.10	4.83	4.65	4.50	5.25	4.95	4.75	4.59	5.41	5.09	4.89	4.70
	500 (b)	4.50	4.40	4.10	3.78	4.60	4.55	4.30	3.91	4.91	4.82	4.50	4.10
BF1	25 (R)	2.35	2.24	2.1	1.9	2.4	2.31	2.1	2.12	2.55	2.41	2.33	2.22
	300 (a)	1.83	1.67	1.57	1.13	1.92	1.77	1.59	1.15	1.98	1.8	1.65	1.2
	500 (b)	1.42	0.86	0.78	0.5	1.47	0.9	0.83	0.51	1.67	0.92	0.85	0.54

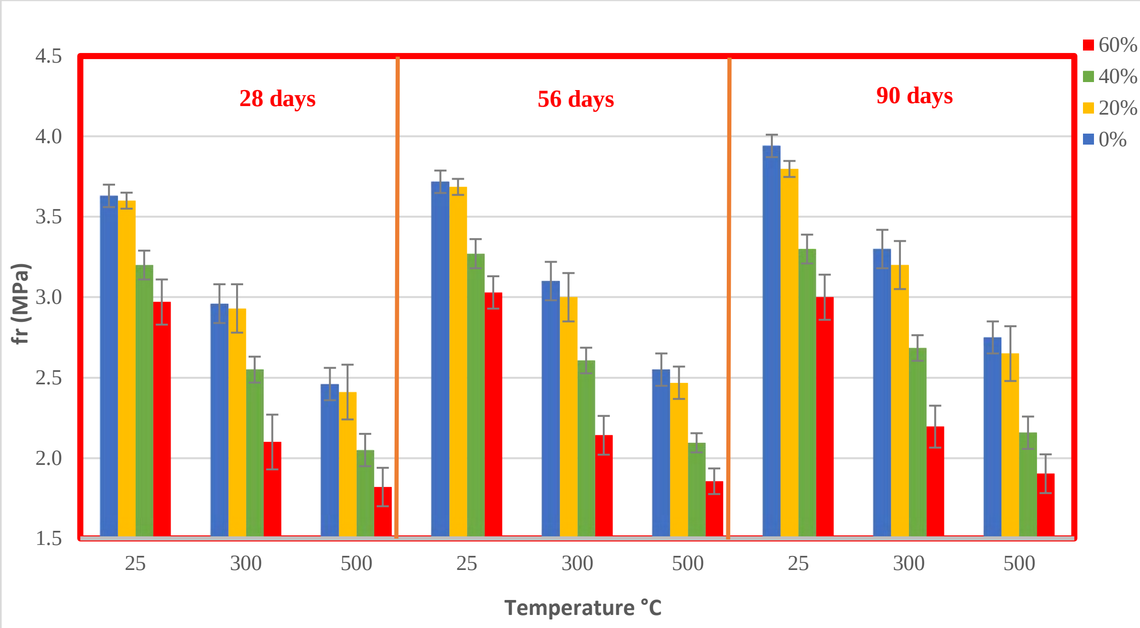

Fig. (4-7): *Flexural strength of NSC under the effect of imposed load and elevated temperature.*

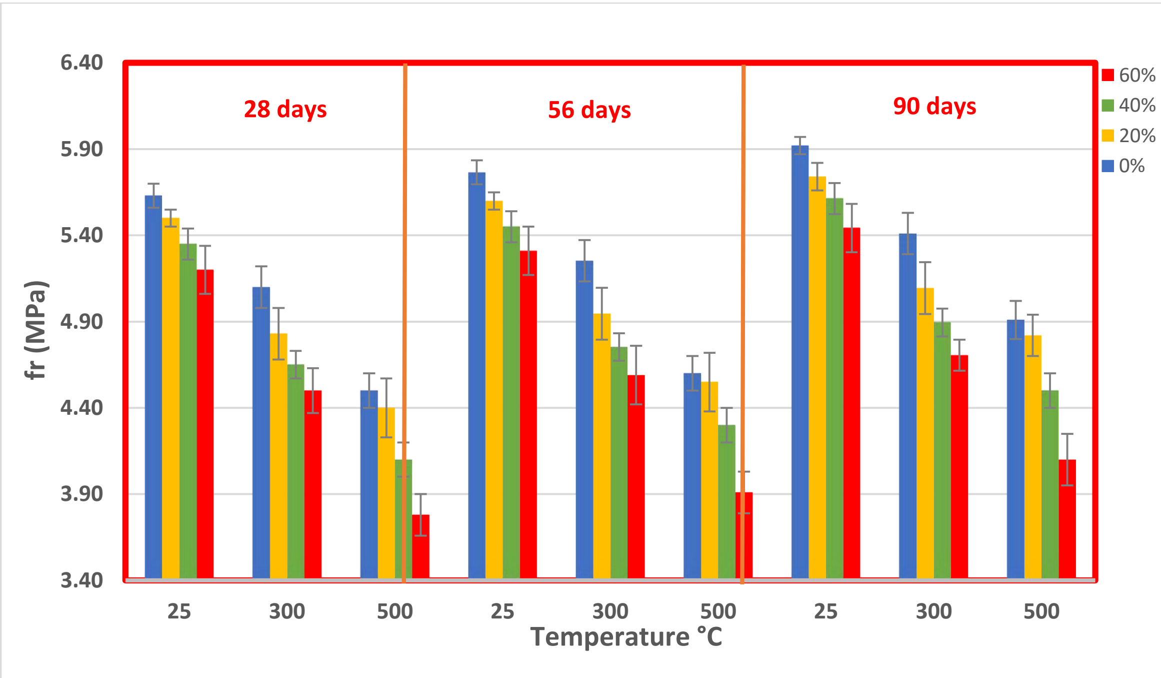

Fig. (4-8): *Flexural strength of SF1 under the effect of imposed load and elevated temperature*

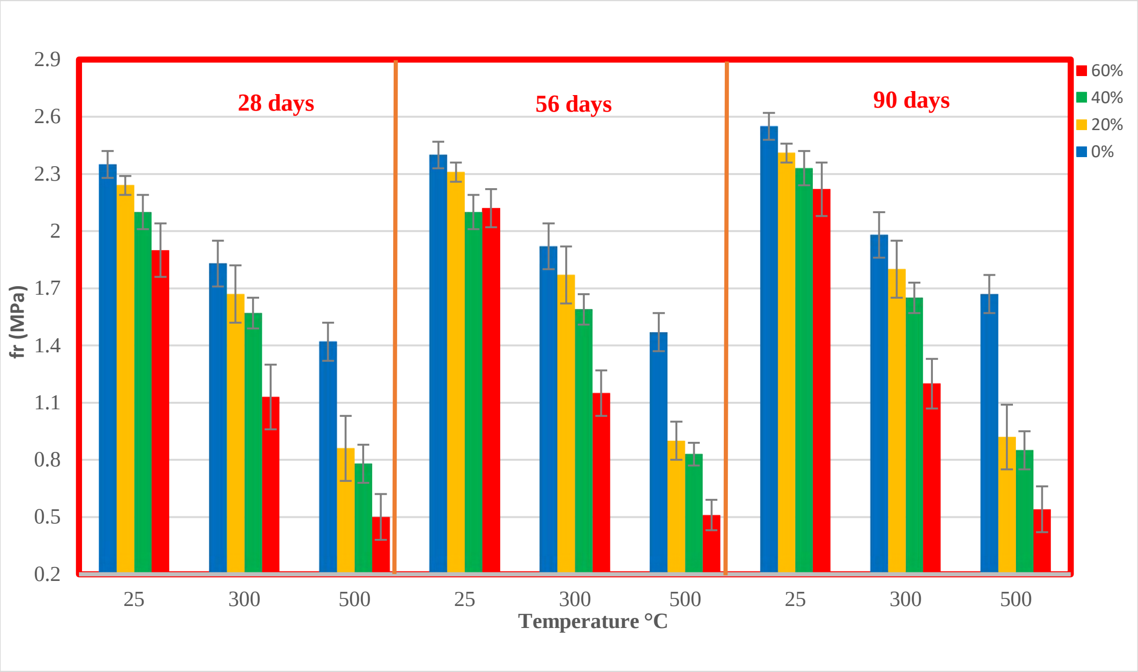

Fig. (4-9): *Flexural strength of BF1 under the effect of imposed load and elevated temperature*

The minimum reduction in the flexural strength is (6-9) % and (23-27) % at 300°C and 500° C respectively for SF1 mixture as compared with other mixes. Steel fibers are thought to be more effective than compressive strength mixture that have fibers in reduce the damaging impacts of high temperature for (SF1) mixture.

The flexural strength of BF1 mixture is less than other mixes (SF1 and NSC) for all temperature and load cases. The results of earlier literature don't match up with the concrete's measured flexural strength in this study. **(Alaskar et al., 2021)** found that specimens containing 0.3% chopped basalt fibers had the highest strength, and that strength decreased somewhat above this level. This might be explained by the fiber agglomeration and reduced number of accessible bonds in cement paste. Beyond this point, adding more fiber has negative consequences that are attributable to the fibers' tendency to aggregate and the development of internal spaces between the cement paste and aggregates. Because of this, fractures in the concrete begin to appear. Prior research has shown that as the number of fibers is raised, especially above the optimum level, there is an increase trend of the air that is trapped **(Pickel et al., 2018).** Moreover, the weak interface of the connection between the fibers and cement paste may also reduce the strength **(Mohammadhosseini et al., 2020).**

Additional stress was observed to be released by the weakening of basalt fibers as the surface-bound water evaporated. Furthermore, as the hydration products of concrete started to disintegrate at such high temperatures, basalt fibers held the aggregates and cement paste in place by grabbing the macro-cracks. However, when fiber addition was beyond the recommended level, agglomeration and irregular fiber dispersion were seen, which reduced the performance of the concrete **(Alaskar et al., 2021).**

