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Effect of Polypropylene and Steel Fibers on Fire Resistance of Ultra High Performance Concrete

تأثير إضافة ألياف البولي بروبيلين والألياف المعدنية على مقاومة الحريق للخرسانة فائقة الأداء

Prepared By

Ahmed Maher M. Seyam

Supervised By

Prof. Samir M. Shihada

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أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

" تأثير اضافة ألياف البولي بروبيلين و الألياف المعدنية على مقاومة الحريق للخرسانة فائقة الأداء"

"Effect of Polypropylene and Steel Fibers on Fire Resistance of Ultra High Performance Concrete"

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Signature: Seyam
Date: 29-12-2014

اسم الطالب: احمد ماهر صيام
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التاريخ: 29-12-2014

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **أحمد ماهر محمد صيام** لنيل درجة الماجستير في **كلية *الهندسة*** قسم **الهندسة المدنية– تصميم وتأهيل المنشآت** وموضوعها:

تأثير إضافة ألياف البولي بروبيلين والألياف المعدنية على مقاومة الحريق للخرسانة فائقة الأداء

Effect of Polypropylene and Steel Fibers on Fire Resistance of Ultra High Performance Concrete

وبعد المناقشة العلنية التي تمت اليوم الاثنين 07 ربيع الأول 1436هـ، الموافق 2014/12/29م الساعة الواحدة ظهراً بمبنى القدس، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

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٢٠١٥

أ.د. فؤاد علي العاجز

ABSTRACT

The main goal of this research is study the effect of polypropylene and steel Fibers on fire resistance of Ultra High Performance Concrete. Different trial mixes were used to obtain the effect of high temperature to different durations in the strength of mixes.

The research includes also the use of a recognized manufacturer mineral admixture, steel fibers, polypropylene, quartz sand, superplasticizers and without using any type of aggregates other than the quartz sand.

The effect of heating samples to 250 ºC and 500 ºC for 2.5 hours and 5 hours was studied for each mix and comparing the compressive and tensile strength among the mixes.

Results obtained showed that adding 0.75% of polypropylenes fibers and 16% of Steel fibers to the concrete mix, improved the fire resistance of the concrete mix by 50% and 150% when the samples exposed to 250 ºC and 500 ºC for 2.5 hours respectively, compared with concrete mix without fibers. More ones, fire resistance was improved by 77% and 153% when the samples exposed to 250 ºC and 500 ºC for 5 hours respectively.

Also results obtained showed that adding 16% of steel fibers only to the concrete mix, improved the fire resistance of the concrete by 58% and 85% when the samples exposed to 250 ºC and 500 ºC for 2.5 hours respectively, compared with concrete mixes without fibers. Fire resistance was improved by 57% and 88% when the samples exposed to 250 ºC and 500 ºC for 5 hours, respectively.

Also results showed that adding 0.75% of polypropylenes fibers only to the concrete mix, improved the fire resistance of the concrete by 27% and 72% when the samples exposed to 250 ºC and 500 ºC for 2.5 hours respectively, compared with concrete mixes without fibers. In addition, fire resistance was improved by 39% and 14% when the samples exposed to 250 ºC and 500 ºC for 5 hours, respectively.

ARABIC ABSTRACT

إن الهدف الرئيسي من هذا البحث هو دراسة تأثير اضافة ألياف البولي بروبلين و الألياف المعدنية على خواص مقاومة الحريق للخرسانة فائقة الأداء، حيث تم دراسة تأثير تعرض العينات الخرسانية للخلطات المختلفة لدرجات الحرارة العالية ولمدة زمنية مختلفة.

للوصول لهدف البحث تم تجهيز عدة خلطات خرسانية باستخدام الألياف المعدنية وألياف البولي بروبيلين ورمل الكوارتز بالإضافة لبعض الملدنات ودون استخدام أي نوع من انواع الحصويات بخلاف الرمل.

فقد تم دراسة تأثير تعرض الخرسانة لدرجة حرارة 250 درجة مئوية و 500 درجة مئوية لمدة ساعتين ونصف و لخمس ساعات و مقارنة قوة الخرسانة بعد تعرضها لتلك الحرارة مع العينات التي لم يتم تعريضها لدرجات الحرارة العالية، بالإضافة لتسجيل نتائج كل فحص لكل نوع من الخلطات و تحديد الخلطات التي ابدت اعلى مقاومة للحريق ودرجات الحرارة العالية.

وقد بينت النتائج بأن اضافة 0.75% من الياف البولي بروبلين و 16% من الألياف المعدنية للخلطة الخرسانية ساهمت في زيادة مقاومة الخرسانة للحريق بما لا يقل عن 50% و 150% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية –بالترتيب- لمدة ساعتين و نصف مقارنة بتلك الخلطات الخالية من الألياف المعدنية وألياف البولي بروبلين، كما زادت مقاومة الحريق بما لا يقل عن 77% و 153% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية بالترتيب لمدة خمس ساعات.

كما بينت النتائج بأن اضافة الألياف المعدنية وحدها بنسبة 16% الى الخلطة الخرسانية زادت من مقاومة الخرسانة للحريق بنسبة 58% و 85% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية لمدة ساعتين ونصف و بنسبة 57% و 88% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية لمدة خمس ساعات.

كذلك بينت النتائج بأن اضافة ألياف البولي بروبلين وحدها بنسبة 0.75% الى الخلطة الخرسانية زادت من مقاومة الخرسانة للحريق بنسبة 27% و 72% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية لمدة ساعتين ونصف و بنسبة 39% و 14% عند تعرضها لدرجة حرارة 250 و500 درجة مئوية لمدة خمس ساعات.

DEDICATIONS

To …

- The Teacher of all teachers, ***Muhammad***, Mercy be upon him.
- The Soul of all Martyrs.
- My Beloved Country which My Hearts are hung to "***Palestine***"
- The Symbol of Sacrifice, Faith and Giving, "***My Father***"
- The Moon is Jealous from the light of their faces; Allah made Paradise under their feet, their Blessings are the secret of my success "***My Mother***"
- The Fine Hearts that my Happiness cannot be completed without them, those who shared my Happiness and Sadness all my live "***my Brothers & Sisters***"
- My meritorious supervisor "***Prof. Samir Shihada***".
- My friends, and to whom I belong.
- My work colleagues at "***Skills and Quality Construction Co***.".

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INTRODUCTION

Chapter 1

Introduction

1.1 General Background

Reinforced concrete is the most commonly used construction material worldwide. High performance concrete (HPC) is a novel construction material with improved properties like higher strength, longer durability, and higher workability etc. than conventional concretes **(Aïtcin, 1998)**. Concrete with increased strength and durability has been primarily used in special constructions such as high rise buildings, infrastructures and nuclear power plants since it became commercially available **(Akca and Zihnioğlu, 2013)**.

High strength concrete offers various benefits derived from its higher strength and stiffness. In the last few years, the use of high strength concrete has become increasingly popular. A greater understanding of its behavior under different conditions will improve confidence in its use. As the use of high strength concrete becomes common, the risk of exposing it to elevated temperatures also increases. In order to predict the response of structures employing high strength concrete during and after exposure to elevated temperatures, it is essential for the microstructural properties of high strength concrete subjected to elevated temperatures to be clearly understood **(Noumowe, 2005)**.

Ultra High Performance Fiber Reinforced Concrete is a newly developed material that has gained more interest in the concrete construction industry. Fibers added to concrete improve its mechanical properties, reduce its plastic shrinkage, improves its resistance to fire, to abrasion and to impact and decrease its permeability. With such material, engineers are able to design new structures, original in their design or their ability to resist severe conditions.

Materials such as: steel fibers, silica fume, Polypropylene fibers and Superplasticizers will be used to produce these types of concrete.

Since the strength development and durability characteristics of high-performance concrete may be different from ordinary concrete, it follows that actual performance of UHPC using steel fibers and polypropylene under elevated temperature should be studied. Since high-performance concrete is a relatively new class of concrete, additional research is needed to understand more fully the factors affecting the development of its physical and mechanical characteristics. Thus, one of the critical aspects for the successful production of high-performance concrete is to know the main components affecting the production of UHPC and their proportions. Eventually, design codes will need to be revised to incorporate the necessary requirements for the safe and efficient use of high-performance concrete.

1.2 Statement of the problem

A- The damage caused by fire is one of the most serious problems that faces civil engineers, especially in countries that are susceptible to wars and enemy fighting such as Gaza Strip. During the last war perpetrated by the Israelis on Gaza Strip, large number of buildings were subjected to fires lasting for long periods of time. Some of these buildings are repairable, while others are beyond repair and need to be demolished and reconstructed. Also while the activity of concrete rehabilitation or reconstruction usually takes place in areas which are more exposed to fire risk. In these cases, a special type of concrete should be used.

B- The usage of ultra-high strength concrete with high compressive strength in construction applications has been increasing worldwide and will make an impact on Gaza strip construction industry due to the limited land area available for construction and the fast growing population. High-rise reinforced concrete multistory buildings have increasingly used, where the large loads in high rise buildings lead to the design of large sections when ordinary concretes are used. But when ultra-high performance fiber reinforced concrete is used, small cross sections can be designed. Also, this type of concrete will be used in rehabilitation techniques.

1.3 Research objectives

The main goal of this research is to produce Ultra High Performance Fire Resistant Concrete (UHPFRC) in Gaza strip using available materials and to study the effect of polypropylene and steel Fibers on improving fire resistance of Ultra High Performance Concrete. This will open new possibilities for the production of a new material, locally. This can be achieved through the following objectives:

1- Study the effect of using polypropylene fibers on fire resistance of UHPC.
2- Study the effect of using steel fibers on fire resistance of UHPC.
3- Study the effect of using polypropylene and steel fibers combined on fire resistance of UHPC.

1.4 Methodology:

In general, the following methodology is to be followed:

1- Conduct comprehensive literature review related to subject of UHPFRC.
2- Selection of suitable local available materials required for producing UHPFRC, including cement, silica fume, steel fibers, polypropylene fibers and plasticizers.
3- Determine the mix proportions for producing UHPFRC.
4- Performing physical and mechanical laboratory tests on UHPFRC samples.
5- Analyze the results and draw conclusion.

1.5 Scope of work

This research intends to produces UHPFRC in the IUG lab and to investigate the fresh and hardened properties of this type of concrete.

a. Characteristics of fresh (UHPFRC)

In order to obtain the characteristics of fresh UHPFRC, the following aspects are considered:

- Mix design.
- Workability.
- Homogeneity (No separation/ segregation).

b. Characteristics of hardened (UHPFRC)

The following tests are carried out in order to establish the mechanical properties of UHPC subjected to various heating temperature:

- Compressive strength.
- Flexural strength.
- Hardened density.

1.6 Thesis structure:

The research consists of five chapters arranged as shown below. This section presents a brief description of these chapters.

- **Chapter 1 (Introduction)**

This chapter gives general background about UHPFRC, statement of problem, goals and objectives of the research, scope of work and the methodology adopted.

- **Chapter 2 (Literature Review)**

This chapter gives general review of previous research related to UHPFRC and the main materials used, advantages and disadvantages and applications.

- **Chapter 3 (Constituent Materials and Experimental Program)**

This chapter discusses types of laboratory tests, standards, adopted procedures, materials properties, curing condition and schedules of the testing program.

- **Chapter 4 (Results and Discussion)**

Test results and analysis of results are discussed.

- **Chapter 5 (Conclusion and Recommendations)**

General conclusion and recommendations from this research work are stated.

- **(References)**
- **(Appendices)**

CHAPTER 2

LITERATURE REVIEW

Chapter 2

Literature Review

2.1 General Definition of Ultra High Performance Fire-Resistant Concrete

2.1.1 High strength concrete and Ultra-high-performance concrete

Concrete with compression strength exceeding 40 MPa are referred to as high strength concrete. Another name sometimes given to them is high performance concrete because they have other excellent characteristics beside its high strength. For instance, the low permeability of such concrete causes them to be quite durable as regards the various physical and chemical agent on them may cause material to deteriorate.

Up until few decades ago, structural designers felt that ready mix companies could not deliver concretes with compressive strength higher than 27 or 35 MPa. This situation, however, is no longer the case as these companies can today deliver concrete with compressive strength up to at least 40 MPa. At Two Union Square in Seattle 130 MPa concretes have been produced in laboratories. Perhaps these latter concretes should be called High performance concrete or super high performance concrete **(McCrommac and Russell, 2009)**.

2.1.2 Fiber Reinforced Concrete (FRC)

FRC is a concrete containing fibrous material, which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities.

Fiber-cement products had been widely used in the world due to their versatility as corrugated and flat roofing materials, cladding panels, and water containers presented in large number of buildings and agriculture applications **(Ikai et al., 2010)**. The main reason for incorporating fibers into the cement matrix is to improve the toughness, tensile strength, and the cracking deformation characteristics of the resultant composite. It is well known that polymer synthetic fibers, like polyvinylalcohol

(PVA) and polypropylene (PP) fibers, lead to the improvement of the post peak ductility performance, performance under fatigue, impact strength, and also help to reduce the shrinkage cracking **(Tonoli et. al, 2011)**.

2.1.3 Ultra High Performance Fiber Reinforced Concrete

Ultra-High Performance Fiber Reinforced Concrete is a combination of high strength concrete and fibers. In particular, it is a superplasticized concrete, reinforced with fibers, with an improved homogeneity because traditional coarse aggregates are replaced with fine sand, Ultra-High Performance Fiber Reinforced Concrete represents the highest development of High Performance Concrete (HPC) and its ultimate compressive strength depends on the curing conditions (either standard, steam or autoclave curing), possible thermal treatments as well as on the adopted manufacturing technique, and its value could rise up to 800 MPa in the case of compressive molding. For the production of UHPC or Ultra-High Performance Fiber Reinforced Concrete a large amount of cement is normally used **(Yu et al., 2013)**.

2.1.4 Fire Resistant Concrete

Fire resistance can be defined as the ability of structural elements to withstand fire or to give protection from it. This includes the ability to confine a fire or to continue to perform a given structural function, or both. Fire resistance rating (or fire rating), is defined as the duration of time that an assembly (roof, floor, beam, wall, or column) can endure a “standard fire” as defined in **ASTM E119**.

It's commonly understood in the building industry that concrete is the most fire-resistant building material in everyday use. Because of concrete's high specific heat capacity, a fire will generally not cause a rapid increase in its temperature and may not cause significant damage. Even so, it's necessary to evaluate all structures after a fire event **(Bilow and Kamara, 2008)**.

2.1.4.1 Advantages of using concrete as a fire resistant structural material (Bilow and Kamara, 2008)

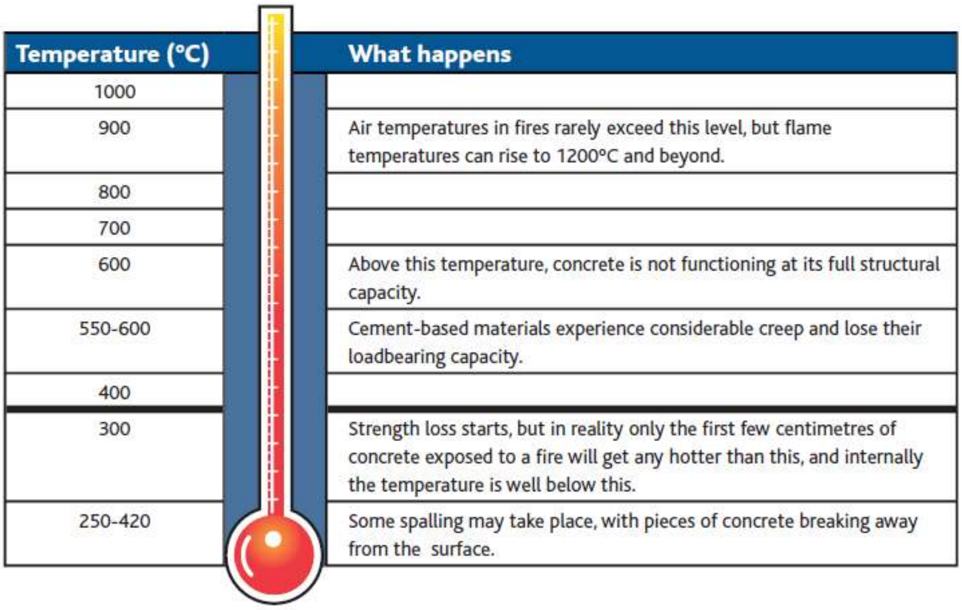
- Concrete is non-combustible (i.e. it does not burn).
- Concrete is inherently fire resistant (i.e. it does not support the spread of fire).
- Concrete has a slow rate of heat transfer (making it an effective fire shield).
- Concrete does not produce any smoke, toxic gases or emissions in a fire situation.

- Concrete does not contribute to the fire load of a building.
- Under typical fire conditions, concrete retains most of its strength.
- Polypropylene fibers can be used to prevent spalling.
- Skillful mix design further refines concrete’s inherent performance.
- For the vast majority of applications, concrete does not require any additional, costly fire proofing measures.
- Concrete has been given the highest possible material classification for its fire resistance.
- Connections designed using concrete are more robust in a fire situation.
- Concrete mixes can be designed to cater for extreme fire loads.

2.1.4.2 Concrete under elevated temperature

Fire poses one of the most severe risks to buildings and structures **(Lau and Anson, 2006).** With development in materials and application of HPC, understanding of its behavior when subjected to fire is needed to guarantee its safe application. HPC exhibits inferior thermal behavior with its dense and complex microstructure, which yet has been not been fully understood. This is a threat to HPCs application in many types of engineering structures such as high rise buildings, bridges, tunnels, offshore platforms, nuclear reactor, power industries, other forms of infrastructures etc. and risk to the human society **(Chan et al., 1999, Peng and Huang, 2006)**. As HPC is exposed to elevated temperatures in an accidental building fire, sabotages, or a natural hazard, its mechanical properties such as concrete strength and modulus of elasticity may decrease with increasing temperature remarkably, crack developments result in undesirable fractures and explosive spalling seems to increase with decreased permeability, increased moisture content compared with conventional concrete when exposed to same heating condition **(Husem 2006, Phan and Carino 1998).**

The behavior of HPC in fire depends on factors like the type of aggregate, pozzolonic material, fiber used in its composition, the temperature and duration of the fire, type of cooling, sizes of structural members, and presence of moisture in concrete. The HPC behavior at elevated temperature plays a vital role in design of concrete structures for fire resistance and to ensure the serviceability at elevated temperatures. When Concrete is exposed to high temperature of fire, a number of physical and chemical changes can take place. These changes are shown in Figure 2.1, which relates temperature level within the concrete to some indicative change in properties.



Temperature (°C)	What happens
1000	
900	Air temperatures in fires rarely exceed this level, but flame temperatures can rise to 1200°C and beyond.
800	
700	
600	Above this temperature, concrete is not functioning at its full structural capacity.
550-600	Cement-based materials experience considerable creep and lose their loadbearing capacity.
400	
300	Strength loss starts, but in reality only the first few centimetres of concrete exposed to a fire will get any hotter than this, and internally the temperature is well below this.
250-420	Some spalling may take place, with pieces of concrete breaking away from the surface.

Figure 2.1: Physiochemical Process **(Khoury, 2000)**

2.2 Advantages of using fibers in UHPC

The mechanical properties of normal-strength concrete (NSC), high-strength concrete (HSC) and ultra high performance concrete (UHPC) decline gradually with the increasing temperature, and there is explosive spalling occurring in the heating process of HSC. Steel fibers and polypropylene fibers mixed in UHPC can effectively prevent spalling and improve the residual mechanical properties of UHPC after high temperature. Through elimination of the coarse aggregates and reducing the water-to-cementations material ratio, Reactive Powder Concrete (RPC) has the denser internal structure than HSC, so RPC is more prone to spalling under the effect of high temperature. The same with UHPC, HSC, RPC mixed with steel fibers and polypropylene fibers can also enhance its capacity in resistance to high temperature **(Zheng et al., 2012)**.

2.3 Advantages of using polypropylene fibers to improve fire resistant

(Noumowé et al., 2009) carried out an experimental investigation to predict the behavior of concrete intended for nuclear applications. For this purpose, normal concrete having compressive strength of 40MPa was designed using limestone aggregates and subjected to heating–cooling cycles at 110, 210 and 310 °C. The behavior of concrete at high temperature was compared to that at ambient temperature. The results obtained showed that concrete containing limestone aggregates could be possibly used in applications involving elevated temperatures. Also, there was no significant deterioration of the mechanical properties of the concrete between 20 and 110 °C; and the reduction in compressive strength values remained lower than 40% of the initial value even after a temperature of 310 °C.

(Tanyildizi and Çevik, 2009) studied the effect of polypropylene fiber and silica fume on the mechanical properties of lightweight concrete exposed to high temperatures, experimentally and statistically. The mixes containing silica fumes (0% and 10%) and polypropylene fibers (0%, 0.5%, 1% and 2%) were prepared. The compressive and flexural strength of lightweight concrete samples were determined after being exposed to high temperatures (400, 600 and 800 °C). Three control factors (silica fume percentage, polypropylene fiber percentage and high temperature degree) were used for this study. He demonstrated that the compressive and flexural strength of polypropylene fiber reinforced lightweight concrete drops with temperature starting from 400 °C. The test results indicated that each temperature range had a distinct pattern of strength loss.

(Komonen and Penttala, 2003) investigated the effect of high temperature on the residual properties of plain and polypropylene fiber reinforced Portland cement paste. Plain Portland cement paste having water/cement ratio of 0.32 was exposed to the temperatures of 20, 50, 75, 100, 120, 150, 200, 300, 400, 440, 520, 600, 700, 800, and 1000 °C. Paste with polypropylene fibers was exposed to the temperature of 20, 120, 150, 200, 300, 440, 520, and 700 °C. Residual compressive and flexural strengths were measured. The gradual heating coarsened the pore structure. At 600 °C, the residual compressive capacity (fc_{600} °C/fc_{20} °C) was still over 50% of the original. Strength loss due to the increase of temperature was not linear. Polypropylene fibers produced a finer residual capillary pore structure, decreased compressive strengths, and improved residual flexural strengths at low temperatures. According to the tests, it seems that exposure temperatures from 50 °C to 120 °C can be as dangerous as exposure temperatures 400–500 °C to the residual strength of cement paste produced by a low water cement ratio.

2.4 Advantages of using Steel fibers to improve fire resistant

(**Tai et al., 2011**) investigated the stress–strain relation of RPC in quasi-static loading after an elevated temperature. The cylinder specimens of RPC are examined at the room temperature and after 200-800 °C. Experimental results indicate that the residual compressive strength of RPC after heating from 200–300 °C increases more than that at room temperature, but, significantly decreases when the temperature exceeds 300 °C. The residual peak strains of RPC also initially increase up to 400-500 °C, then decrease gradually beyond 500 °C. Meanwhile, Young's modulus diminishes with an increasing temperature. Based on the regression analysis results, this study also develops regression formulae to estimate the mechanical properties of RPC after an elevated temperature, thus providing a valuable reference for industrial applications and design.

An experimental research is performed on the complete compressive stress-strain relationships for reactive powder concrete (RPC) with various steel fiber contents after exposure to 20-900 °C. The steel fiber volume dosage is 1%, 2% and 3%. The results indicate that the compressive strength and elastic modulus of RPC increase at first, then decrease with the increasing temperature, and the loss of elastic modulus is quicker than the compressive strength. The peak strain and ultimate strain reach peaks at 600 °C and 700 °C respectively, and they increase exponentially before the peak points, but decrease linearly after the peak points **(Zheng et al., 2012)**.

After being subjected to different elevated heating temperatures, ranging between 105°C and 1200 °C, the compressive strength, flexural strength, elastic modulus and porosity of concrete reinforced with 1% steel fiber (SFRC) and changes of color to the heated concrete have been investigated. The results show a loss of concrete strength with increased maximum heating temperature and with increased initial saturation percentage before firing. For maximum exposure temperatures below 400°C, the loss in compressive strength was relatively small. Significant further reductions in compressive strength are observed, as maximum temperature increases, for all concretes heated to temperatures exceeding 400 °C.

High performance concretes (HPC) start to suffer a greater compressive strength loss than normal strength concrete (NSC) at maximum exposure temperatures of 600 °C. It is suggested that HPC suffers both chemical decomposition and pore-structure coarsening of the hardened cement paste when C–S–H starts to decompose at this high temperature. Strengths for all mixes reached minimum values at 1000 or 1100 °C. No evidence of spalling was encountered. When steel fibers are incorporated, at 1%, an improvement of fire resistance and crack, resistance as characterized by the residual strengths were observed. Mechanical strength results indicated that SFRC performs better than non-SFRC for maximum exposure temperatures below 1000 °C, even though the residual strength was very low **(Lau and Anson, 2006)**.

2.5 Advantages of using Steel fibers and Polypropylene fibers to improve fire resistant

(Pliya et al., 2010) studied the contribution of cocktail of polypropylene and steel fibers in improving the behavior of high strength concrete subjected to high temperature. Concrete mixes were studied by adding polypropylene fibres, steel fibres and cocktail of fibres. The concrete specimens were subjected to various heating–cooling cycles. The initial and residual mechanical properties, the porosity and the mass loss of the studied concrete mixes were investigated. Different concretes compositions with various amounts of polypropylene and/or steel fibres were tested. Experimental results show the significant improvement of the residual mechanical properties of concretes containing the cocktail of fibres compared to concretes without fibres.