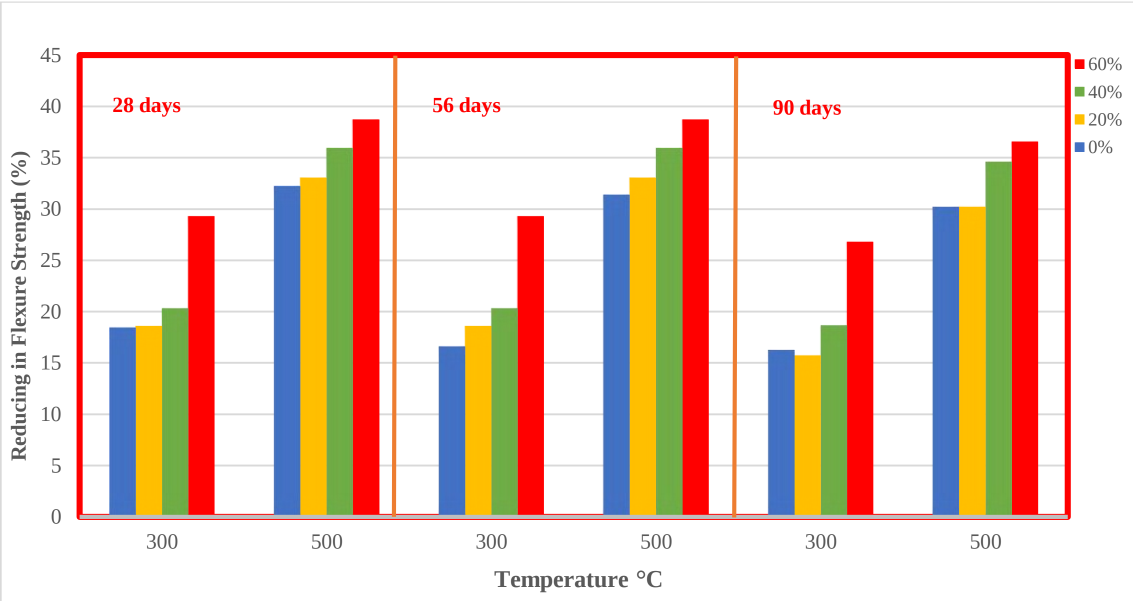

Fig. (4-10): *Reducing in Flexural Strength of NSC.*

Table (4-4): *Percentage reduction of Flexural strength for NSC, SF1 and BF1.*

The percentage of change in Flexural Strength % (REDUCING)														
Type	**change in (fcu) %**	**Temperature °C**	**28 days**				**56 days**				**90 days**			
			Load (%)				**Load (%)**				**Load (%)**			
			0	**20**	**40**	**60**	**0**	**20**	**40**	**60**	**0**	**20**	**40**	**60**
NSC	(a-R)/(R)%	300	15	14	18	17	15	15	17	17	15	15	17	17
	(b-R)/(R)%	500	31	31	34	36	31	31	33	35	30	30	33	35
SF1	(a-R)/(R)%	300	6	6	8	9	6	6	8	9	5	6	7	8
	(b-R)/(R)%	500	23	23	25	28	22	23	25	27	22	23	24	27
BF1	(a-R)/(R)%	300	22	25	25	41	20	23	24	46	22	25	29	46
	(b-R)/(R)%	500	40	62	63	74	39	61	60	76	35	62	64	76

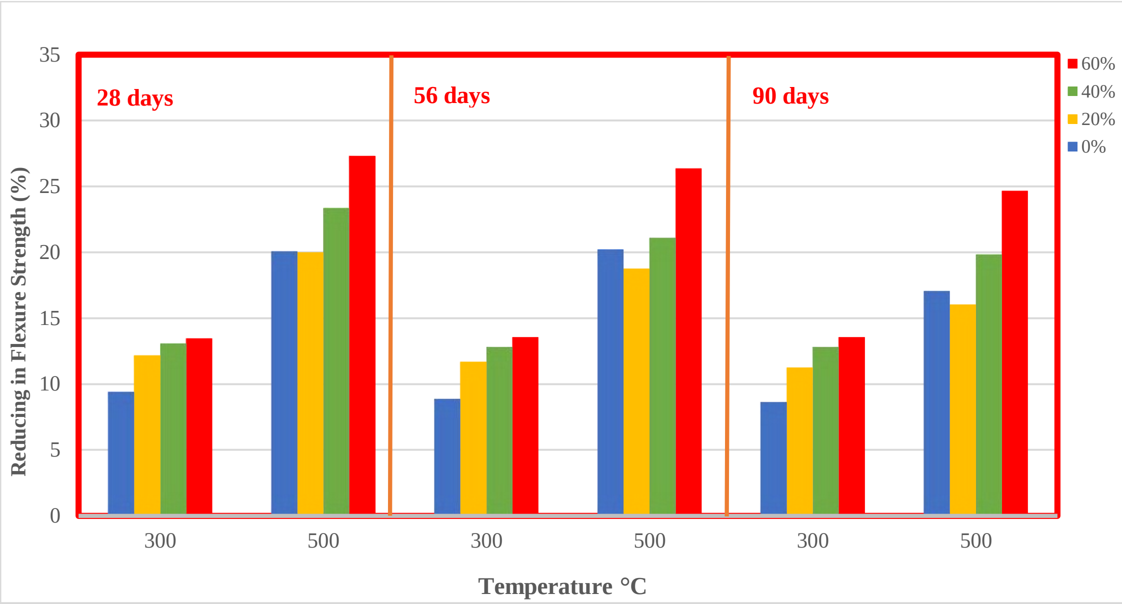

Fig. (4-11): *Reduce in Flexural Strength of SF1.*

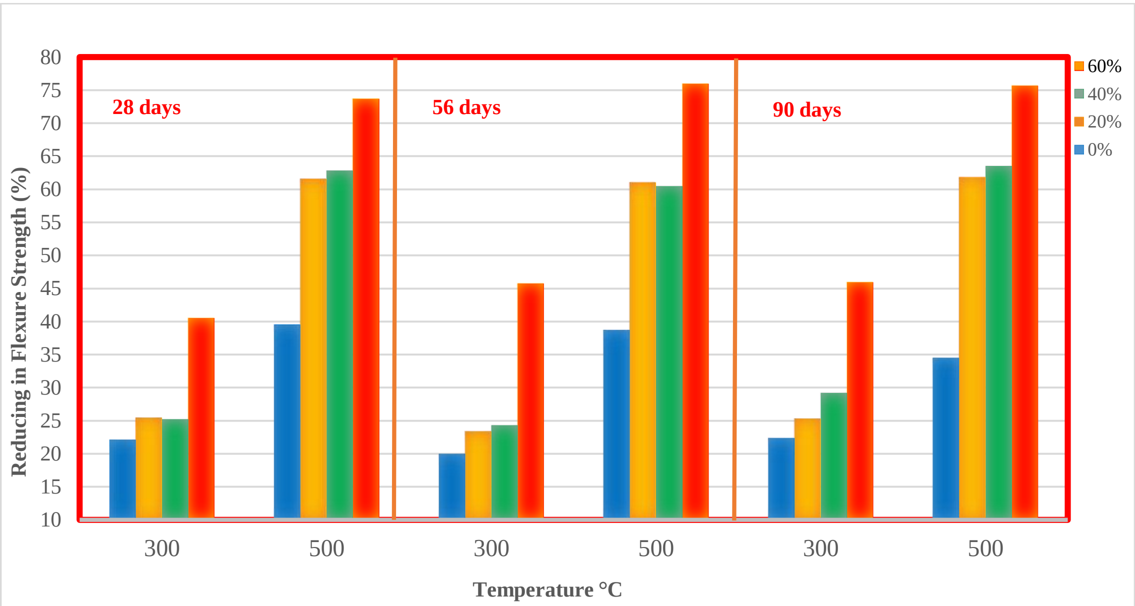

Fig. (4-12): *Reduce in Flexural Strength of BF1.*

4.2.2.2 Non-destructive Tests

4.2.2.2.1 Ultrasonic Pulse Velocity Results (U.P.V)

With an increase in curing age, ultrasonic pulse velocity increased due to more production of gel that leads to delay the transfer time the wave. The results of ultrasonic pulse velocity test for cubes are listed in Table (4-5). Figures (4-13) through (4-15), are shown the relationship between pulse velocity, elevated temperature (300 and 500°C) and load cases (20, 40 and 60) %, for all specimens of cube at all ages. It was shown that pulse velocity drops down as temperature and load rate rise. While, Table (4-6) and Figures (4-16) through (4-18), shown the reduction in pulse velocity for the mixes (NSC, SF1 and BF1) for prism symbols, exposed to elevated temperature (300 and 500°C) at ages (28, 56 and 90 days). It was found that for period of exposure (2 hours) and at 300° C temperature, the percentage of reducing of ultrasonic pulse velocity between (5-20%), (6-14%) and (2-10%) for cube symbols, while the reduce of ultrasonic pulse velocity for prism symbols between (14-18%), (5-9%) and (5-17%) for mixes (NSC, SF1 and BF1) respectively for all load cases as shown in Table (4-8). While, for the same period of exposure and at 500° C temperature, the percentage of reducing of ultrasonic pulse velocity between (29-54%), (36-52%) and (36-43%) for cube symbols, while the reducing of ultrasonic pulse velocity for prism symbols between (30-36%), (22-28%) and (26-45%) for mixes (NSC, SF1 and BF1) respectively for all load cases. The results indicate that cubes show less difference in ultrasonic pulse velocity for mixtures (NSC, SF1 and BF1) in all load cases at the 300 ^{O}C, whereas at 500 ^{O}C, NSC mix has a higher ultrasonic pulse velocity than SF1 and BF1 for (40% and 60%) of load.

Table (4-5): *Test results of Ultrasonic Pulse Velocity for cube symbols.*

Ultrasonic Pulse Velocity (Km/sec)														
			28 days				56 days				90 days			
			Load (%)				Load (%)				Load (%)			
Type	Temperature °C		0	20	40	60	0	20	40	60	0	20	40	60
NSC	25	before loading	4.9	------	------	------	4.9	------	------	------	4.9	------	------	------
	25 (M)	after loading	4.9	4.5	4.5	4.1	4.9	4.7	4.4	4.1	4.9	4.7	4.8	4.4
	300 (a)	after heating	4.4	4.3	4.0	3.3	4.5	4.4	4.2	3.3	4.7	4.4	4.4	3.6
	500 (b)	after heating	3.5	3.1	2.3	1.9	3.5	3.3	2.8	2.4	3.6	3.3	2.9	2.9
SF1	25	before loading	4.9	------	------	------	4.9	------	------	------	4.9	------	------	------
	25 (M)	after loading	4.9	4.9	4.7	4.3	4.9	4.9	4.7	4.3	4.9	4.9	4.7	4.4
	300 (a)	after heating	4.5	4.2	4.1	4.0	4.6	4.5	4.3	4.0	4.7	4.6	4.4	4.1
	500 (b)	after heating	3.0	2.5	2.3	2.1	3.0	2.7	2.4	2.1	3.1	2.7	2.5	2.3
BF1	25	before loading	4.7	------	------	------	4.7	------	------	------	4.7	-------	-------	-------
	25 (M)	after loading	4.7	4.6	4.5	4.5	4.7	4.7	4.6	4.6	4.7	4.7	4.6	4.6
	300 (a)	after heating	4.5	4.3	4.1	4.0	4.6	4.5	4.3	4.1	4.6	4.5	4.4	4.1
	500 (b)	after heating	2.8	2.7	2.7	2.5	2.9	2.8	2.8	2.6	3.0	2.9	2.8	2.7

Since the effect of steel fibre is obvious at 500 ^{O}C, as a result, the samples' internal thermal conductivity increases, increasing heat absorption as well as the number of cracks and wave transmission time, which lowers the ultrasonic pulse velocity. The ultrasonic pulse velocities of prisms differ significantly. It is evident that when temperature rises, the pulse velocity decreases. Because high temperatures cause moisture that isn't bound by the concrete to evaporate hydrated substances (free moisture), which leave gaps in the concrete mass ***(Hassan, 2007).*** In addition, the heating process causes volume changes as a result of thermal movements between the cement paste and aggregate, which is linked to the differing rates of thermal expansion of the two materials. Also, the chemical and physical effects of the heating process at higher temperature (dehydration of calcium silicate at about 400°C) **(Zoldners, 1971).** The key factor contributing to the cracking and degradation of NSC at high temperatures is the sustained load. Because of the cracks' origin in the concrete mass, increased porosity, and concurrent decrease in velocity, these cracks cause the ultrasonic pulse to delay, lengthening its travel time ***(Sideris, 2007).***