(Sideris et al., 2008) investigated the performance of thermally damaged fibre reinforced concretes. In this study, three different concretes were prepared: a normal strength concrete (NSC) and two High Performance Concretes (HPC1 and HPC2). Fibre reinforced concretes were produced by addition of steel or polypropylene fibers in the above mixtures at dosages of 40 kg/m^3 and 5 kg/m^3, respectively. A total of nine concrete mixtures were produced and fibers were added in six of them. At the age of 120 days, specimens were heated to maximum temperatures of 100, 300, 500 and 700 °C. Specimens were then allowed to cool in the furnace and tested for compressive strength, splitting tensile strength, modulus of elasticity and ultrasonic pulse velocity. Reference tests were also performed at air temperature (20 °C). Residual strength of NSC and HPC1 was reduced almost linearly up to 700 °C and 500 °C, respectively whereas the residual strength of HPC2 was sharply reduced up to 300 °C. Explosive spalling was observed on both HPC. Addition of steel fibers increased the residual strength up to 300 °C, but spalling still occurred in HPC1 and HPC2. Such an explosive behavior was not observed when polypropylene fibers were added in the mixtures; however, in this case the residual mechanical characteristics of all concretes were significantly reduced.

2.6 Previous related studies carried out in IUG lab

(Shihada, 2011) examined the impact of polypropylene fibers on fire resistance of concrete by heating samples to 200°C, 400°C and 600°C for exposure up to 6 hours. He was concluded that the relative compressive strengths of concretes containing polypropylene fibers were higher than those of without polypropylene fibers. The optimum percentage of polypropylene for use in improving fire resistance of concrete was 0.45 kg/m^3. For a temperature of 600°C sustained for 6 hours, the loss in compressive strength was about half of that loss when polypropylene fibers were not used.

(Shihada and Arafa, 2012) examined the impact of polypropylene fibers on fire resistance of steel reinforced concrete beams., concrete mixtures are prepared by using different contents of polypropylene; 0, 0.45 and 0.67 kg/m^3. Simply supported beams are heated in an electric furnace to a temperature of 400° for exposure up to 4.5 hours and tested under a static point load on a universal loading frame. The researchers concluded that the ultimate residual strengths of RC beams containing polypropylene fibers are higher than those without polypropylene fibers. Furthermore, the researchers find out that RC beams which are prepared using 0.67 kg/m^3 of polypropylene fibers can significantly promote the residual ultimate strengths during heating.

(Arafa et al., 2013) carried out an experimental tests to produce Ultra High Performance Fiber Reinforced Self Compacting Concrete UHPFRSCC using materials available at the local markets of Gaza strip, They concluded that self compacting concrete with compressive strength of 177 MPa at the age of 28 days can be produced with W/C ratio of 0.24, steel fibers (16% by the weight of cement), polypropylene fibers (0.9 Kg/m^3), quartz sand, and silica fume (15% by the weight of cement) as the mineral admixture (3% superplasticizer by the weight of cement).

2.7 Full-Scale Experiments For Fire Resistant Concrete

Since the mid 1900s, a large number of large-scale standard fire resistance tests have been performed on reinforced concrete structural elements in standard fire testing furnaces [e.g. ISO 1999, ASTM 2011]. Various prior research needs assessments have highlighted a large number of deficiencies associated with such tests and have identified a range of general structural fire engineering research needs which have yet to be properly addressed.

In addition to standard furnace tests, a smaller number of ad-hoc, non-standard structural fire tests performed in laboratories have also been presented in the literature. Several authors have presented results from fire tests on concrete elements or assemblies using custom made or modified standard furnaces to study specific structural response issues or specific types of concrete structures which cannot be easily investigated using a standard ‘single element’ approach. For instance, **(Herberghen and Damme, 1983)** used a modified standard floor furnace to study the fire resistance of post-tensioned continuous (unrestrained) flat floor slabs with unbonded prestressing tendons in standard fire conditions; **(Kordina, 1997)** used a modified floor furnace to investigate the punching shear behavior of reinforced concrete flat slabs in standard fire conditions; **(Kelly and Purkiss, 2008)** used an oversized floor furnace to study the fire resistance of simply-supported, partly-restrained, long-span post-tensioned concrete slabs under standard fire exposure; **(Li-Tang et al., 2008)** studied the structural fire behavior of model-scale, three-span continuous unbonded post-tensioned concrete slab strips in a custom built furnace subject to a standard fire; **(Zheng et al., 2010)** performed a series of standard fire tests on two-span, continuous post-tensioned concrete slabs in a furnace with a central support built inside the heating chamber; and **(Annerel et al., 2011)** used a modified standard floor furnace to perform punching shear tests on concrete slabs subjected to a standard fire. Several other examples are available in the literature however an exhaustive summary is avoided here.

Only one large-scale natural fire test of a ‘real’ multi-storey concrete building appears to have ever been performed. **(Bailey, 2002)** presented the results of a natural fire test on a full-scale, seven-storey cast in-place concrete building that was performed at the UK Building Research Establishment (BRE) Cardington test site. The full-scale building was a concrete frame three bays by four bays. It had two cores that incorporated cross bracing for lateral load support, and the floor slab was 250 mm thick. The main aim of the test was to investigate the behavior of a full-scale concrete building during a realistic compartment fire, under sustained design load. (Bailey, 2002) states that the test aimed to:

- Investigate how the whole building resisted or accommodated large thermal expansions from the heated parts of the structure (lateral thermal expansion of the floor slab in particular).
- Identify both beneficial and detrimental modes of whole building behavior that cannot be observed through standard furnace tests on isolated structural elements.
- Investigate the effects of concrete spalling and its possible significance on whole building response.
- Compare test results and observations from large-scale fire tests with current methods of SFE design.

A fire compartment was built into an edge bay of the building with an area of 225 m^2 between the ground and first floor. One internal column was exposed to the fire and eight additional columns were partially exposed to the fire. The columns were made from high strength concrete (103 MPa cube strength), incorporating 2.7 kg/m^3 of polypropylene (PP) fibers to prevent explosive spalling.

Two further large-scale non-standard structural fire tests were also performed to study the performance of hollowcore concrete slabs resting on steel beam flooring systems **(Bailey and Lennon, 2008)**. These were performed after worrying results from tests and incidences of failures of hollowcore slabs during real building fires in Europe **(Acker, 2003 and Feijter et al., 2007)**. The tests were intended to demonstrate that tying together and grouting of hollowcore slabs could prevent premature shear failure (this having been observed in smaller scale tests on hollowcore slabs).

The fire compartment was 7.0 m × 17.8 m in plan with a height of 3.6 m. Fifteen 1200 mm wide × 200 mm hollowcore slabs, with concrete compressive strength of 85 MPa and moisture content of 2.8% by mass, were placed in a single row to form the compartment roof. The slabs were loaded with sandbags and exposed to a natural fire using 32.5 kg/m^2 of wooden cribs; the intent being to follow the ISO 834 [ISO 1999] standard fire for the first 60 minutes. Observations and conclusions were that (Bailey and Lennon 2008):

- Properly designed and detailed hollowcore floor systems behave well when subjected to severe fire scenarios, as well as during the *cooling phase* of the fire.
- Edge units fractured during the cooling phase however this did not lead to loss of load bearing capacity.
- No significant spalling of the units was observed.
- Different end restraint conditions did not affect the measured vertical displacement, however restraint conditions kept outer portions of the edge slab in place when it fractured along its length.
- There was evidence of a lateral compressive strip forming at the ends of the units caused by restraint to thermal expansion; thus may have enhanced the flexural and shear capacity of the slabs.

Large-scale non-standard fire tests on unloaded and loaded concrete columns and unloaded post-tensioned concrete slabs in real fires have also been reported by **(Wong et al., 2011)** and **(CCAA, 2010)**, however neither of these studies is particularly scientific or instructive. The CCAA tests in particular aimed (but largely failed) to assess the magnitude and extent of spalling for various types of Australian aggregates in a real fire, and to provide guidance on possible measures to limit its effects.

(Ring et al., 2011) presented limited results of four large-scale non-standard fire tests on ‘frame-like’ concrete structures performed to investigate redistribution of loading within reinforced concrete structures subjected to fire. These tests were designed to provide data for the development, assessment, and validation of numerical tools for predicting the structural response of concrete tunnels in fire. Triangular tubular frames were constructed on slope and loaded to simulate a soil overburden. Two of these frames incorporated PP fibers in their concrete mix. Oil burners were used to heat the atmosphere inside the tubes to 1200 °C in nine minutes and remaining at 1200 °C for three hours. These tests are not particularly helpful in studying the fire resistance of buildings; however, they do provide data for validation of computational models and they clearly demonstrate the benefits of PP fibers in preventing heat-induced spalling.

In general the available non-standard testing of concrete structures presented above shows that the behavior of concrete in fire is considerably more complicated than would be assumed on the basis of the available prescriptive guidance, which typically prescribes only overall member dimensions and minimum concrete cover. This may present possible benefits and/or risks for concrete structures in fire. Whole building response has not been widely investigated for concrete buildings.

Some laboratories, such as BAM (Germany), NRC (Canada) and CERIB (France) are able to carry out Hybrid Fire Testing (HFT). HFT couples physical tests on part of a structure with real-time computational simulation of the rest of the structure **(Mostafaei, 2013).** HFT allows reproduction, in a more realistic way, of the boundary conditions and the applied external loads during a fire. However, HFT is not yet widely accepted or properly validated for whole frame reinforced concrete structures **(Mostafaei, 2014)**.

2.8 Materials of Ultra High Performance Fire Resistance Concrete (UHPFRC)

Materials used for producing Fire Resistant UHPC are those used for producing UHPC and UHPSCC, except that Fire Resistant UHPC contain a different percentage of steel fibers and polypropylene fibers, no large aggregates, although containing large amounts of binder (i.e. cement). Silica fume, quartz powder …etc. are used as filler materials.

To ensure and improve high workability properties, without causing segregation; Large amounts of superplasticizers are to be used.

2.8.1 Portland Cement

Portland cement concrete is foremost among the construction materials used in civil engineering projects around the world. The reasons for its often use are varied, but among the more important are the economic and widespread availability of its constituents, its versatility, and adaptability, as evidenced by the many types of construction in which it is used, and the minimal maintenance requirements during service life.

2.8.1.1 Hydration of Portland cement

When Portland cement is mixed with water, its constituent compounds undergo a series of chemical reactions that are responsible for the eventual hardening of concrete. Reactions with water are designated hydration, and the new solids formed on hydration are collectively referred to as hydration products. (Figure 2.2) shows schematically the sequence of structure formation as hydration proceeds. This involves the replacement of water that separates individual cement grains in the fluid paste (Figure 2.2.a) with solid hydration products that form a continuous matrix and bind the residual cement grains together over a period of time, as illustrated in (Figure 2.2 b, d) .The calcium silicates provide most of the strength developed by Portland cement. C_3S provides most of the early strength in the first three to four weeks and both C_3S and C_2S contribute equally to ultimate strength (**Mindess, et al., 2002**).

The hydration reactions of the two calcium silicates are very similar, differing only in the amount of calcium hydroxide formed as seen in the following equations: (**Mindess et al., 2002**).

$$\mathbf{2C_3S \quad + \quad 11H \quad \rightarrow \quad C_3S_2H_8 \quad + \quad 3\,CH}$$

Tricalcium silicate water calcium silicate hydrate calcium hydroxide

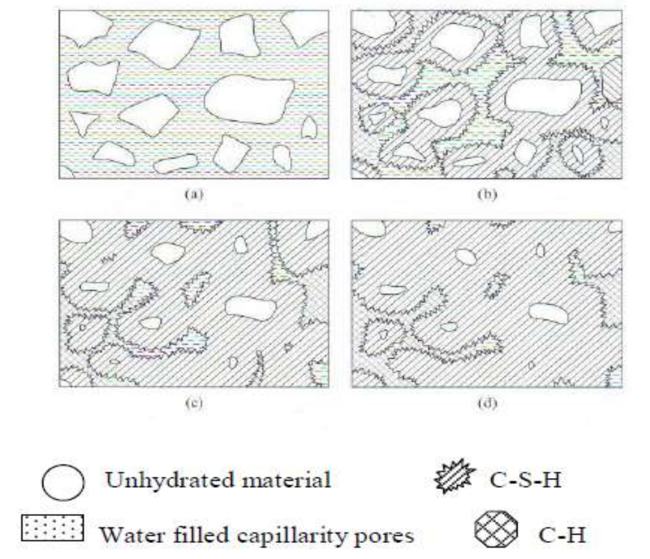


Figure 2.2: Microstructure development in Portland cement pastes

$$\underset{\text{dicalcium silicate}}{\mathbf{2C_2S}} \quad + \quad \underset{\text{water}}{\mathbf{9H}} \quad \rightarrow \quad \underset{C-S-H}{\mathbf{C_3S_2H_8}} \quad + \quad \underset{\text{calcium hydroxide}}{\mathbf{CH}}$$

C-S-H or $C_3S_2H_8$ is called calcium silicate hydrate and is the principal hydration product.

The formula $C_3S_2H_8$ is only approximate because the composition of this hydrate is actually variable over quite a wide range.

In Portland cement, the hydration of tricalcium aluminate C_3A involves reactions with sulfate ions that are supplied by the dissolution of gypsum, which is added to temper the strong initial reaction of C_3A with water that can lead to flash set. The primary initial reaction of C_3A is as follows:

$$\underset{\text{tricalcium aluminate}}{\mathbf{C_3A}} \quad + \quad \underset{\text{gypsum}}{\mathbf{3\ CSH_2}} \quad + \quad \underset{\text{water}}{\mathbf{26H}} \quad \rightarrow \quad \underset{\text{ettringite}}{\mathbf{C_6AS_3H_{32}}}$$

Where S is equivalent to SO_3 and ettringite is a stable hydration product only while there is an ample supply of sulfate available.

2.8.1.2 Cement grains Size Distribution, Packing and Dispersion

Portland cements are ground to a rather narrow range of particle sizes, varying only from about 1μ m to about 85 μm, with a mean size of the order of 82 to 85 μm. Cements are ground slightly finer, but not much. the mean size being of the order of 9 to 85μ m. In visualizing the state of the flocculated mass of cement grains in fresh Portland cement mixes, it appears that the variation in particle size between larger and smaller cement particles does not result a dense packing. To a considerable extent this is due to the flocculated character particles once bumped together are "stuck" together by forces of attraction cannot readily slide to accommodate each other better. However, even if they could, they are far too close to being of the same order of size to be able to form dense local mixes. Water filled pockets of roughly the same size as the cement particles exist throughout the mass (**Neville, 1993**).

It is obvious that what is needed is an admixture of much finer particles to pack into the water filled pockets between the cement grains. Silica fume (or "micro silica") provides such particles, the mean particle size of commercial silica fume being typically less than 0.2 μm. When micro silica is added to ordinary cement paste a denser packing that may be ensued. In order to get the desired state of dense particle packing, not only must the fine particles be present, but must be effectively deflocculated during the mixing process. Only then can the cement particle move around to incorporate the fine micro silica particles. The fine micro silica particles must themselves be properly dispersed so that they can separate from each other and pack individually between and around the cement grains. Another requirement for best packing is that the mixing used be more effective than the relatively usual mixing done in ordinary concrete production. High shear mixers of several kinds have been explored. Proper dispersion and incorporation of fine micro silica particles thus can results in a dense local structure of fresh paste with little water-filled space between the grains. When the cement hydrates, the overall structure produced in the groundmass is denser, tighter, and stronger (**Young and Menashi, 1993**).

2.8.2 Silica Fume

Silica fume is an ultra fine powder, with individual particle sizes between 50 and 100 times finer than cement, comprising solid spherical glassy particles of amorphous silica (85-96 percent SiO_2). However, the spherical particles are usually agglomerated so that the effective particle size is much coarser. Silica fume, also known as microsilica, which is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferro-ilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete **(ACI 548.6R)**.

2.8.2.1 The pozzolanic reactions

In the presence of hydrating Portland cement, silica fume will react as any finely divided amorphous silica-rich constituent in the presence of (CH) the calcium ion combines with the silica to form a calcium-silicate hydrate through the pozzolanic reaction. (Figure 2. 3)

$$\underset{\text{Portland cement}}{(C_3S + C_2S)} \quad + \quad \underset{\text{Water}}{H} \quad \rightarrow \quad C\text{-}S\text{-}H + CH + \underset{\text{Silica}}{S} \rightarrow C\text{-}S\text{-}H$$

The simplest form of such a reaction occurs in mixtures of amorphous silica and calcium hydroxide solutions.

(**Buck and Burkes, 1981**) studied the reactivity of silica fume with calcium hydroxide in water at 38 C. Silica fume to calcium hydroxide ratios (SF:CH) 2:1, 1:1 and 1:2.25 were included. They found that a well-crystallized form of CSH was formed by 7 days of curing. For the 2:1 mixtures, all CH was consumed by 7 days; for the 1:1 mixtures, 28 days was required to consume the CH.

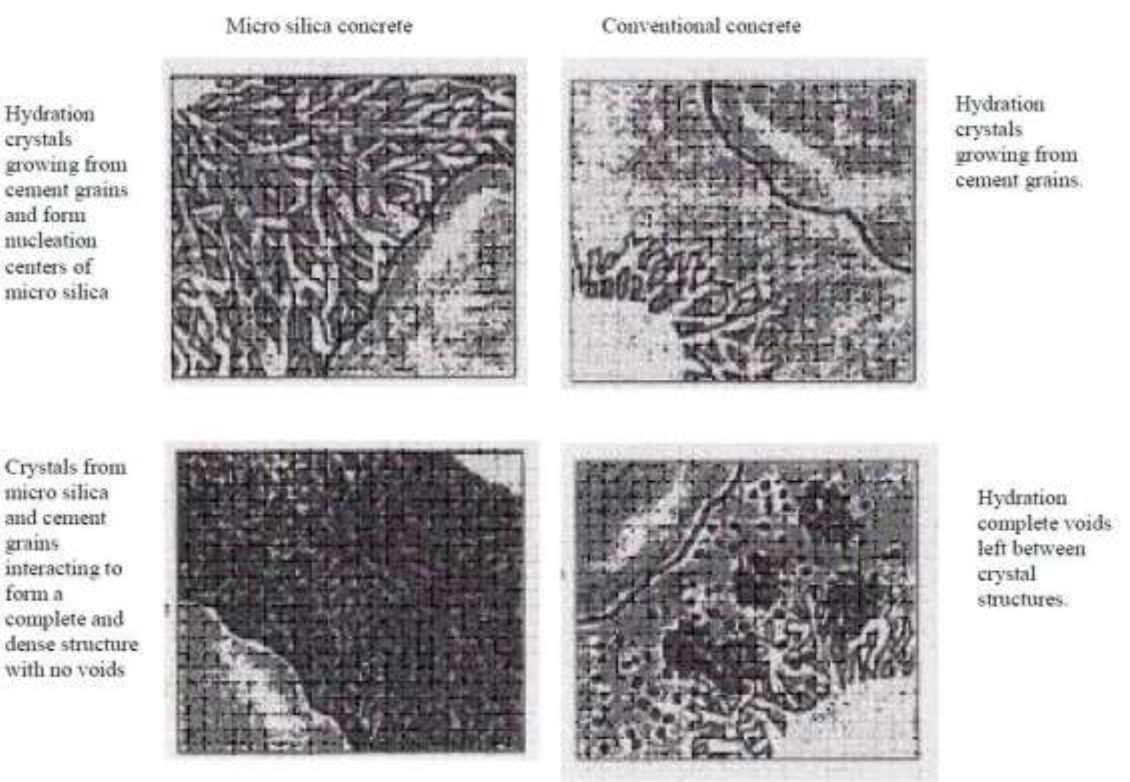


Figure 2.3: Effect of micro silica in densifying the concrete mix - comparison between conventional and micro silica concretes

(Grutzeck et al., 1995) suggested a gel model of silica fume-cement hydration. According to this model, silica fume contacts mixing water and forms a silica-rich gel, absorbing most of the available water. Gel then agglomerates between the grains of unhydrated cement, coating the grains in the process. Calcium hydroxide reacts with the outer surface of this gel to form C-S-H. This silica-fume gel C-S-H forms in the voids of the C-S-H produced by cement hydration, thus producing a very dense structure.

(Ono et al., 1985) studied the cement-silica fume system in low water-cement ratio (0.23) pastes at 20 C. The amounts of CH present after various periods of hydration at Portland cement: silica fume ratios of 100:0, 90:10, 80:20, and 60:40. At very high levels of silica fume, almost all CH are consumed by 28 days. At lower levels of silica fume, e.g., 10 percent, typical of those used in practice, CH is reduced by almost 50 percent at 28 days. These results are supported by those of Huang and Feldman who found that while silica fume accelerates early hydration and leads to increased production of CH at times up to 8 hours, at later ages CH is consumed, and for a mixture containing 50 percent silica fume, no CH is detectable after 14 days.

2.8.2.2 The physical effects

(**Mindess S., 1988**) silica fume increases the strength of concrete largely because it increases the strength of the bond between the cement paste and the aggregate particles.

(**Wang et al., 1986**) found that even small additions (2 to 5 percent) of silica fume produced a denser structure in the transition zone with a consequent increase in micro hardness and fracture toughness.

(**Monteiro and Mehta, 1986**) stated that silica fume reduces the thickness of the transition zone between cement paste and aggregate particles. One reason for this is the reduction in bleeding. The presence of silica fume accelerates the hydration of cement during the early stages.

(**Sellevold et al., 1982**) found that equal volumes of inert filler (calcium carbonate) produced the same effect. They concluded that the mere presence of numerous fine particles whether pozzolanic or not has a catalytic effect on cement hydration.

(**Wang et al., 1986**) also found that the mean size and orientation index of the CH crystals within the transition zone were reduced by the addition of silica fume. At the interface itself, the CH crystals will be oriented parallel to the aggregate surface whether silica fume is present or not, in a study of the texture (preferred orientation) of CH crystals in the transition zone.

(**Bache, 1981**) explained the theory of the packing of solid particles and its effect on the properties of the material. Because it is a composite, concrete is affected not only by the packing of particles in the cement paste, but also by their packing near the surfaces of aggregate particles. Figure (2.4) illustrates how the minute silica fume particles can improve packing in the boundary zone. Since this is frequently weakest part of a concrete, it is especially important to improve packing in this region.

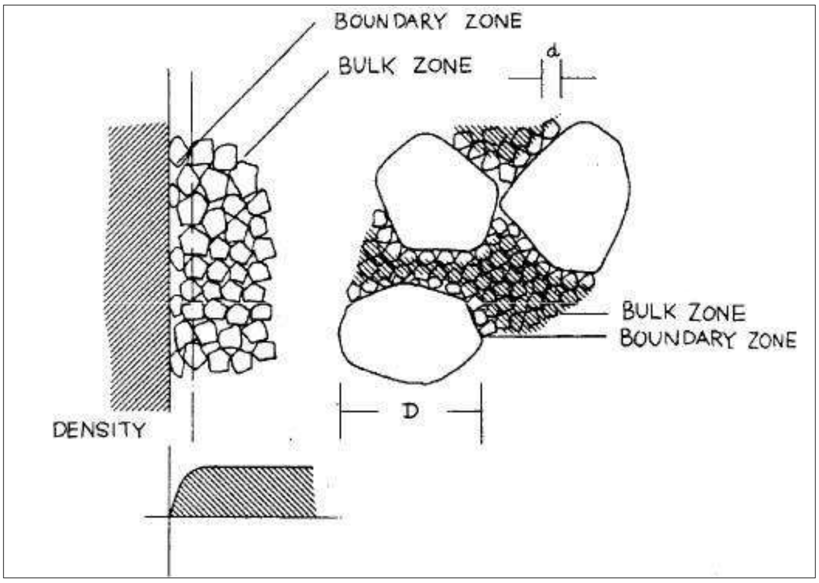


Figure (2.4): The boundary zone and the bulk zone between the aggregates

Bache also showed that addition of silica fume could reduce water demand because the silica-fume particles were occupying space otherwise occupied by water between the cement grains. This reduction only applies for systems with enough admixtures to reduce surface forces.

It is worth emphasizing here that all of these physical mechanisms depend on thorough dispersion of the silica-fume particles in order to be effective. This requires the addition of sufficient quantities of water-reducing admixtures to overcome the effects of surface forces and ensure good packing of the solid particles. The proper sequence of addition of materials to the mixer as well as thorough mixing is also essential.

2.8.3 Steel Fibers

Steel fibers are manufactured fibers composed of stainless steel. Composition may include carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), and other elements.

(**Hoang et al., 2008**) studied the influence of types of steel fiber on properties of ultra-high performance concrete and self-compacting ultra-high strength concrete has been manufactured, short steel fiber (straight fiber)with $L_{f1}/d_{f1} = 17/0.2$ and long steel fiber (hooked ends) with $L_{f2}/d_{f2} = 35/0.5$ have been added, in order to improve ductility. By a reasonable combination of two steel fiber types guarantee for high flowability, flexural strength of over 20 MPa and compressive strength of over 150 MPa.

(**Kang et al., 2010**) studied the tensile fracture properties of Ultra High Performance Fiber Reinforced Concrete considering the effects of the fiber content, they found that flexural tensile strength of Ultra High Performance Fiber Reinforced Concrete linearly increases with increasing fiber volume ratio.

(**Koksal et al., 2008**) conducted an experimental study to understand combined effect of silica fume and steel fiber on the mechanical properties of high strength concretes, Results show that the use of silica fume increased both the mechanical strength and the modulus of elasticity of concrete. On the other hand, the addition of steel fibers into concrete improve toughness of high strength concrete significantly. As the steel fiber volume fraction increases, the toughness increases, and high values of aspect ratios give higher toughness. The toughness of high strength steel fiber concrete depends on silica fume content, the fiber volume fraction and the fiber aspect.