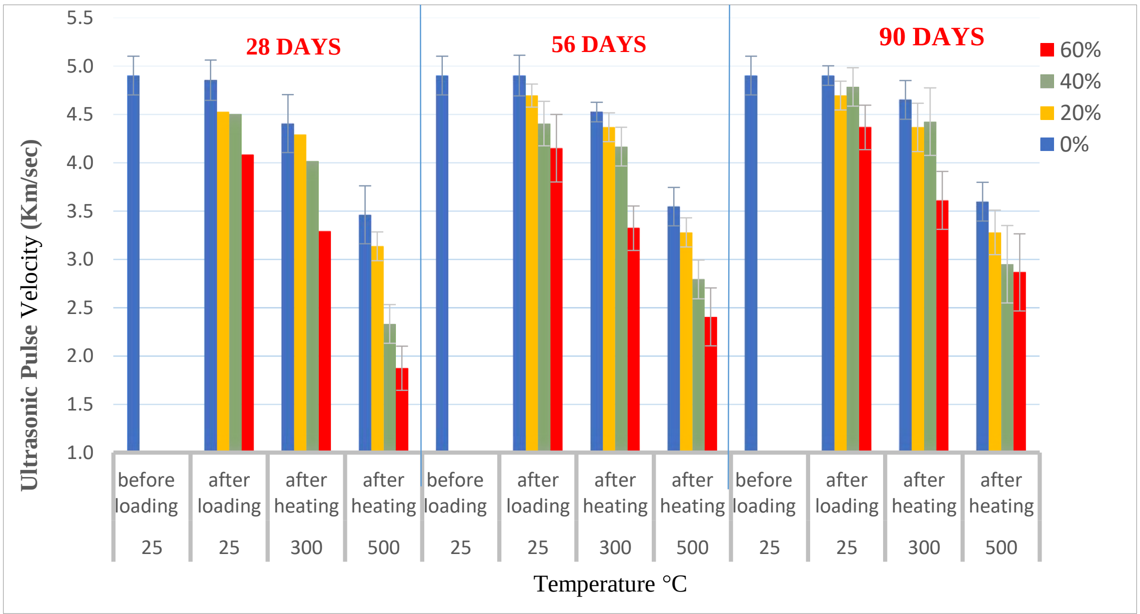

Fig. (4-13): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in NSC for cube symbols at age (28, 56 and 90) days.*

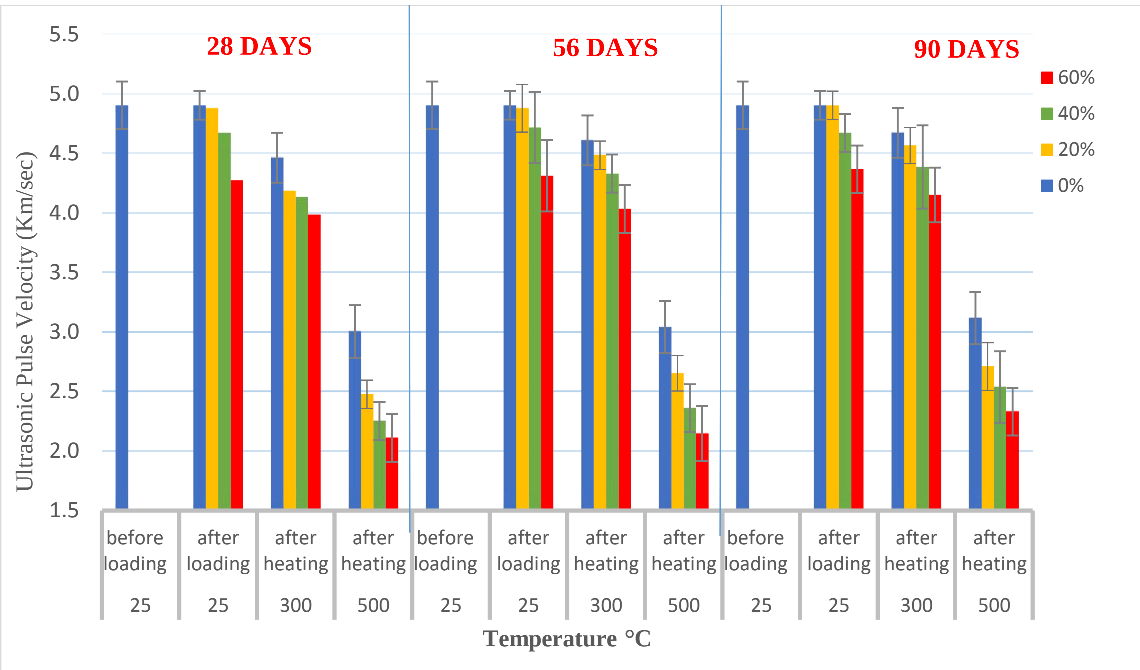

Fig. (4-14): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in SF1 for cube symbols at age (28, 56 and 90) days.*

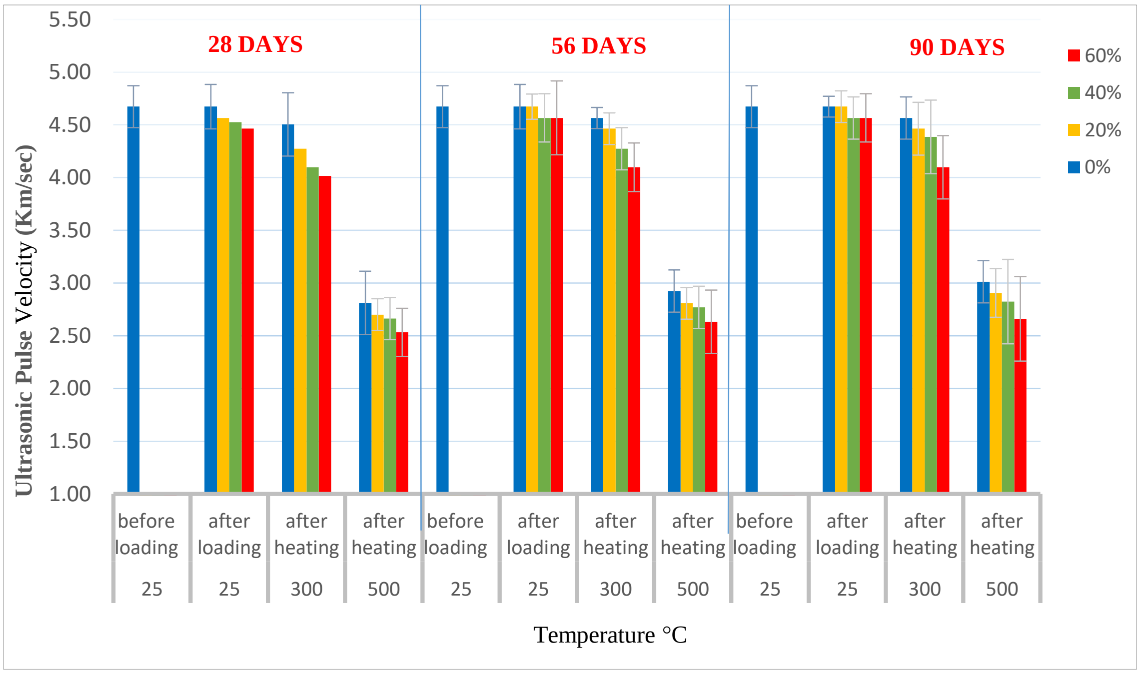

Fig. (4-15): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in BF1 for cube symbols at age (28, 56 and 90) days*

Ultrasonic pulse velocity measurements seem to be more susceptible to heat degradation. This is expected because heat-induced cracks more frequently prevent waves from propagating. The effect of fibers is important because their bridging mechanism enables transmission across cracks. This is more apparent for high residual strength levels because there are fewer internal cracks caused by heat damage **(Hodhod & Abdeen, 2010).**