2.8.4 Polypropylene Fiber

Polypropylene fiber is a synthetic fiber that is widely used in the nonwovens industry. As a syn-thetic fiber it is not derived from plants like cotton, but it is a man-made plastic material and is derived from oil. It was invented in 1954. Polypropylene staple fiber is made by melting poly-propylene chips in an extruder and forcing the melted plastic through spinning plates containing thousands of tiny holes. The resulting strands of molten plastic are cooled, stretched, and cut into staple fiber.

Polypropylene is used in several ways in nonwoven plants. It is a commonly used staple fiber in blending and carding machines for needle punch and thermal bonding lines. It is also used in spunbond lines where chips are extruded into continuous fibers, caught on a traveling conveyor screen, and cooled into fabric. In the melt blowing process; hot, liquid polypropylene is sprayed by high pressure air onto a conveyor to make a fabric of fine denier fibers.

Finished polypropylene fabric can also be treated with heat by calenders, infrared heaters, and ovens to impart additional characteristics to the fabric. Polypropylene is a thermoplastic which means that it can be melted, cooled, remelted and cooled again. Polypropylene melts at 320 degrees Fahrenheit , is a tough fiber, and resists many chemicals. It is lightweight, with a density less than water. It does degrade in sunlight, but additives can be put in to lessen the degradation. In its natural state it is a milky-white fiber. However, it can be colored during the spinning process.

(Sideris et al., 2009) studied the mechanical characteristics of Fiber Reinforced Concrete (FRC) subjected to high temperatures, experimentally. Fiber reinforced concrete was produced by addition of polypropylene fibers in the mixtures at dosages of 5 kg/m^3. At the age of 120 days specimens were heated to maximum temperatures of 100, 300, 500 and 700 °C. Specimens were then allowed to cool in the furnace and tested for compressive strength. Residual strength was reduced almost linearly up to 700 °C. Explosive spalling was not observed when polypropylene fibers were added in the mixtures; however, in this case the residual mechanical characteristics were significantly reduced. They concluded that addition of polypropylene fibers seems to be effective. It was reported that polypropylene melts at 160-168 °C and creates an additional pathway for release of internal vapor stresses at higher temperatures.

2.9 Concluding Remarks

Ultra High Performance Fire Resistance Concrete (UHPFRC) is one of the latest developments in concrete technology. UHPFRC refers to materials with a cement matrix and a characteristic compressive strength in excess of 120MPa. The hardened concrete matrix of Ultra High Performance Fire Resistance Concrete (UHPFRC) shows extraordinary strength, durability properties and improves the ability of concrete to withstand elevated temperature or fire.

These features are the result of using very low amounts of water, high amounts of cement, fine aggregates, steel fibers, polypropylene fibers and micro fine powders. These materials are characterized by a dense microstructure. The sufficient workability is obtained by using superplasticizer.

UHPC locally produced in Gaza strip using 900 kg/m^3 of cement, 15% of silica fume, 125% of quartz sand, 3% Superplastizer by weight of cement and 0.24 w/c ratio.

As a result of its superior performance, UHPFRC has found application in the storage of nuclear waste, tall buildings, Military constructions, oil silos and any facility exposed to fire or/and High temperatures.

CHAPTER 3

CONSTITUENT MATERIALS AND EXPERIMENTAL PROGRAM

Chapter 3

Constituent Materials and Experimental Program

3.1 Introduction

This chapter presents the experimental program and the constituent materials used to produce ultra high performance fire resistant concrete associated with this research work.

The laboratory investigation consisted of tests for hardened concrete. The tests for hardened concrete included compressive and flexural strengths.

The influence of the Polypropylene fibers “PP” was studied in order to obtain the optimum percentage for the mix and to reduce the loss in compressive strength due to high temperature by preparing different mixes with different percentages of “PP”.

The influence of silica fume dosages, cement/ultra-fine ratio, superplasticizer, steel fibers and polypropylene fibers amounts on the compressive strength concrete that’s subjected to high temperatures together with the workability and density of UHPFRC were studied by preparing several concrete mixes.

The properties of the different constituent materials used to produce UHPFRC were also discussed such as moisture content, unit weight, specific gravity and the grain size distribution. The test procedures, details and equipment used to assess concrete properties are also shown.

3.2 Characterizations of constituent materials

UHPFRC constituent materials used in this research included ordinary portland cement, silica fume, quartz sand, polypropylene and steel fibers. In addition, superplasticizer was used to ensure suitable workability. Proportions of these constituent materials have been chosen carefully in order to optimize the packing density of the mixture.

3.2.1 Cement

Cement paste is the binder in UHPFRC that holds the aggregate (fine, micron fine) together and reacts with mineral materials in hardened mass. The property of UHPFRC depends on the quantities and the quality of its constituents. Because cement is the most active component of UHPFRC and usually has the greatest unit cost, its selection and proper use is important in obtaining most economically the balance of properties desired of UHPFRC mixture.

The cement used throughout the experiments is Ordinary Portland Cement (OPC) I 52.5N that has a 28-day mortar compressive strength of 52 MPa. It was manufactured by Sinaa Cement, of Egypt, Figure (3.1). The results of physical and mechanical tests of the cements are summarized in Table (3.1) along with the requirements of ASTM C150 specifications for comparison purposes.

Table 3.1: Cement characteristics according to manufacturer data sheet

Test type		**Ordinary Portland Cement**	
		Results	**ASTM C 150**
Setting time (Vicat test) hr min	Initial	1 hr. 30 min.	More than 60 min.
	Final	3 hr. 12 min.	Less than 6 hr 15 min.
Mortar Compressive Strength (MPa)	3 Days	18 MPa	Min. 12 MPa
	7 Days	34 MPa	Min. 19 MPa
	28 Days	52 MPa	No Limits
Fineness (cm^2/gm)		3390	Min. 2800
Water demand		27.5 %	No Limits

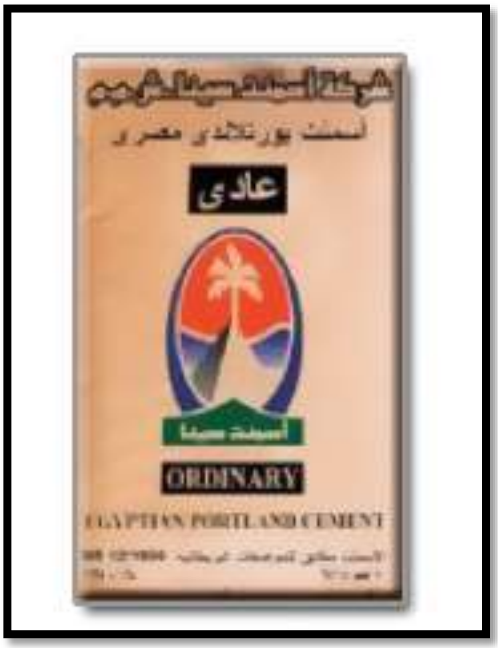


Figure 3.1: Cement used in preparing the mixes

3.2.2 Silica Fume

Silica fume is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. The silica fume, which condenses from the gases escaping from the furnaces, has a very high content of amorphous silicon dioxide and consists of very fine spherical particles **(ACI 548.6R-96)**.

Silica fume is extremely fine with particle size of 0.1 µm. It exists in grey powder form that contains latently reactive silicon dioxide and no chlorides or other potentially corrosive substances. The dry bulk density is 0.65 + 0.1 kg..

The silica fume was supplied by SIKA Company. It is known as "Sika –Fume", Figure (3.2). Table (3.2) shows the technical data, as supplied by the SIKA Company.

Figure 3.2: Silica Fume used in mixes

Table 3.2: The technical data for the "Sika - Fume"

Type	Property
Appearance	Grey powder
Specific gravity	2.20
Chloride Content	Nil
Toxicity	Non-Toxic

3.2.3 Quartz Sand

Aggregate is relatively inexpensive and strong making material for concrete. It is treated customarily as inert filler. The primary concerns of aggregate in mix design for Ultra High Performance Fiber Reinforced Concrete are gradation, maximum size, and strength. Providing that concrete is workable, the large particles of aggregate are undesirable for producing UHPFRC. For producing UHPFRC, the nominal size ranges from 0.15 to 0.6 mm for quartz sand (fine aggregate) [Figure (3.3)] which are locally available in Gaza markets. In addition, it is important to ensure that the aggregates are clean, since a layer of silt or clay will reduce the cement aggregate bond strength, in addition to increasing the water demand.

Figure 3.3: Aggregate used in mixes: Quartz sand.

3.2.3.1 Specific gravity and Unit weight:

The density of the aggregate is required in mix proportions to establish weight volume relationships. The density is expressed as the specific gravity, which is dimensionless relating the density of the aggregate to that of water. The determination of specific gravity of quartz sand was done according to ASTM C128. The specific gravity was calculated at two different conditions; which are the dry condition which equals to 2.61 and the saturated surface dry condition (SSD) and that's 2.632.

The unit weight or the bulk density of the aggregate is the weight of the aggregate per unit volume. The unit weight is necessary to select concrete mixture proportions in UHPFRC .The unit weight was determined according to ASTM C556 in two cases, the dry unit weight which is 1649.44 kg/m^3 and for the SSD unit weight is 1669.20 kg/m^3.

3.2.3.2 Moisture content:

The aggregate moisture is the percentage of water present in the sample aggregates, either inside pores or at the surface. Moisture content of the fine aggregate was done according to ASTM C128, but the final moisture content was zero because fine aggregates were dried in an oven at a temperature of 110 ^{o}C±5. Table (3.3) illustrates the absorption percentages of quartz sand.

Table 3.3: Water absorption of quartz sand

Aggregate Size(mm)	Water Absorption
0.6	0.620
0.5	0.625
0.4	0.628
0.3	0.636
0.15	0.639
Average	0.629

3.2.4 Water

Tap water was used in all concrete mixtures and in the curing all of the tests specimens. The water source was used from the soil and material laboratory at IUG.

3.2.5 Steel fiber

The combination of ultra fine ingredients in UHPFRC leads to an extremely brittle matrix generally not suitable for structural use. Steel fibers provide much needed ductility and enhanced post cracking performance (Schimdt et al., 2012 & Chanh, 1990) . The steel fibers used in UHPFRC exhibit a high tensile strength and to study the effect of using it in improving fire resistant for the ultra high performance concrete.

Straight stainless steel fibers with rectangularity ratio L/d ≈ 65, Tensile strength ≈ 655 MPa, and density is 7.8 g/cm^3.

Figure 3.4: Steel Fibers used in mixes

3.2.6 Polypropylene Fibers PP :

Polypropylene is a plastic polymer that was developed in the middle of the 20th century. Over the years, polypropylene has been used in a number of applications, most notably as fiber for carpeting and upholstery for furniture and car seats. Polypropylene has also make an industrial revolution with the plastics industry, providing an inexpensive material that can be used to create all sorts of plastic products for the home and office, recently become widely used in the construction industry in order to enhance fire resistance of concrete. Table (3.4) and figure (3.5) shows property of the used polypropylene in this research work.

Table 3.4 : Polypropylene Fibers properties

Property	Polypropylene
Unit weight (g/cm3)	0.9 – 0.91
Reaction with water	Hydrophobic
Tensile strength (ksi)	4.5 – 6.0
Elongation at break (%)	100 – 600
Melting point (C^o)	175
Thermal conductivity (w/m/k)	0.12
Length of fibers (mm)	15

Figure 3.5 :Polypropylene Fibers

3.2.7 Admixtures:

The chemical admixture used is superplasticizer which is manufactured to conform to ASTM-C-494 specification types G and F. When added to concrete mix, it improves the properties of fresh and hardened concrete. This plasticizing effect can be used to increase the workability of fresh concrete, extremely powerful water reduction (resulting in high density and strengths), excellent flowability (resulting in highly reduced placing and compacting efforts, reduce energy cost for steam cured precast elements, improve shrinkage and creep behavior, also it reduces the rate of carbonation of the concrete and finally improves water impermeability. This type is known as "Sika ViscoCrete -10" Figure (3.6) delivered from SIKA Company. Some technical data for the "Sika ViscoCrete - 10" are shown in Table (3.5).

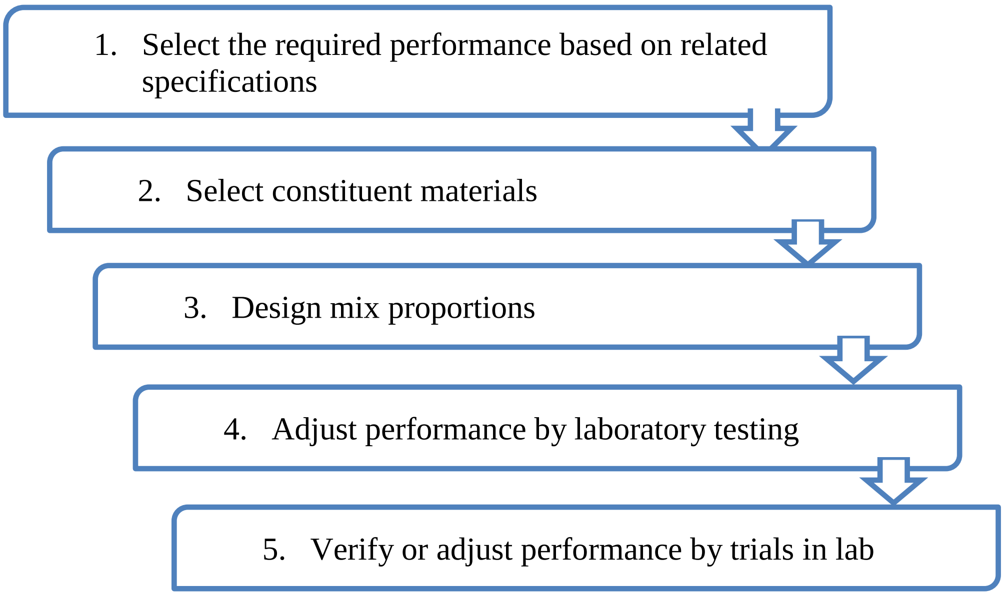
Table 3.5: The technical data for the "Sika ViscoCrete - 10"

Type	Property
Appearance	Turbid liquid
Density	1.08 kg/lt.±0.005
PH value	7.50
Basis	Aqueous solution of modified polycarboxylate
Toxicity	Non-Toxic under relevant health and safety codes

Figure 3.6: The chemical admixture (Superplastisizer).

3.3 Mix design of UHPFRC

The design process is graphically summarized in Figure (3.7)



1. Select the required performance based on related specifications
2. Select constituent materials
3. Design mix proportions
4. Adjust performance by laboratory testing
5. Verify or adjust performance by trials in lab

Figure 3.7: Mix design process

3.4 Preparation of UHPFRC

After selection of all needed constituent materials and amounts to be used (mix designs); all materials are weighed properly. Then mixing with a power-driven tilting revolving drum mixer (figure 3.8) started to ensure that all particles are surrounded with cement paste, silica fume and all other materials and fibers (i.e. steel and polypropylene fibers) should be distributed homogeneously in the concrete mass.

Mixing procedure was carried out according following steps: (Arafa et.al, 2010):

1. Placing all dry materials (cement, silica fume, quartz sand, steel fibers and polypropylene fibers) in the mixer pan [Figure (3.8)], and mixing for 2 minutes.
2. Adding 40 % of superplasticizer to the mixing water.
3. Adding water (with 40% of superplasticizer) to the dry materials, slowly for 2 minutes.
4. Waiting 1 minute then adding the remaining superplasticizer to the dry materials for 30 seconds.
5. Continuation of mixing as the UHPFRC changes from a dry powder to a thick paste.
6. After final mixing, the mixer is stopped, turned up with its end right down, and the fresh homogeneous concrete is poured into a clean plastic pan.

The casting of all UHPFRC specimens used in this research was completed within 20 minutes after being mixed. All specimens were cast and covered to prevent evaporation**.**

Figure 3.8: The drum mixer

3.5 Test Program

As stated before, the aim of this research is to study the effects of adding steel and polypropylene fibers on fire resistance of Ultra High Performance Concrete (UHPFRC) using local available materials in Gaza Strip. The test program adopted to achieve this objectives is summarized in Figure (3.9).

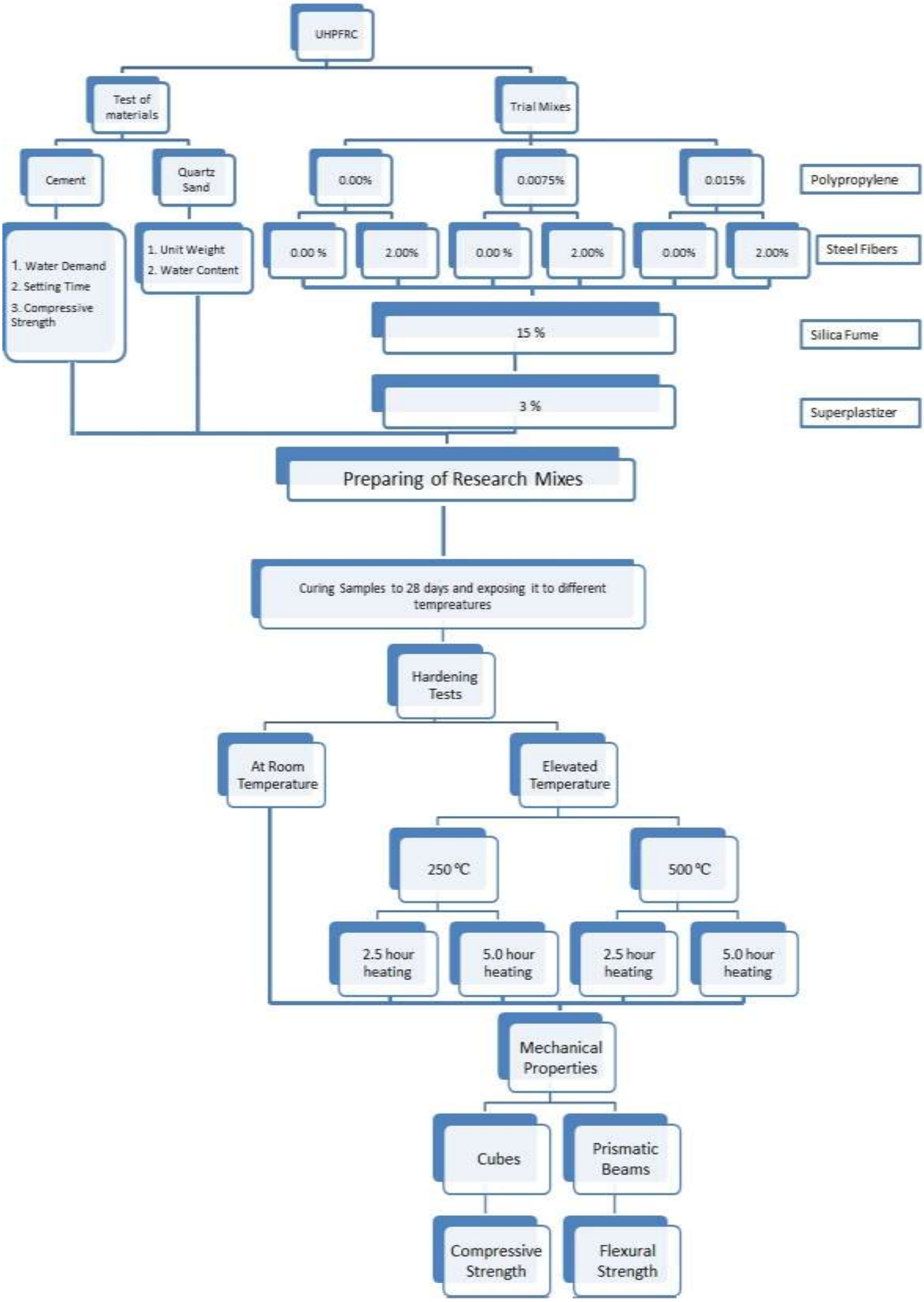


Figure 3.9: Testing program

3.6 Equipment and testing procedure

The laboratory testing of UHPFRC consists of tests for hardened concrete (Heated and unheated samples).

3.6.1 Heating Test:

The fire test was undertaken in a DRX-36 electric furnace Figure (3.10). All the samples are heated in the laboratory of the Industrial Engineering Department at IUGAZA ovens for the required high temperatures and needed periods. Temperatures were set at two values, (250 °C & 500 °C). After reaching the target temperature, the temperature was maintained for about 2.5 hours (soaking period). Under this regime, the temperature on the surface can be considered to be similar to that at the center of the specimens. Then the furnace door was opened, and the specimens were cooled down to the room temperature inside the furnace. All the surface changes (i.e. color and crack's, etc.) of the specimens after the temperature exposure were observed and recorded carefully.

Figure 3.10: The oven used for heating the specimens

3.6.2 Curing Procedure

Curing is protection of concrete from moisture loss as soon after placing as possible, and for the first few days of hardening, bad curing will make concrete lose 7- 56 % of its strength.

All specimens were placed in a curing basin after 24 hours from casting and remained there until the day of the testing. The curing process was done at the Soil and Material laboratory of IUG which follows ASTM C192

3.6.3 Compression Test

One of the most important tests for concrete is the compressive strength; this test was done according to the ASTM C109.

Numerous trial mixtures were prepared. For each batch of UHPFRC made, “10x10x10 cm” cubes and “40x10x10 cm” prisms of plain concrete were prepared. For each group, three samples were prepared and tested in order to obtain averaged value.

The compressive strength machine in the Soil and Materials Laboratory at the IUG Figure (3.11) was used for determining the maximum compressive loads carried by concrete cube specimens.

The compressive strength for the specimen σ_{comp} in MPa can be calculated by dividing the maximum compressive load by the area loaded;

$$\sigma_{comp} = \frac{P}{A} \qquad \text{Eq. 3.1}$$

Where: P = maximum load carried by the cube specimen during the test, A = the cross sectional area of the specimen.

Figure 3.11: The compressive test machine

3.6.4 Flexural Test

The flexural strengths of concrete specimens were determined by the use of simple beam with center point loading in accordance with **(ASTM C293, 1994)**. The spacemen is a beam 100 x 100 x 400 mm. the mold is filled in one layer, without any compacting or rodding, and then immersed in water at 25ºC.

The cast beam specimens are tested turned on their sides with respect to their position as molded. This should provide smooth, plane and parallel faces for loading if any loose sand grains or incrustations are removed from the faces that will be in contact with the bearing surfaces of the points of support and the load application, Figure (3.12, 3.13).

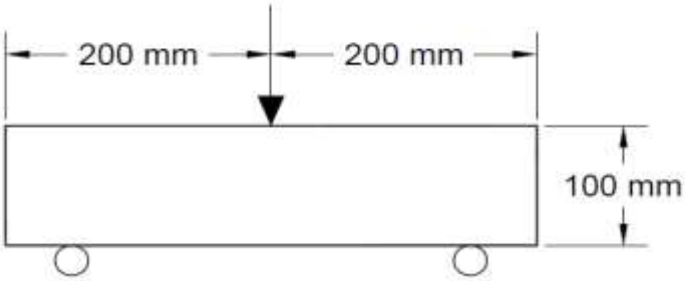


Figure 3.12: Diagrammatic view for flexure test of concrete by center-point loading

Figure 3.13: Samples at flexure strength test machine

The pedestal on the base plate of the machine is centered directly below the center of the upper spherical head, and the bearing plate and support edge assembly are placed on the pedestal. The center point loading device is attached to the spherical head. The test specimen is turned on its side with respect to its position as molded and it is placed on the supports of the testing device. This provides smooth, plane, and parallel faces for loading. The longitudinal center line of the specimen is set directly above the midpoint of both supports.

If full contact is not obtained between the specimen and the load applying or the support blocks so that there is a gap, the contact surfaces of the specimen are ground.

The specimen is loaded continuously and without shock at until rupture occurs. Finally, the maximum load indicated by the testing machine is recorded.

The flexural strength of the beam, F_r (in MPa), is calculated as follows:

$$F_r = \frac{3PL}{2BD^2} \qquad \text{Eq. 3.2}$$

Where: P = maximum applied load indicated by the testing machine, L = span length, B = average width of specimen, at the point of fracture, D = average depth of specimen, at the point of fracture.

The specimen beams tested after 28 days. At least three of these beams were tested for each period and the mean values are determined.

CHAPTER 4

TEST RESULTS AND DISCUSSION

Chapter 4

Test Results and Discussion

4.1 Introduction

Series of tests were carried out on the concrete specimens to study and evaluate the effects of polypropylene and steel fibers on improving fire resistance of ultra high performance fiber reinforced concrete. This chapter discusses the results obtained from the different tests adopted in the testing program. Results include heating test, unit weight, compressive strength and tensile strength tests.

All mixtures were subjected to hardened concrete tests in order to be classified as UHPFRC. Some mixing ingredients were fixed and the others were variable. Table (4.1) summarizes the different mix proportions. The percentage of Silica fume, Quartz sand, Super- plasticizer and water was used was the same percentage obtained by (Madhoun A., 2013) in his research at IUG

Table 4.1: Different mix proportions of UHPFRC by weight of cement

Mix No.	Cement	Silica Fume	Quartz Sand	Super-plasticizer	Steel Fibers	PP Fiber	Water
Mix-1	1.00	15 %	125%	3%	0 %	0%	24%
Mix-2	1.00	15 %	125%	3%	0 %	0.75%	24%
Mix-3	1.00	15 %	125%	3%	0 %	1.50%	24%
Mix-4	1.00	15 %	125%	3%	16%	0%	24%
Mix-5	1.00	15 %	125%	3%	16%	0.75%	24%
Mix-6	1.00	15 %	125%	3%	16%	1.50%	24%

4.2 Hardened properties results

Laboratory tests were conducted to evaluate and study the hardened properties of UHPFRC. Results are the unit weight, compressive strength and tensile strength tests. Mean results for concrete mixtures at several ages are summarized in Table 4.2 and Figures 4.1 through 4.3. These results are the base line in comparing the strength reduction of the samples after being subjected to the heating tests.