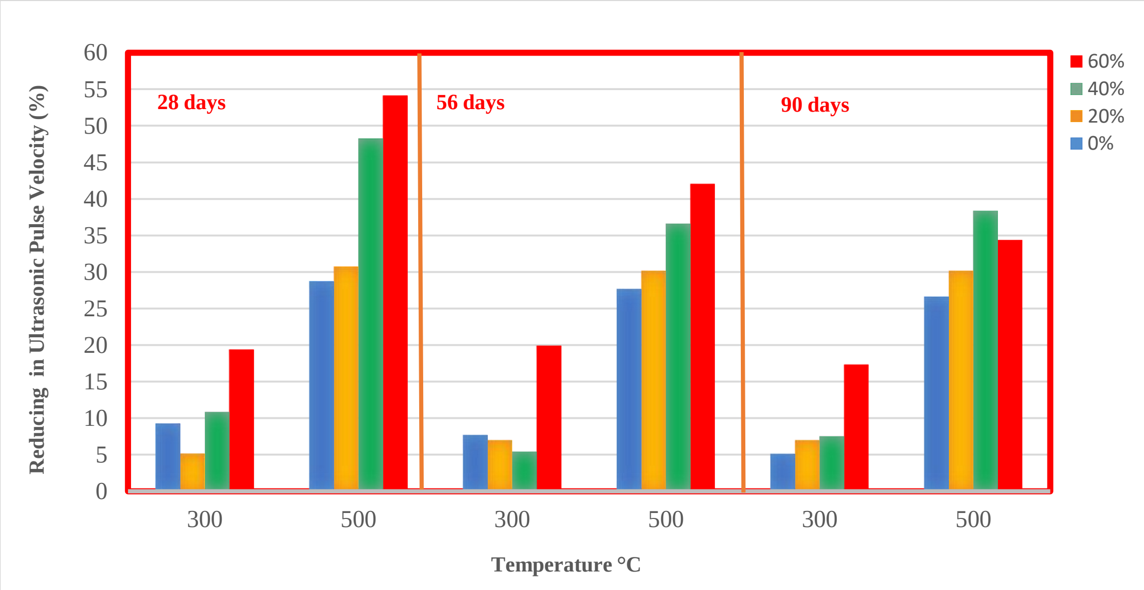

Fig. (4-16): *Reducing in ultrasonic pulse velocity of NSC for cube symbols.*

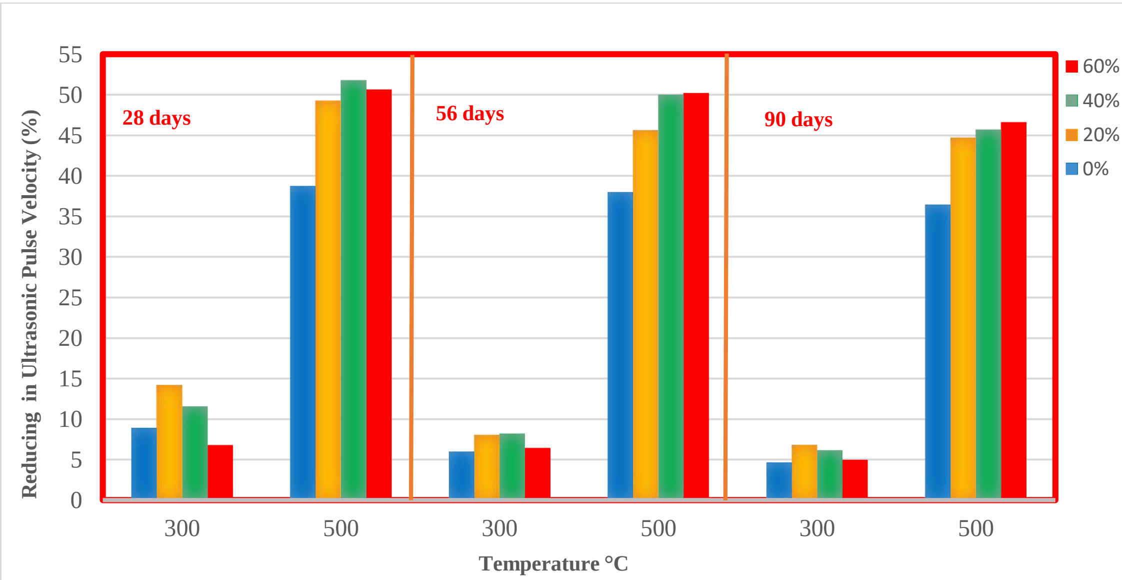

Fig. (4-17): *Reducing in ultrasonic pulse velocity of SF1 for cube symbols.*

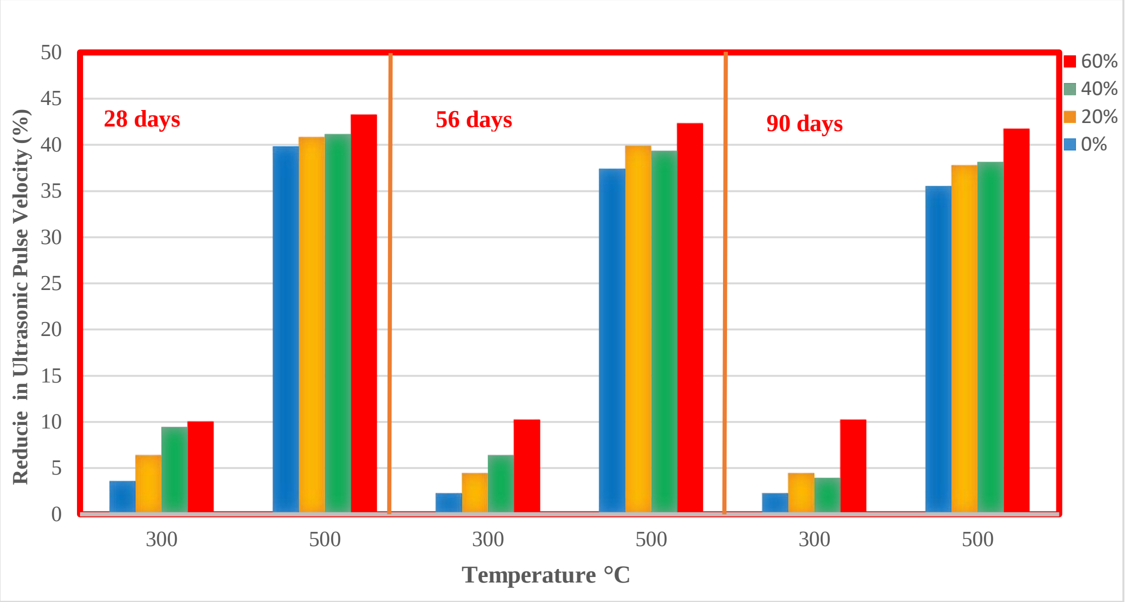

Fig. (4-18): *Reduce in ultrasonic pulse velocity of BF1 for cube symbols.*

Table (4-6): *Percentage reducing of Ultrasonic Pulse Velocity for cube symbols.*

The percentage of reducing in Ultrasonic Pulse Velocity (%)														
Type	Change in Velocity	Temperature °C	28 days				56 days				90 days			
			Load (%)				Load (%)				Load (%)			
			0	20	40	60	0	20	40	60	0	20	40	60
NSC	(a-M)/(M)%	300	9	5	11	19	8	7	5	20	5	7	8	17
	(b-M)/(M)%	500	29	31	48	54	28	30	37	42	27	30	38	34
SF1	(a-M)/(M)%	300	9	14	12	7	6	8	8	6	5	7	6	5
	(b-M)/(M)%	500	39	49	52	51	38	46	50	50	36	45	46	47
BF1	(a-M)/(M)%	300	4	6	9	10	2	4	6	10	2	4	4	10
	(b-M)/(M)%	500	40	41	41	43	37	40	39	42	36	38	38	42

Table (4-7): *Test results of Ultrasonic Pulse Velocity for prism symbols.*

Ultrasonic Pulse Velocity (km/sec)														
Type	**Temperature °C**		**28 days**				**56 days**				**90 days**			
			Load (%)				**Load (%)**				**Load (%)**			
			0	**20**	**40**	**60**	**0**	**20**	**40**	**60**	**0**	**20**	**40**	**60**
NSC	25	before loading	4.8	------	------	------	4.9	------	------	------	5.0	------	------	------
	25 (M)	after loading	4.8	4.8	4.8	4.7	4.9	4.9	4.9	4.8	5.0	4.9	4.9	4.8
	300 (a)	after heating	4.1	4.1	3.9	3.9	4.2	4.1	4.0	4.0	4.2	4.2	4.1	4.0
	500 (b)	after heating	3.3	3.3	3.2	3.0	3.4	3.4	3.2	3.1	3.5	3.5	3.3	3.1
SF1	25	before loading	4.6	------	------	------	4.7	------	------	------	4.7	------	------	------
	25 (M)	after loading	4.6	4.6	4.6	4.5	4.7	4.7	4.6	4.6	4.7	4.7	4.7	4.7
	300 (a)	after heating	4.3	4.3	4.2	4.1	4.4	4.4	4.3	4.2	4.5	4.5	4.4	4.3
	500 (b)	after heating	3.5	3.5	3.4	3.3	3.6	3.6	3.5	3.4	3.7	3.7	3.6	3.4
BF1	25	before loading	4.2	------	------	------	4.4	------	------	------	4.5	------	------	------
	25 (M)	after loading	4.2	4.1	4.0	4.0	4.4	4.3	4.3	4.3	4.5	4.4	4.4	4.3
	300 (a)	after heating	3.9	3.7	3.5	3.4	4.1	3.8	3.8	3.6	4.2	4.0	3.8	3.6
	500 (b)	after heating	3.1	2.9	2.5	2.2	3.2	3.0	2.7	2.4	3.3	3.0	2.7	2.4

Table (4-8): *Percentage reducing of Ultrasonic Pulse Velocity for prism symbols.*

The percentage of reduction in Ultrasonic Pulse Velocity (%)														
Type	Change in Velocity	Temperature °C	28 days				56 days				90 days			
			Load (%)				Load (%)				Load (%)			
			0	20	40	60	0	20	40	60	0	20	40	60
NSC	(a-M)/(M)%	300	15	14	18	17	15	15	17	17	15	15	17	17
	(b-M)/(M)%	500	31	31	34	36	31	31	33	35	30	30	33	35
SF1	(a-M)/(M)%	300	6	6	8	9	6	6	8	9	5	6	7	8
	(b-M)/(M)%	500	23	23	25	28	22	23	25	27	22	23	24	27
BF1	(a-M)/(M)%	300	8	11	13	16	6	11	12	17	5	9	12	16
	(b-M)/(M)%	500	27	30	38	45	26	30	37	44	26	31	37	44

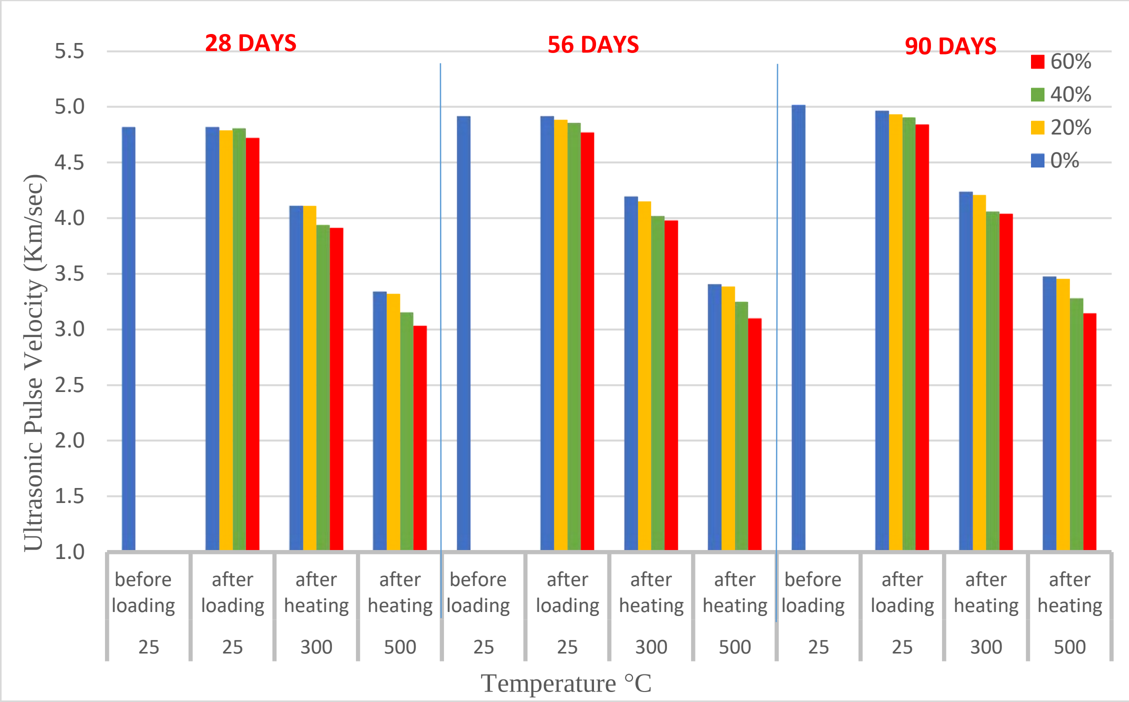

Fig. (4-19): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in NSC for prisms symbols at age (28, 56 and 90) days.*

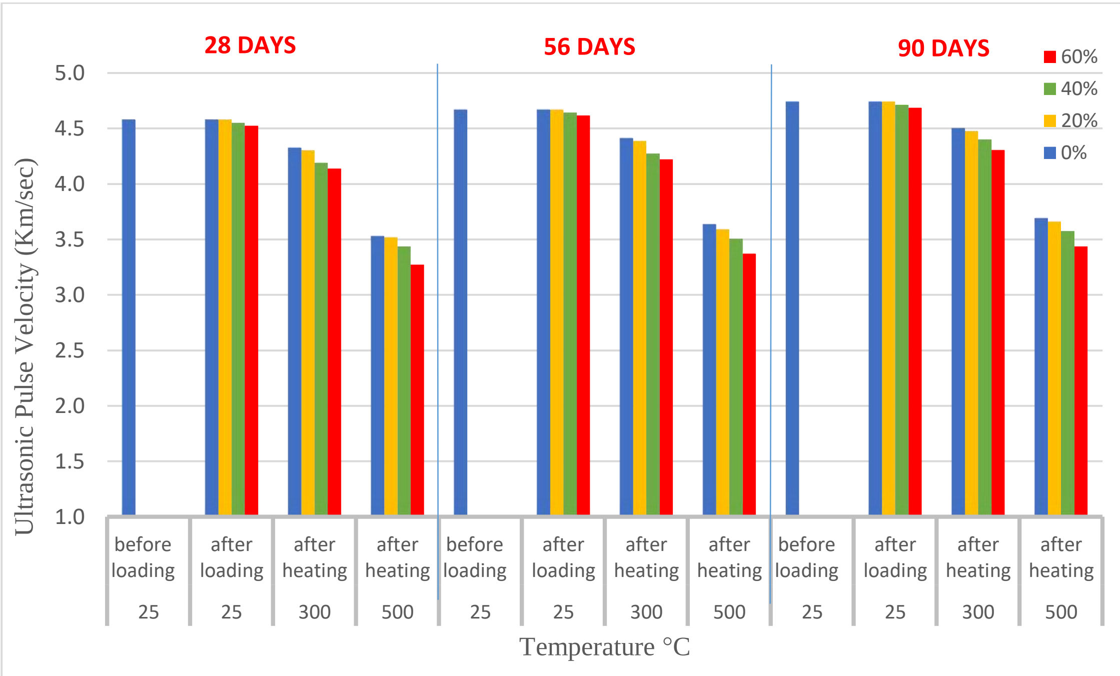

Fig. (4-20): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in SF1 for prisms symbols at age (28, 56 and 90) days.*

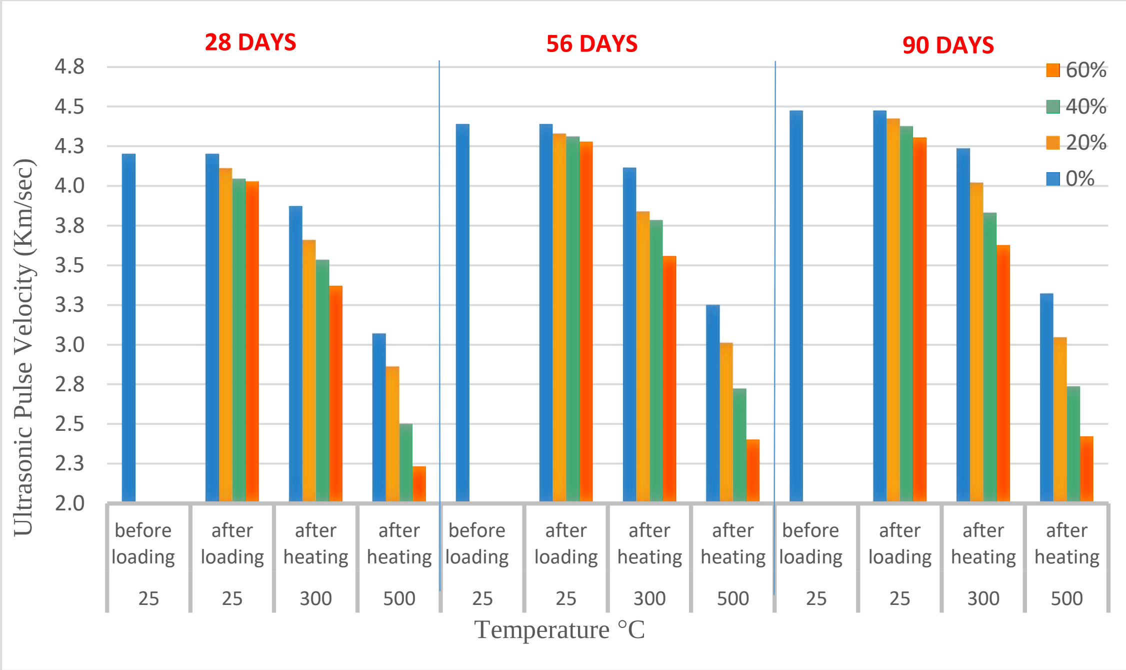

Fig. (4-21): *Effect of imposed load and elevated temperature on ultrasonic pulse velocity in BF1 for prisms symbols at age (28, 56 and 90) days.*

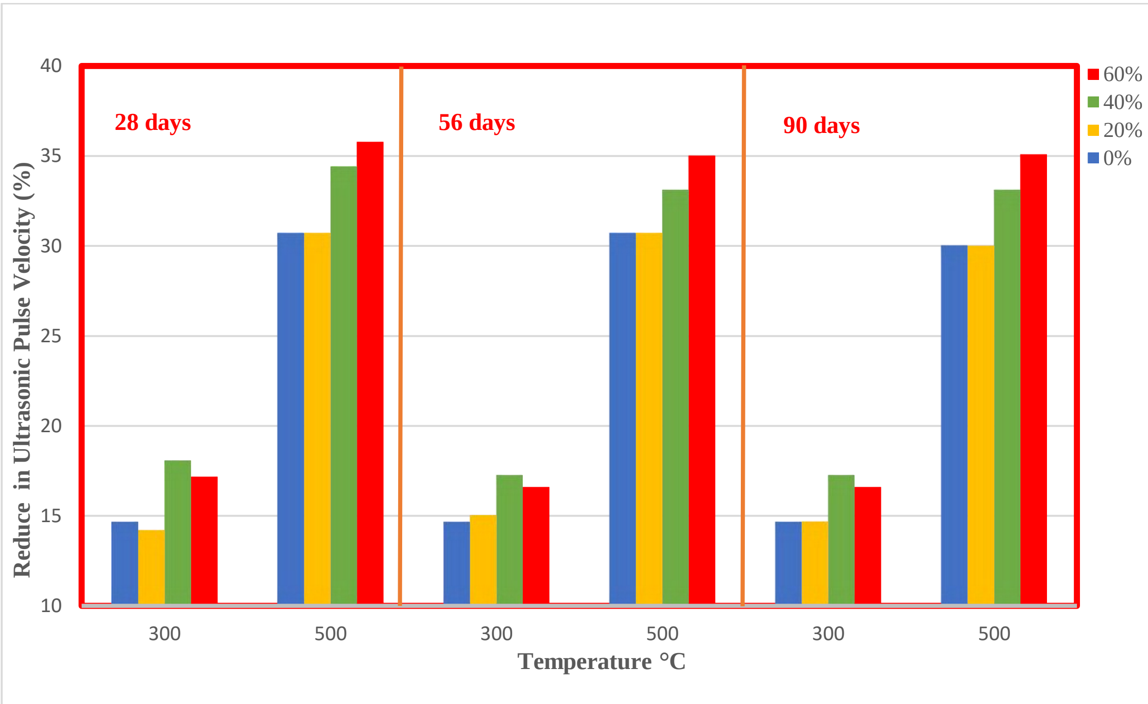

Fig. (4-22): *Reduce in ultrasonic pulse velocity of NSC for prisms symbols.*

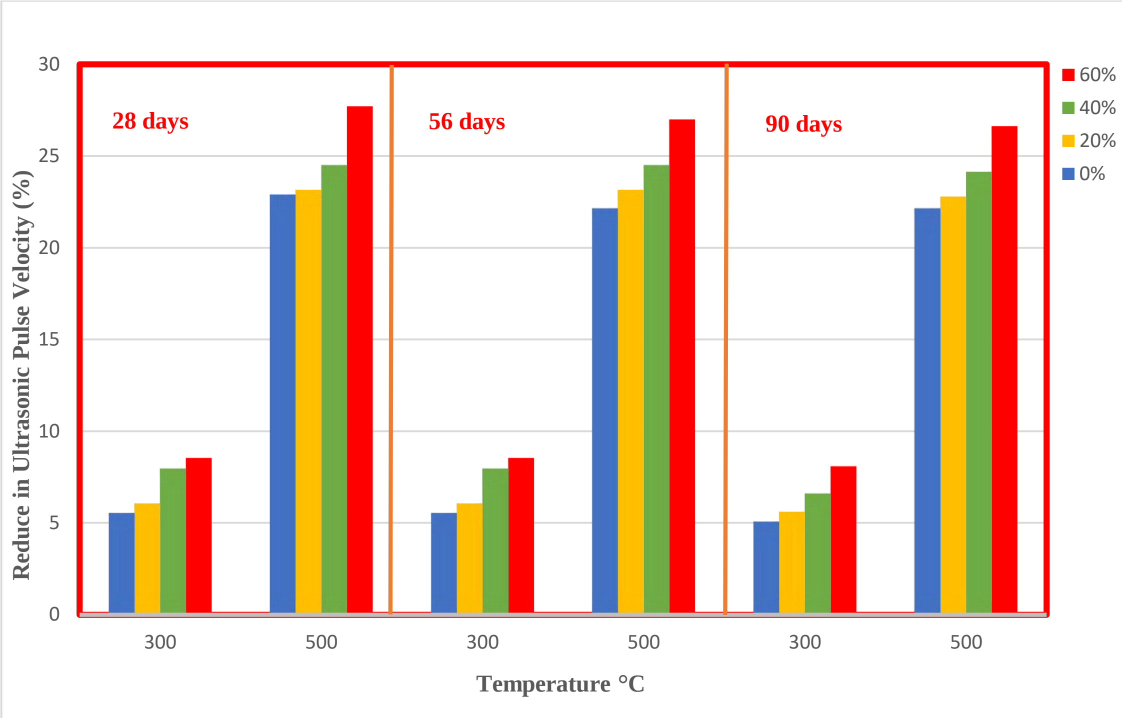

Fig. (4-23): *Reduce in ultrasonic pulse velocity of SF1 for prisms symbols.*

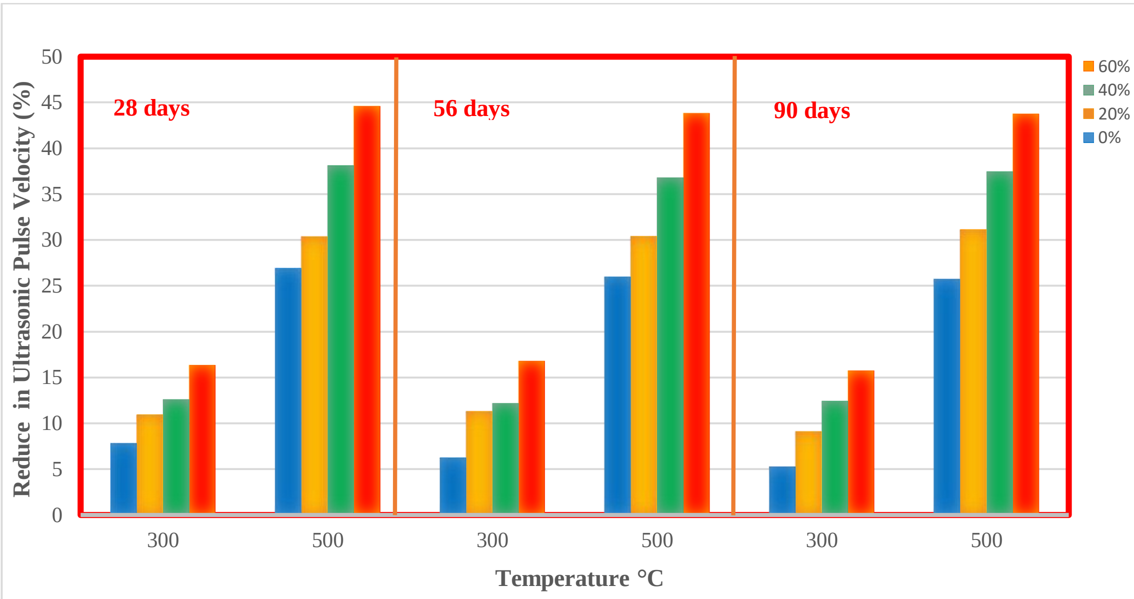

Fig. (4-24): *Reducing in ultrasonic pulse velocity of BF1 for prisms symbols.*

4.2.2.2.2 Surface Hardness Results (Rebound Number).

The "Schmidt rebound hammer test" was used to determine the surface hardness of the 100 mm concrete cubes. The findings of the rebound number developed as the curing age increased. For all mixtures before and after loading and heating, the values of the rebound number results at (28, 56, and 90 days) are shown in Table (4-9) and displayed in Figures (4-25) through (4-27). Figures show the relationship between rebound number and elevated temperature (300 and 500°C) under the effect of imposed load, for all specimens. While Table (4-10) and Figures (4-28) through (4-30), show the reduction in rebound number for the three mixes (NSC, SF1 and BF1) exposed to elevated temperature (300, and 500° C) at ages (28, 56 and 90 days). For a two-hour exposure period and at a temperature of 300°C, it was discovered that the percentage of rebound number reduction fell between (4-17%), (7-12%), and (4-7%) while at a temperature of 500° C, the percentage of rebound number reduction fell between (15-26%), (22-26%), and (14-18%) for mixes (NSC, SF1, and BF1), respectively, for all load cases for cube symbols. Due to steel fiber's tendency to retain temperature for a longer time than other materials, which causes fractures to form on the cubes' outer surface and diminish stiffness, the maximum reducing in rebound number for all imposed load scenarios for SF1 combination occurs at 500°C as shown in Figure (4-29). Particularly for normal strength concrete, the association between the rebound number and plain and fiber reinforced concretes is closer **(Hodhod & Abdeen, 2010).**