Table 4.2: Compressive and tensile strengths for samples without heating

Mix No.	Unit weight kg/m^3	Compressive strengths MPa			Flexural strengths at 28 days, MPa
		7 days	14 days	28 days	
Mix-1	2335	84.84	109.11	138.18	14.23
Mix-2	2320	99.17	128.50	150.57	16.71
Mix-3	2315	101.52	130.91	171.39	19.19
Mix-4	2395	97.37	130.32	173.14	21.29
Mix-5	2372	113.44	154.59	176.93	22.46
Mix-6	2345	119.67	146.84	171.36	21.75

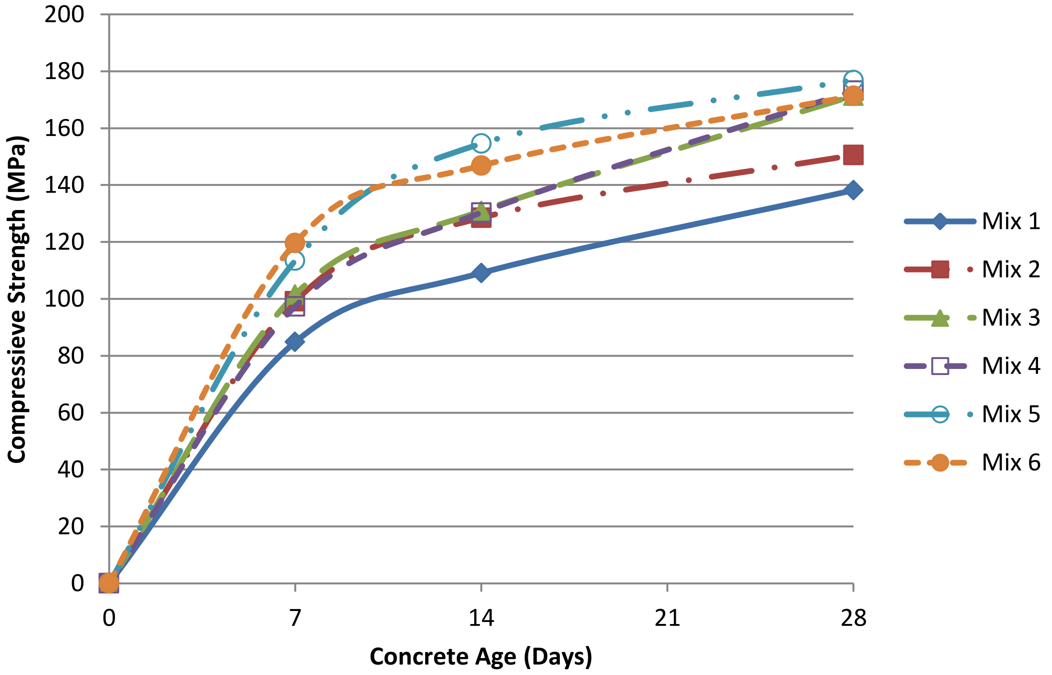


Figure 4.1: Mean compressive strengths Vs. age for unheated samples

Results shown in Table 4.2 and Figure 4.1 demonstrate that it is possible to develop UHPFRC with different polypropylene and steel fibers amounts.

It can be observed that increasing the polypropylene content from 0.75% to 1.5% effectively increases the compressive strength of concrete when it was used alone. Also it was observed that adding of steel fibers by 16% effectively increases the compressive strength of concrete. But increasing the polypropylene content from 0.75% to 1.5% when 16% of steel fibers used decreases the compressive strength. results agree with that of (Madhoun A., 2013)in the increasing of compressive strength for samples containing of 16% steel fibers.

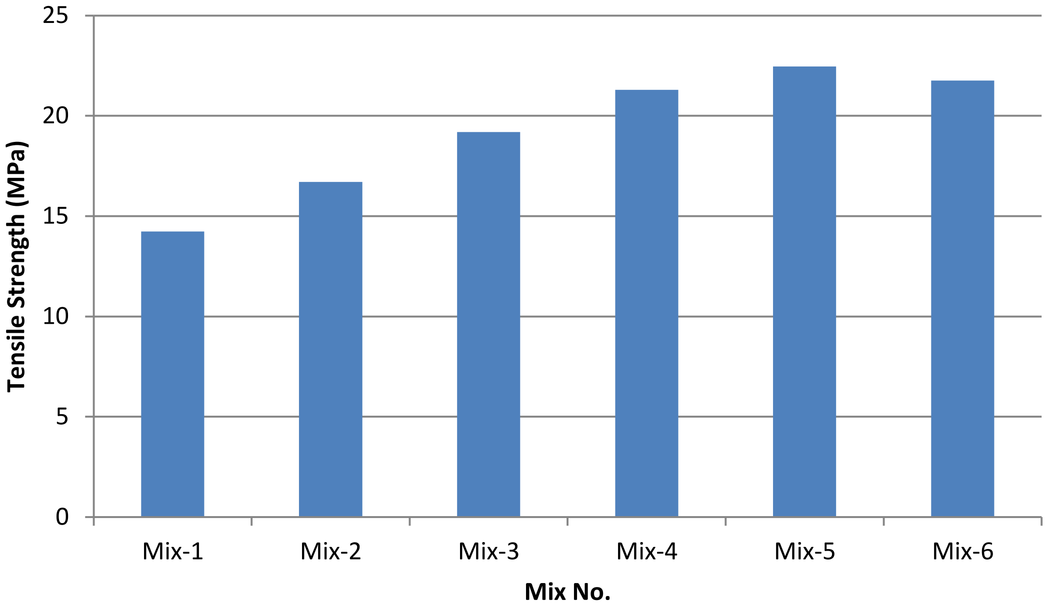


Figure 4.2: Mean tensile strengths for unheated samples

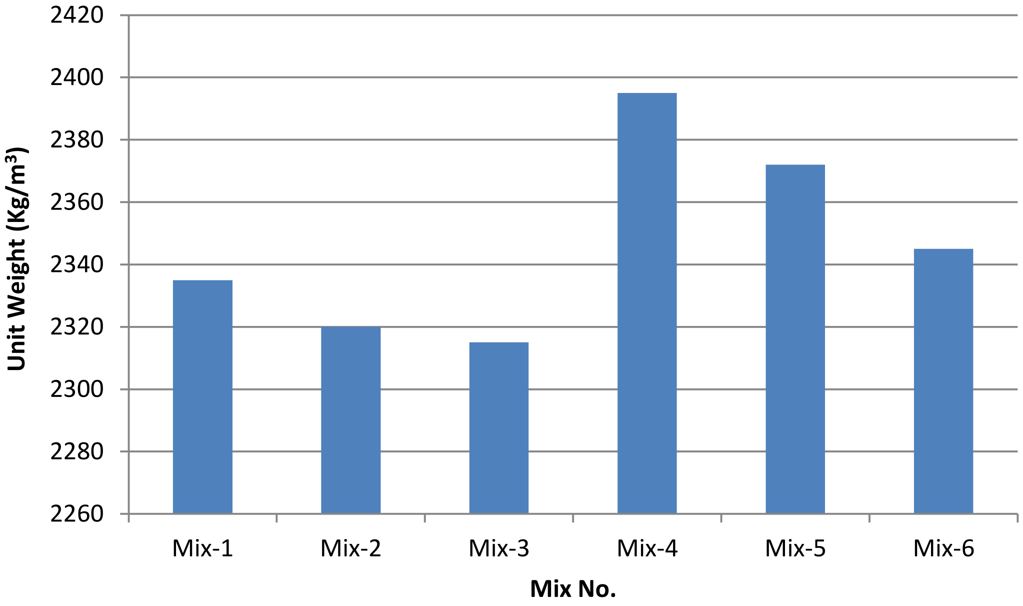


Figure 4.3: Mean unit weights for unheated samples

4.2.1 Compressive strength tests results of heated samples

Results of the compressive strength tests are shown in Table 4.3 and Figures 4.5 through 4.6 for different percentages of polypropylene (0% , 0.75% and 1.5%), different percentages of steel fibers (0% and 16%), different heating temperatures (Room temperature, 250°C and 500°C) and heating durations (0 , 2.5 and 5 hours).

Table 4.3: Compressive strengths for heated samples

2.5-hour heating					
Mix No.	**% of (Polypropylene)**	**% of (Steel Fibers)**	**Average compressive strength, MPa**		
			Room Temp.	**250 °C**	**500 °C**
Mix-1	0.00 %	0.00 %	138.18	113.31	40.07
Mix-2	0.75 %	0.00 %	150.57	145.00	69.26
Mix-3	1.50 %	0.00 %	171.39	168.74	63.58
Mix-4	0.00 %	16.00 %	173.14	179.20	74.45
Mix-5	0.75 %	16.00 %	176.93	170.21	102.62
Mix-6	1.50 %	16.00 %	171.36	166.90	83.96
5-hour heating					
Mix No.	**% of (Polypropylene)**	**% of (Steel Fibers)**	**Average compressive strength, MPa**		
			Room Temp.	**250 °C**	**500 °C**
Mix-1	0.00 %	0.00 %	138.18	92.58	21.83
Mix-2	0.75 %	0.00 %	150.57	128.73	34.93
Mix-3	1.50 %	0.00 %	171.39	140.90	37.80
Mix-4	0.00 %	16.00 %	173.14	145.44	41.20
Mix-5	0.75 %	16.00 %	176.93	164.55	55.38
Mix-6	1.50 %	16.00 %	171.36	152.51	46.43

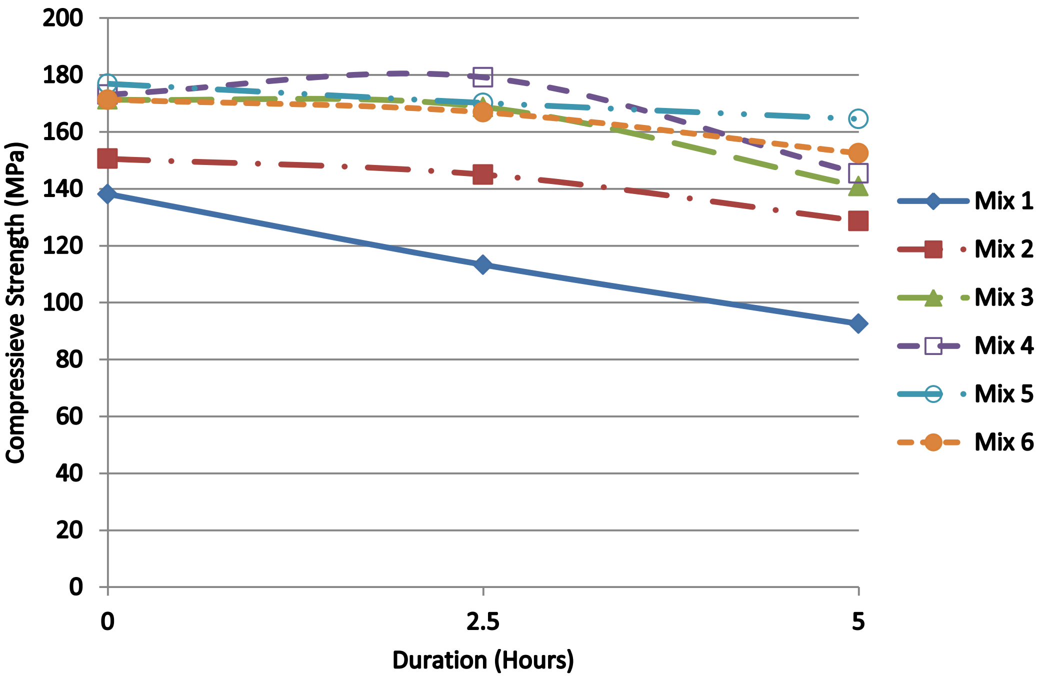


Figure 4.4: Compressive strength results for samples heated to 250 C°.