As indicated in Table (4–10), the BF1 mixture exhibits the lowest levels of decreasing rebound number values. The addition of basalt fibers is reduced the brittleness of concrete **(Serbescu et al., 2015; Yildizel et al., 2020).**

Table (4-9): *Surface Hardness Results (Rebound Number).*

Rebound Number														
Type	Temperature °C		28 days				56 days				90 days			
			Load (%)				Load (%)				Load (%)			
			0	20	40	60	0	20	40	60	0	20	40	60
NSC	25	before loading	25	------	------	------	26	------	------	-----	27	------	------	-----
	25	after loading	25	25	23	19	26	26	25	24	27	27	26	25
	300	after heating	23	22	19	15	25	25	23	20	26	26	24	21
	500	after heating	20	20	17	14	22	22	19	18	23	22.7	20	18.8
SF1	25	before loading	18	------	------	------	23	------	------	------	23	------	------	------
	25	after loading	18	18	17	16	23	21	20	19	23	21	21	20
	300	after heating	17	16	15	14	22	20	18	17	22	20	19	18
	500	after heating	14	14	13	12	18	16	15	14	18	16	16	15
BF1	25	before loading	22	------	------	------	21	------	------	------	23	------	------	------
	25	after loading	22	21	21	20	21	21	20	19	23	23	22	21
	300	after heating	21	20	20	19	20	20	19	18	22	22	21	20
	500	after heating	19	18	17	16	18	18	17	16	20	20	19	18

Table (4-10): *Percentage reducing in Rebound Number value.*

The percentage of reducing in Rebound Number (%)														
			28 days				56 days				90 days			
			Load (%)				Load (%)				Load (%)			
Type	Change in Velocity	Temperature °C	0	20	40	60	0	20	40	60	0	20	40	60
NSC	(a-M)/(M)%	300	8	12	17	21	4	4	8	17	4	4	8	16
	(b-M)/(M)%	500	20	20	26	26	15	15	24	25	15	16	23	25
SF1	(a-M)/(M)%	300	8	9	12	13	7	7	9	11	6	7	10	10
	(b-M)/(M)%	500	22	25	24	26	23	24	25	26	22	22	24	25
BF1	(a-M)/(M)%	300	5	5	6	8	5	5	5	7	4	4	5	5
	(b-M)/(M)%	500	15	16	17	18	14	14	15	16	13	13	14	14

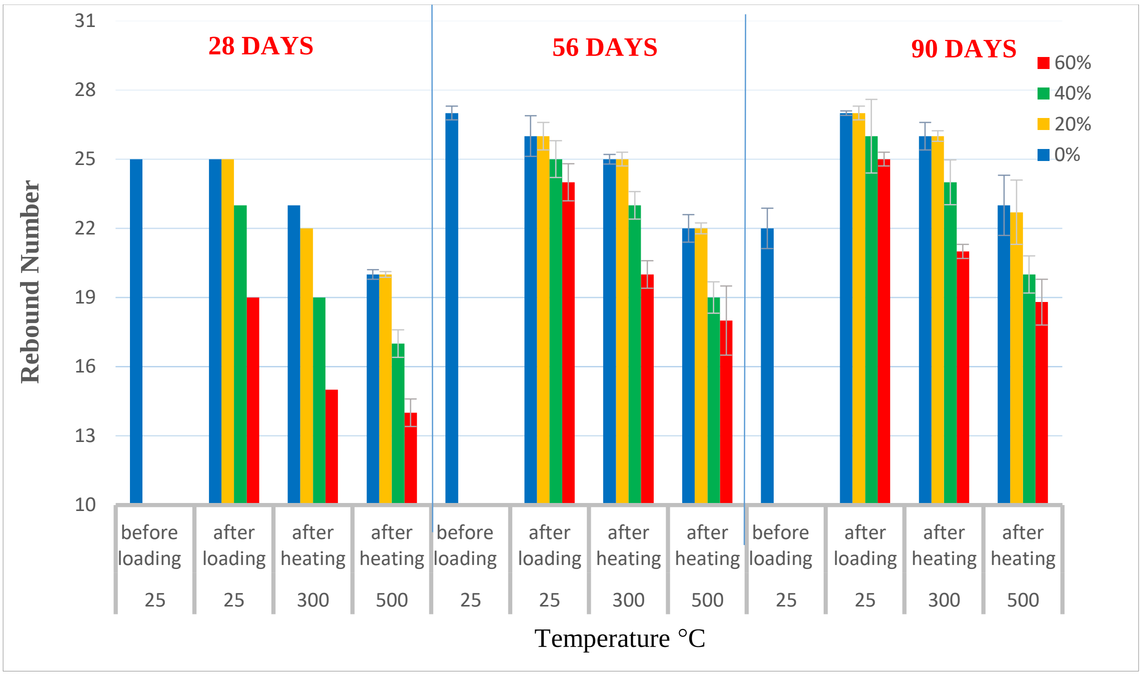

Fig. (4-25): *Effect of imposed load and elevated temperature on Rebound Number for NSC at age (28, 56 and 90) days.*

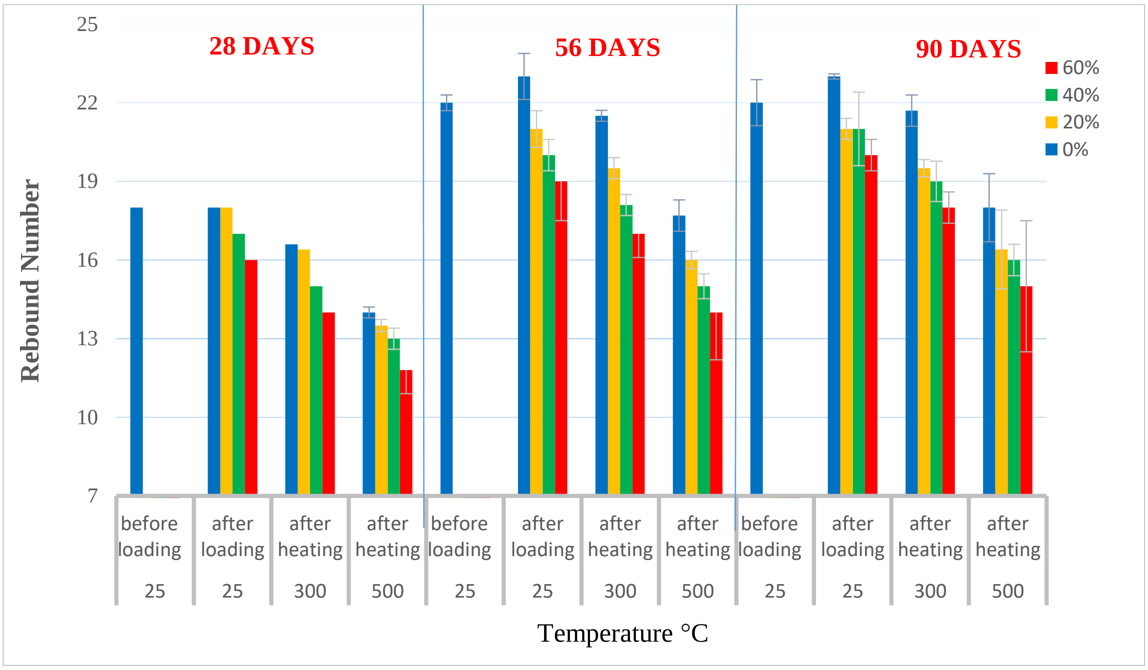

Fig. (4-26): *Effect of imposed load and elevated temperature on Rebound Number for SF1 at age (28, 56 and 90) days.*

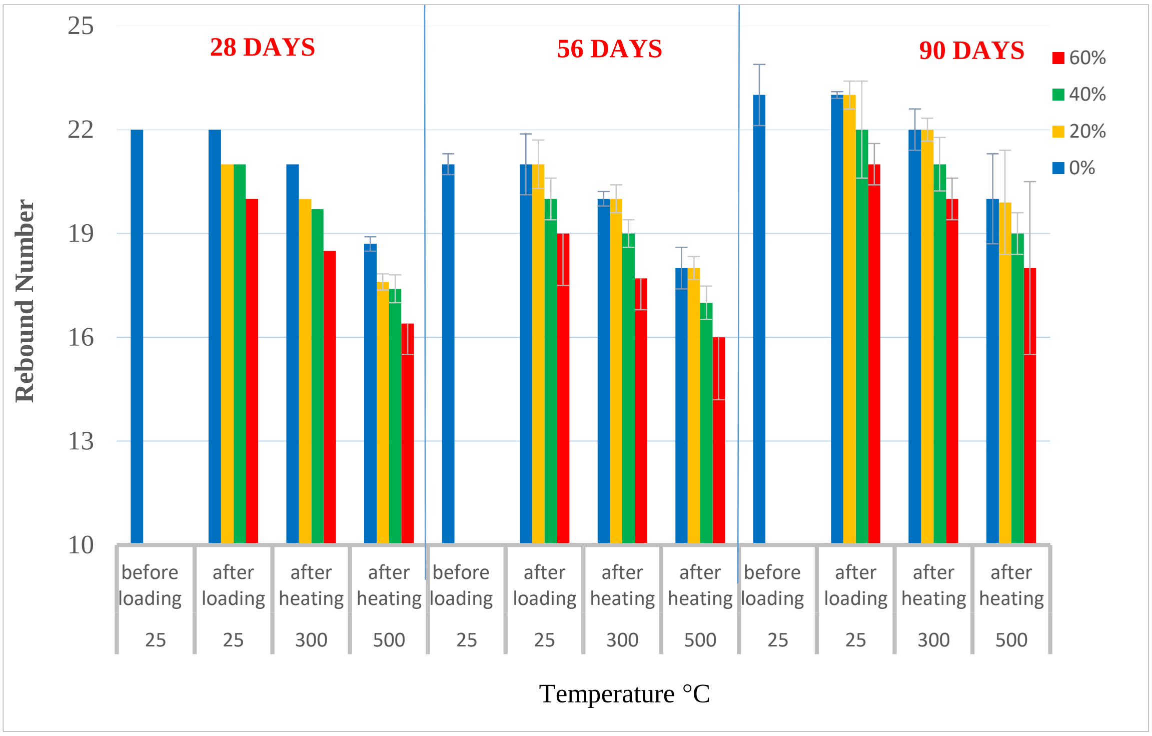

Fig. (4-27): *Effect of imposed load and elevated temperature on Rebound Number for BF1 at age (28, 56 and 90) days.*

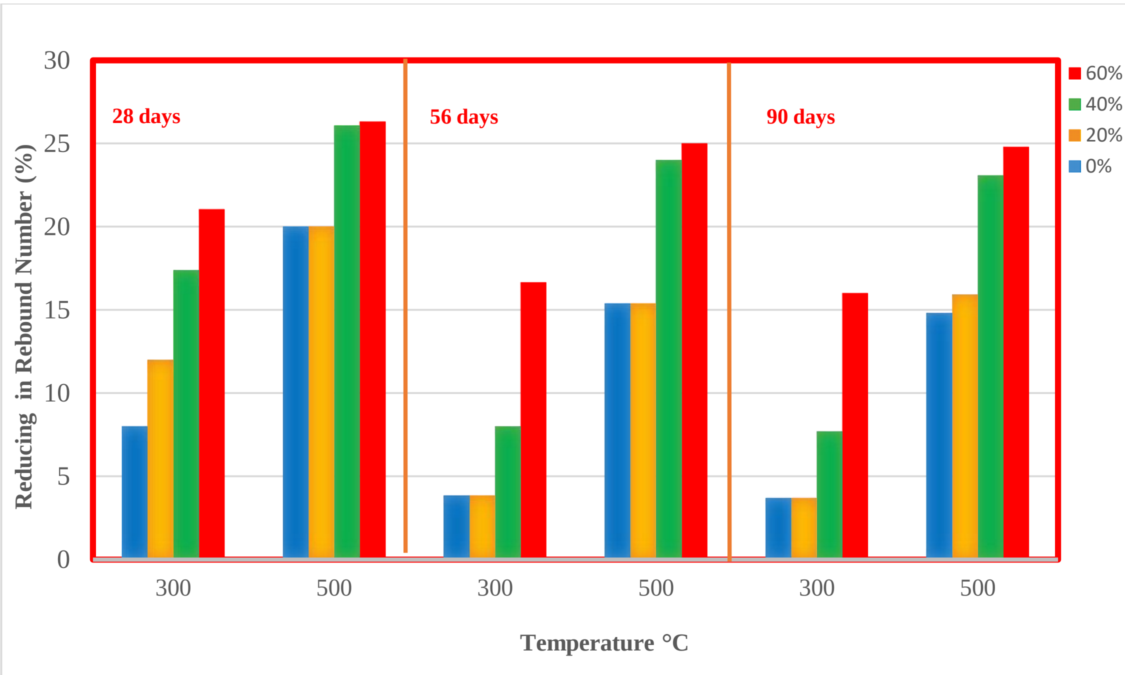

Fig. (4-28): *Reduce in Rebound Number of NSC.*

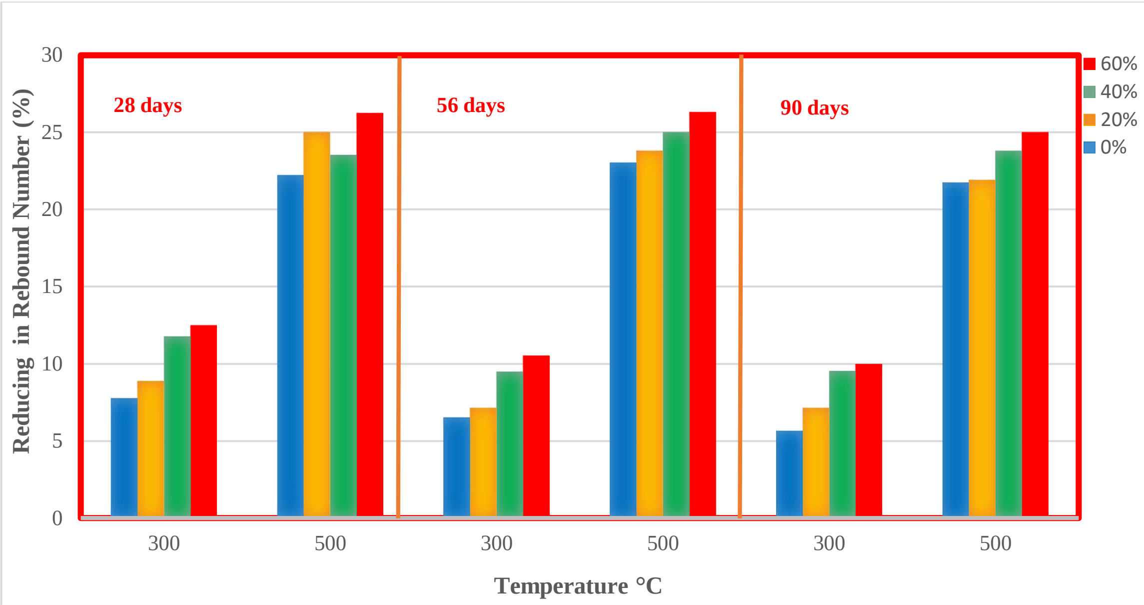

Fig. (4-29): *Reduce in Rebound Number of SF1.*

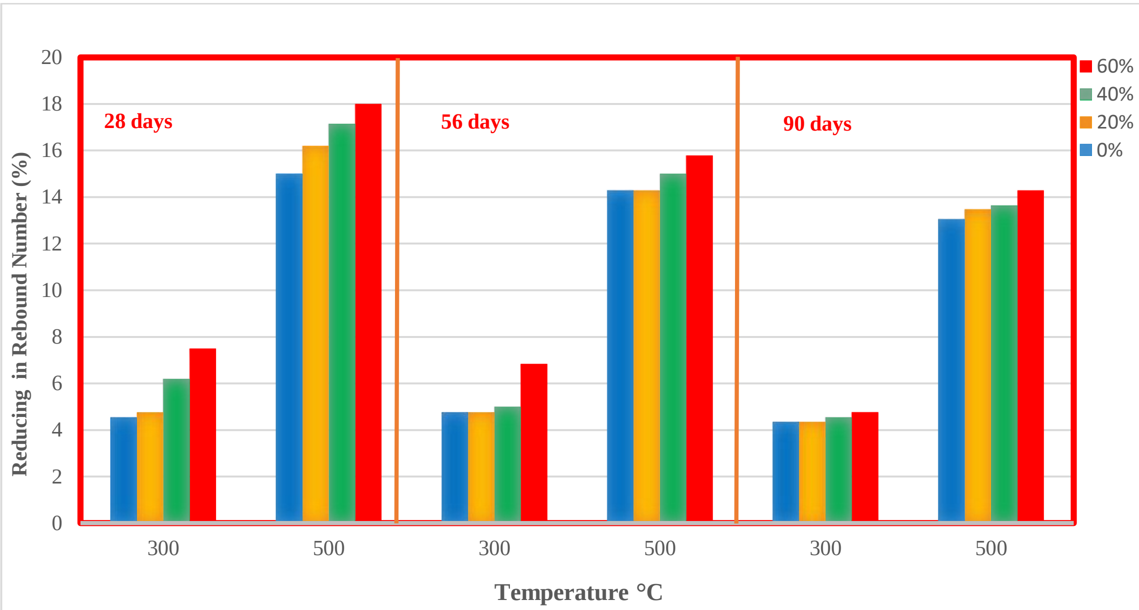

Fig. (4-30): *Reduce in Rebound Number of BF1.*

CHAPTER FIVE

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1Conclusions

The experimental results given in the preceding chapters led to the conclusion that the NSC, SF1, and BF1 in a hardened condition were affected by temperatures (300, and 500 °C) and load rates (20, 40, and 60%) of ultimate load. Samples are exposed to temperature for two hours. The tests that have been carried out include compressive strength, flexural strength, ultrasonic pulse velocity, and rebound number. Based on the observations gathered throughout the course of the current work, the following conclusions were reached:

1. It was observed that the NSC had a higher compressive strength than SF1 and BF1 at all heating and load cases.
2. The loss in compressive strength is minimal at 300° C, where it was observed that the percentages were between (6-16%), (6-10%), and (16-19%), while at 500° C, the percentages were between (14-36%), (22-23%), and (17-22%) for mixes (NSC, SF1, and BF1), respectively, for all load cases.
3. For all ages (28, 56, and 90 days), the compressive strength of NSC at 500 °C is clearly reduced at 60% loading of the maximum load, but the results for SF1 are significantly reduced for all load and temperature cases. While the compressive strength of the BF1 mixture reduces less than that of the NSC and SF1 mixtures.
4. Flexural strength reduced for all specimens with rising temperatures and loads.

5. For a period of exposure (2 hours) and at a temperature of 300° C, it was discovered that the percentage of flexural strength reduction varied between (14-18%), (6-9%), and (20-46%), while at a temperature of 500° C, it varied between (30-36%), (23-27%), and (35-76%) for mixes of NSC, SF1, and BF1 for all load cases.
6. Symbols containing steel fibers in flexural strength tests show only a slight influence of load at the same temperature as normal concrete. In comparison to other mixtures, the minimal reduction in flexural strength for the SF1 mixture is (6–9%) and (23-27%) at 300°C and 500°C, respectively.
7. In a flexural test, steel fibers were found to be more effective than compressive strength mixture that have fibers at minimizing the negative effects of high temperature on the (SF1) mixture.
8. For all temperature and load situations, BF1 has a lower flexural strength than other mixtures (SF1 and NSC).
9. Ultrasonic pulse velocity is constant at all ages. It has been demonstrated that as temperature and load rate increase, pulse velocity decreases.
10. For all load cases, the percentage of reduced ultrasonic pulse velocity at 300°C varied between (5-20%), (6-14%), and (2-10%) for cube symbols, while it varied between (14-18%), (5-9%), and (5-17%) for mixes (NSC, SF1, and BF1) for prism symbols.
11. For all load cases, the percentage of reducing ultrasonic pulse velocity for cube symbols at 500°C, ranged between (29-54%), (36-52%) and (36-43%), while for prism symbols, the reducing ultrasonic pulse velocity ranged between (30-36%), (22-28%), and (26-45%).
12. The results reveal that at 300 °C, mixtures (NSC, SF1, and BF1) do not significantly differ in ultrasonic pulse velocities for any load

situations; however, at 500 °C, the NSC mix has greater ultrasonic pulse velocities than SF1 and BF1 for (40% and 60%) of ultimate loads. Since steel fibers impact becomes apparent at 500 °C.

13. As the curing age increased, the results of the rebound number evolved.
14. For a two-hour exposure period, it was found that the percentage of rebound number reduction fell between (4-17%), (7-12%), and (4-7%) at a temperature of 300° C, while at a temperature of 500° C, the percentage of rebound number reduction fell between (15-26%), (22-26%), and (14-18%) for mixes (NSC, SF1, and BF1), respectively, for all load cases for cube symbols.
15. The highest reduction in rebound number for all imposed load scenarios for the SF1 combination occurs at 500°C, while the BF1 mixture exhibits the lowest levels of decreasing rebound number values.

5.2 Recommendations for Further Studies

There are several recommendations that can be considered for further experimental investigation regarding to the study of effect of elevated temperatures and load on normal concrete with and without fibers reinforced concrete:

1. Adding different types of fibers to normal concrete, such as hybrid fibers, carbon fibers, and micro steel fibers.
2. Investigating how normal concrete with and without fibers and loads responds to temperatures above 500 °C.
3. Researching how the mechanical characteristics of concrete are affected by high temperatures and loads which are 80% from the ultimate load.
4. Using a load and a higher temperature simultaneously.

5. Evaluate how a little amount of basalt fibers (0.25-0.5%) affects the flexural test in the same conditions.
6. Investigating the effect of cooling by air or by water cooling on the properties of normal concrete with/or without different fibers.

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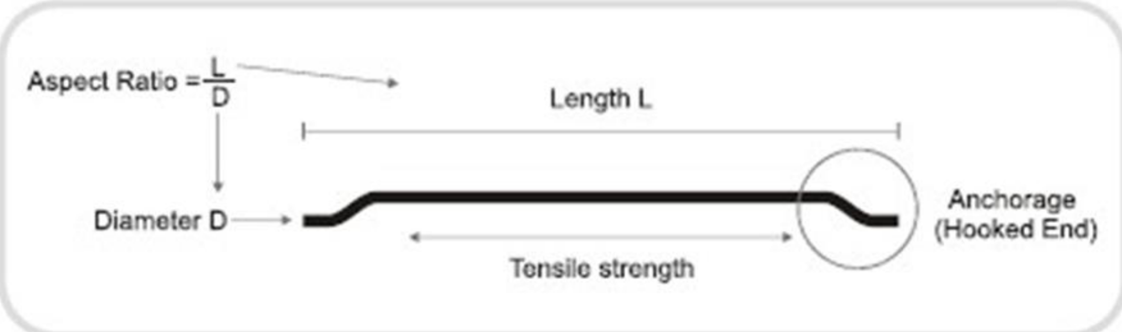
APPENDIX

Material Safety Datasheets

1. **Data sheet of hooked end fibers provided by the manufacturer**

Product Data Sheet



Material Properties

Material	Low Carbon Drawn Wire
Aspect Ratio	60
Length (mm)	30 mm
Diameter (mm)	0.50 mm
Tensile Strength	> 1100 MPa
Appearance	Clear, bright, Loose unglued with hook end anchorage
Conforms to	EN 14889-1, ASTM A820 M04 Standards
Suitable Application	Tunnel Shotcrete, Slope Stabilization, Precast Pipes

Mixing

- Duraflex™ Steel fibers can be added before, during or after the batching of the concrete, as outlined by ASTM C-94 (4-5 minutes at mixing speed or approximately 60-70 revolutions).
- In the batch plant fibers can be added by a shaker or through a hopper to the aggregate on a conveyor belt during aggregate addition and mixed in the normal manner.
- If fibers are added in the mixer truck the drum should be rotating at maximum speed while fibers are slowly added. This is important to avoid clump avoiding balling effect.
- Depending on fiber type and dose rate the concrete slump should be increased by the addition of superplasticiser before fibers are added.
- Use of Micro Silica is beneficial along with steel fibers
- Do not use Steel fiber as a first component in the concrete mix.

Placing and Finishing

- Use of Internal and external vibrator (including vibrating screeds) is recommended.
- Finishing of the concrete surface is usually accomplished by using conventional power or hand equipment.
- The use of a surface hardener to achieve a smooth and hardened surface will also help to cover fibers close to the surface.
- Do not use Wood floats, Wood floats tend to tear the surface and should not be used.

Precaution

- To avoid chocking in the pumping operation of the concrete mix, please note that The Hose diameter should be approximately 50 % greater than the fiber length. Testing is recommended before execution

Safety & Handling

- It is recommended that gloves and appropriate eye protection must be used while using fibers.
- Fibers concretes/shotcretes contain Portland cement and thus normal safety precautions used when handling conventional cement based products should be followed.
- Store in dry place
- Do not use Hooks.
- No Stacking

Packaging

- Available in 15/ 20/25 kg Non Woven HDPE Bags & Paper Laminated Bags.
- Palettes available on request.

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METAL COMPOSITES (P) LTD

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Visit us : www.steelfiberindia.in **Blog :** www.fiberconcrete.in

2. Data sheet of superplasticizer provided by the manufacturer

Hyperplast PC200

High performance concrete superplasticiser (Formerly known as Flocrete PC200)

DCP

Description

Hyperplast PC200 is a high performance super plasticising admixture based on polycarboxylic polymers with long chains specially designed to enable the water content of the concrete to perform more effectively. This effect can be used in high strength concrete and flowable concrete mixes, to achieve highest concrete durability and performance.

Applications

- High strength and high performance concrete.
- Structures with congested reinforcement.
- Pre-cast concrete.
- Improved cohesion allow for use in mass concrete pours and piling.
- Self compacting concrete.

Advantages

- Optimises cement utilization.
- High density and impermeable concrete through very high water reduction.
- Improves shrinkage and creep behaviors.
- Minimises segregation and bleeding problems by improving cohesion.
- Higher early and ultimate compressive strengths.
- Increases durability and resistance to aggressive atmospheric conditions thorough reduced permeability.

Compatibility

Hyperplast PC200 can be used with all types of Portland cement and cement replacement materials.

Hyperplast PC200 should not be used in conjunction with other admixtures unless DCP Technical Department approval is obtained.

Standards

Hyperplast PC200 complies with ASTM C494, Type A and G, depending on dosage used.

Method of Use

Hyperplast PC200 should be added to the concrete with the mixing water to achieve optimum performance.

Technical Properties @ 25ºC:	
Colour:	Light yellow liquid
Freezing point:	≈ -3°C
Specific gravity:	1.05 ± 0.02
Air entrainment:	Typically less than 2% additional air is entrained above control mix at normal dosages

An automatic dispenser should be used to dispense the correct quantity of Hyperplast PC200 to the concrete mix.

Dosage

The guidance dosage of Hyperplast PC200 is 0.50 - 2.50 litre/100 kg of cementitious materials in the mix, including GGBFS, PFA or microsilica.

Representative trials should be conducted to determine the optimum dosage of Hyperplast PC200 to meet the performance requirements by using the materials and conditions in actual use.

Effects of Over Dosage

Over dosing of Hyperplast PC200 will cause the following:

- Significant increase in retardation.
- Increase in workability.

Ultimate concrete strength will not be adversely affected and will generally be increased provided that proper concrete curing is maintained.

Cleaning

Hyperplast PC200 can be washed with fresh cold water.

Packaging

Hyperplast PC200 is available in 25 litre pails, 210 litre drums and 1000 litre bulks supply.

Hyperplast PC200

Storage

Hyperplast PC200 has a shelf life of 12 months from date of manufacture if stored at temperatures between 2°C and 50°C.

If these conditions are exceeded, DCP Technical Department should be contacted for advice.

Cautions

Health and Safety

Hyperplast PC200 is not classified as hazardous material. Hyperplast PC200 should not come into contact with skin and eyes.

In case of contact with eyes wash immediately with plenty of water and seek medical advice promptly.

For further information refer to the Material Safety Data Sheet.

Fire

Hyperplast PC200 is nonflammable.

More from Don Construction Products

A wide range of construction chemical products are manufactured by DCP which include:

- Concrete admixtures.
- Surface treatments
- Grouts and anchors.
- Concrete repair.
- Flooring systems.
- Protective coatings.
- Sealants.
- Waterproofing.
- Adhesives.
- Tile adhesives and grouts.
- Building products.
- Structural strengthening.

الخلاصة

المباني والهياكل الخرسانية المسلحة عند تعرضها للحريق يمكن أن تختلف فيها الصفات الخرسانية في حالة نشوب حريق خارج نطاق السيطرة. من الضروري معرفة كيف يمكن أن تتغير خصائص الخرسانة نتيجة التعرض لدرجات حرارة عالية وتحميل الخرسانة العادية مع / بدون تقوية الألياف. من المهم فهم خصائص قوة الهياكل الخرسانية المعرضة لدرجات حرارة عالية. من أجل التنبؤ بكيفية أداء هذه الهياكل بعد التعرض لهذه الحالة. لذلك، تركز هذه الدراسة على التحقيق في التأثير المشترك للتحميل ودرجة الحرارة المرتفعة على خصائص عينات الخرسانة من خلال اختبار قوة الانضغاط وقوة الانحناء واختبار سرعة الموجات فوق الصوتية (UPV)وعدد الارتداد للخرسانة ذات القوة العادية (NSC) مع / بدون (ألياف فولاذية أو ألياف بازلتية). تم استخدام نوعين من الألياف في هذه الدراسة، ألياف الفولاذية والبازلت. نوع الألياف الفولاذية المستخدمة في هذا البحث هو الألياف الفولاذية ذات النهايات المعقوفة بنسبة 1٪ من حجم الخرسانة بينما نوع الألياف البازلتية عبارة عن ألياف مقطعة بنسبة 1٪ من حجم الخرسانة.

تعرضت العينات الخرسانية لأربع حالات حمل ثابتة (20، 40، 60) ٪ من الحمل النهائي وتعرضت لدرجه حرارة الغرفة ودرجات حرارة مرتفعة (300، 500) درجة مئوية لمدة ساعتين تقريبًا. بالإضافة إلى ذلك، يتم استخدام فحوصات غير اتلافيه قبل وبعد التحميل وبعد التسخين. أشارت النتائج إلى أن الخسارة في مقاومة الانضغاط قليلة حيث لوحظت نسبة انخفاض مقاومة الانضغاط عند 300 درجة مئوية بين (6-16٪) و (6-10٪) و (16-19٪). بينما، عند درجة حرارة 500 درجة مئوية، تراوحت نسبة التدهور في مقاومة الانضغاط (14-36٪) و (22-23٪) و (17-22٪) للخلطات (BF1 , SF1, NSC) على التوالي لجميع حالات الحمل.
عند درجة حرارة 300 درجة مئوية، تكون النسبة المئوية لانخفاض قوة الانحناء بين (14-18٪)، (6-9٪) و (20-46٪) ، بينما عند درجة حرارة 500 درجة مئوية ، فإن النسبة المئوية لانخفاض قوة الانحناء بين (30-36٪) و (23-27٪) و (35-76٪) للخلطات (SF1, NSC , BF1)على التوالي لجميع حالات التحميل. أشارت النتائج أيضًا إلى أن المكعبات لا تظهر فرقًا معنويًا في سرعة النبض بالموجات فوق الصوتية للمخاليط (BF1 , SF1, NSC) في جميع حالات الحمل عند 300 درجه مئوية ، بينما عند 500 درجه مئوية ، يكون لمزيج NSC أعلى سرعة نبض بالموجات فوق الصوتية من SF1 و BF1 لـ (40٪ و 60٪) من الحمل. بالإضافة إلى ذلك، تم اكتشاف أن النسبة المئوية لتخفيض رقم الارتداد انخفضت بين (4-17٪) ، (7-

12٪) ، و (4-7٪) ، بينما عند درجة حرارة 500 درجة مئوية ، كانت انخفاض النسبة المئوية للارتداد بين (15-26٪) و (22-26٪) و (14-18٪) للخلطات (BF1 , SF1, NSC) على التوالي. تم اكتشاف أن ألياف البازلت تحسن مقاومة الانضغاط في درجات الحرارة العالية وتحت جميع ظروف التحميل، ومن ثم يفضل استخدامها في هذا المجال بدلاً من تحسين قوة الانثناء بالمقارنة مع استخدام أنواع أخرى من الألياف، كان أداء الألياف الفولاذية جيدًا في اختبارات الانحناء عندما يتعلق الأمر بمقاومة الأحمال ودرجات الحرارة المرتفعة.

جمهورية العـــــــــــــــــــراق
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التأثير المشترك للأحمال المفروضة ودرجة الحرارة المرتفعة على الخرسانة العادية والخرسانة المسلحة بالألياف.

رسالة

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