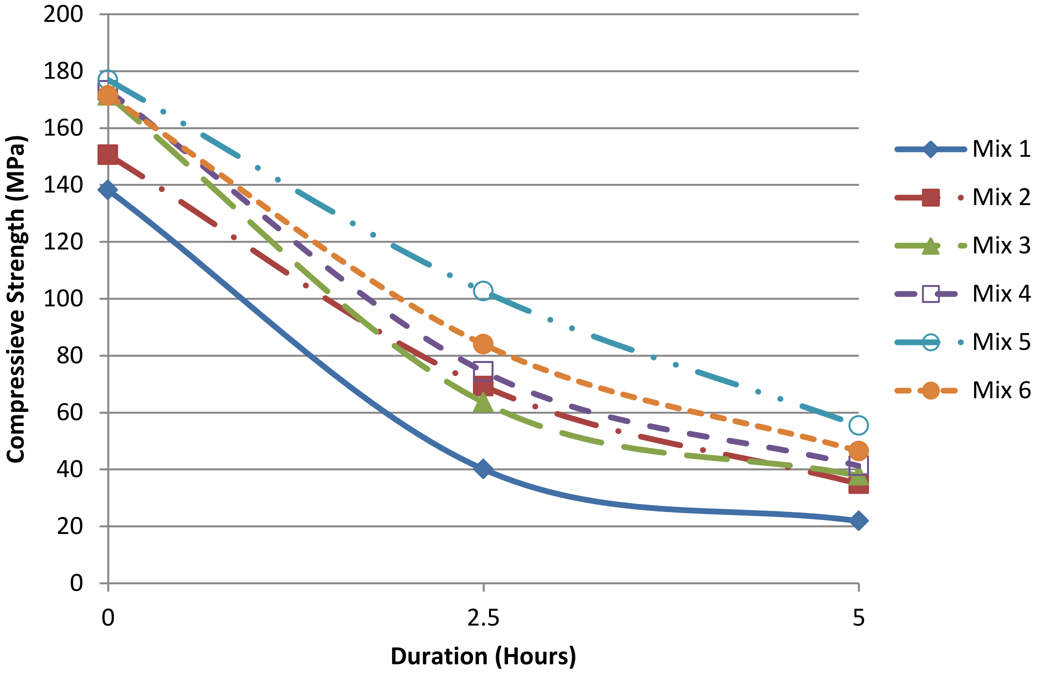


Figure 4.5: Compressive strength results for samples heated to 500 C°.

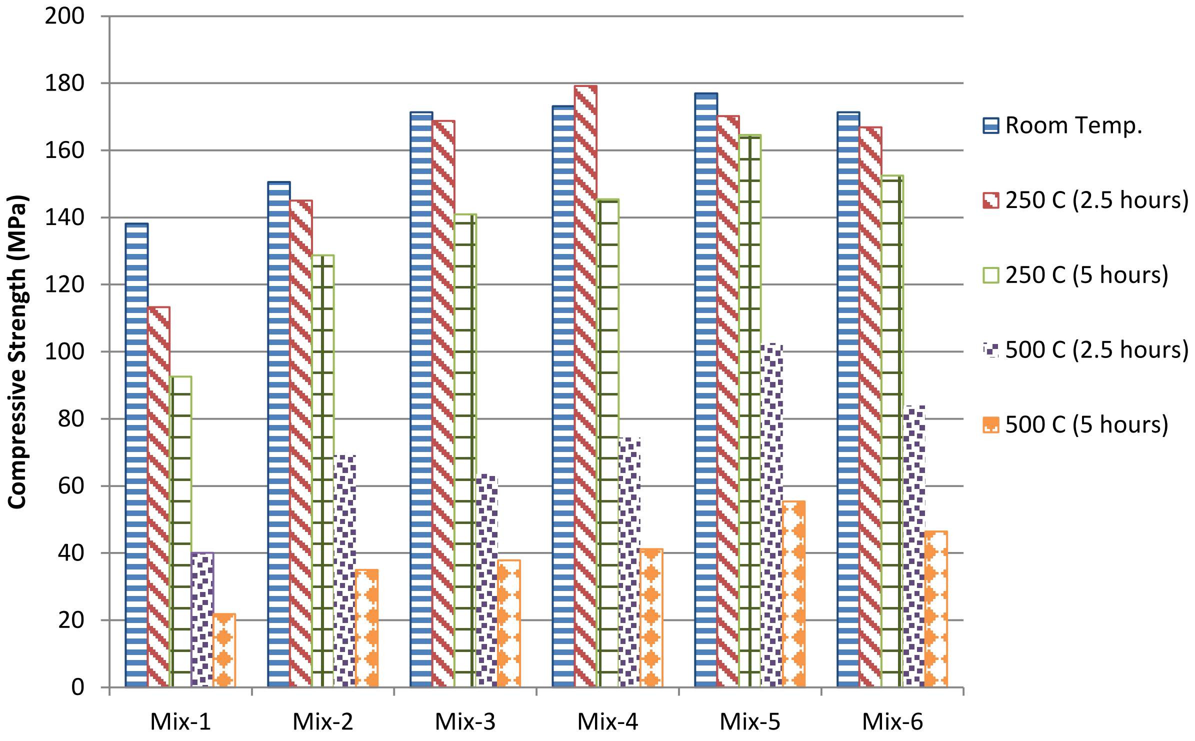


Figure 4.6: Compressive strength results for heated and unheated samples.

Table 4.4: Percentages of reduction in compressive strength with difference % of PP and steel fibers, relative to the control specimens.

Heating to 250 °C					
Mix No.	**% of (Polypropylene)**	**% of (Steel Fibers)**	**Percentage of reduction in compressive strength (%)**		
			0 hours heating	**2.5 hours heating**	**5 hours heating**
Mix-1	0.00%	0.00%	0.00	18.00	33.00
Mix-2	0.75%	0.00%	0.00	3.70	14.50
Mix-3	1.50%	0.00%	0.00	1.55	17.79
Mix-4	0.00%	16.00%	0.00	-3.50	16.00
Mix-5	0.75%	16.00%	0.00	3.80	7.00
Mix-6	1.50%	16.00%	0.00	2.60	11.00
Heating to 500 °C					
Mix No.	**% of (Polypropylene)**	**% of (Steel Fibers)**	**Percentage of reduction in compressive strength (%)**		
			0 hours heating	**2.5 hours heating**	**5 hours heating**
Mix-1	0.00%	0.00%	0.00	71.00	84.20
Mix-2	0.75%	0.00%	0.00	54.00	76.80
Mix-3	1.50%	0.00%	0.00	62.90	77.95
Mix-4	0.00%	16.00%	0.00	57.00	76.20
Mix-5	0.75%	16.00%	0.00	42.00	68.70
Mix-6	1.50%	16.00%	0.00	51.00	72.90

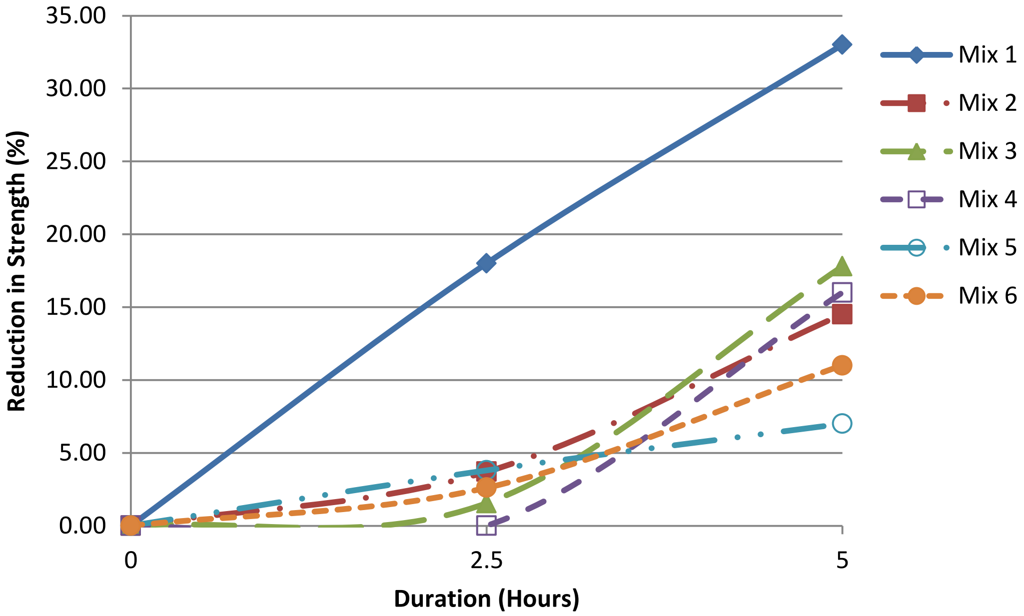


Figure 4.7: Reduction in compressive strength for samples heated to 250 °C

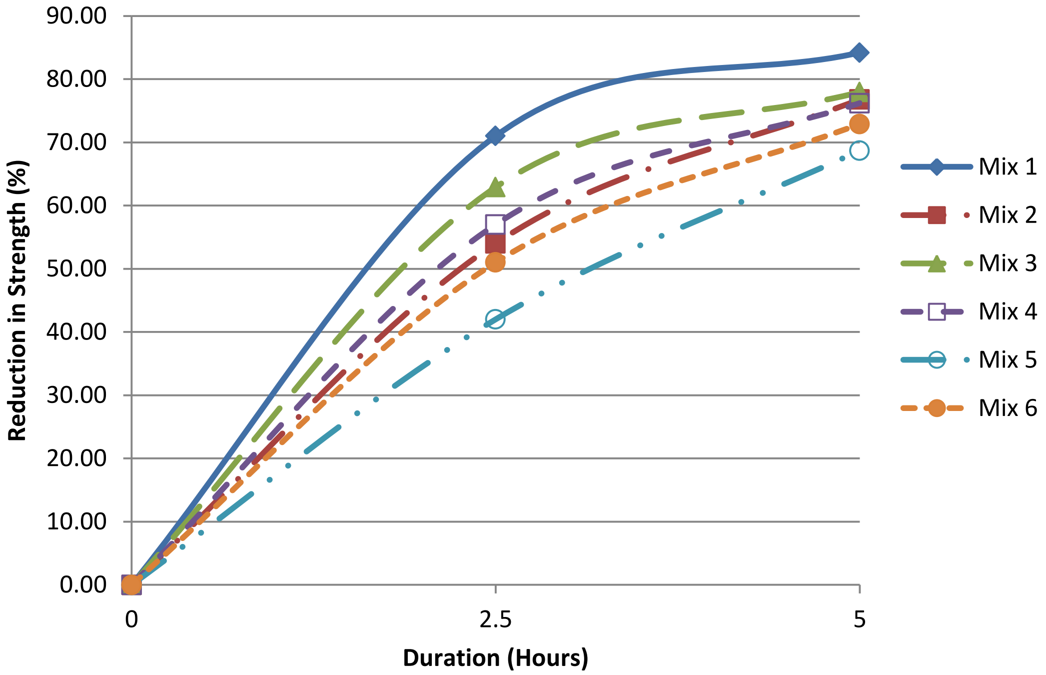


Figure 4.8: Reduction in compressive strength for samples heated to 500 °C

From Tables 4.2 through 4.4 and Figures 4.2 through 4.8, it is noticed that for samples without of polypropylene and steel fibers, the reductions in compressive strengths are larger than those with polypropylene. For example the percentage of strength loss for samples with 0.0% polypropylene and 0.0% steel fibers heated at 250°C for 5 hours was 33%, and when heated at 500°C for 5 hours was 84.2%. On the other hand, the loss for samples with 0.75% polypropylene and 16% steel fibers heated at 250°C for 5 hours was 7% and when heated at 500°C for 5 hours the loss was 68.7 %. For samples with 0.75% polypropylene and without steel fibers heated at 250°C for 5 hours the loss was 14.5% and when heated to 500°C for 5 hours the loss was 76.8%. For samples with 16 % steel fibers and without polypropylene heated at 250°C for 5 hours the loss was 17.79% and when heated to 500°C for 5 hours the loss was 76.2%.

From these results, one may conclude that the addition of polypropylene and steel fibers reduces the loss of concrete strength when it was heated to high temperature. The optimum percentage of polypropylene and steel fibers recommended to be used based on this investigation for improving the concrete resistance against fire is 0.75% and 16% by weight of the cement.

Also, it is noticed that polypropylene and steel fibers not only improves the concrete resistance for fire, but also improves its initial strength before heating, as shown in Table 4.2 and Figure 4.1. The compressive strength increased by 9% when 0.75% polypropylene is used, and by 24 % when 1.5% polypropylene is used. Also the compressive strength increased by 25.3% when 16% steel fibers is used, and when using a combination of polypropylene and steel fibers the compressive strength increased by 28% for 0.75% polypropylene and 16% steel fibers and 24% for 1.5% polypropylene and 16% steel fibers. Results agree with those of (Tai et al., 2011) and (Pliya et al., 2010).

4.2.2 Flexural strengths test results after heating tests

Results of the Flexural tensile strength tests are shown in Table 4.5 and Figures 4.9, for different percentages of PP (0% , 0.75% and 1.5%), different percentages of steel fibers (0% and 16%), different heating temperatures (Room temperature and 250°C) and heating durations (0 , 2.5 and 5 hours).

Table 4.5: Flexural tensile strength for heated samples

Heating to 250 °C					
Mix No.	**% of (Polypropylene)**	**% of (Steel Fibers)**	**Average flexural tensile strength, MPa**		
			0 hour	**2.5 hours**	**5 hours**
Mix-1	0.00%	0.00%	14.23	8.92	4.72
Mix-2	0.75%	0.00%	16.71	10.13	5.26
Mix-3	1.50%	0.00%	19.19	11.51	5.66
Mix-4	0.00%	16.00%	21.29	17.44	10.94
Mix-5	0.75%	16.00%	22.46	18.26	7.57
Mix-6	1.50%	16.00%	21.75	14.86	7.18

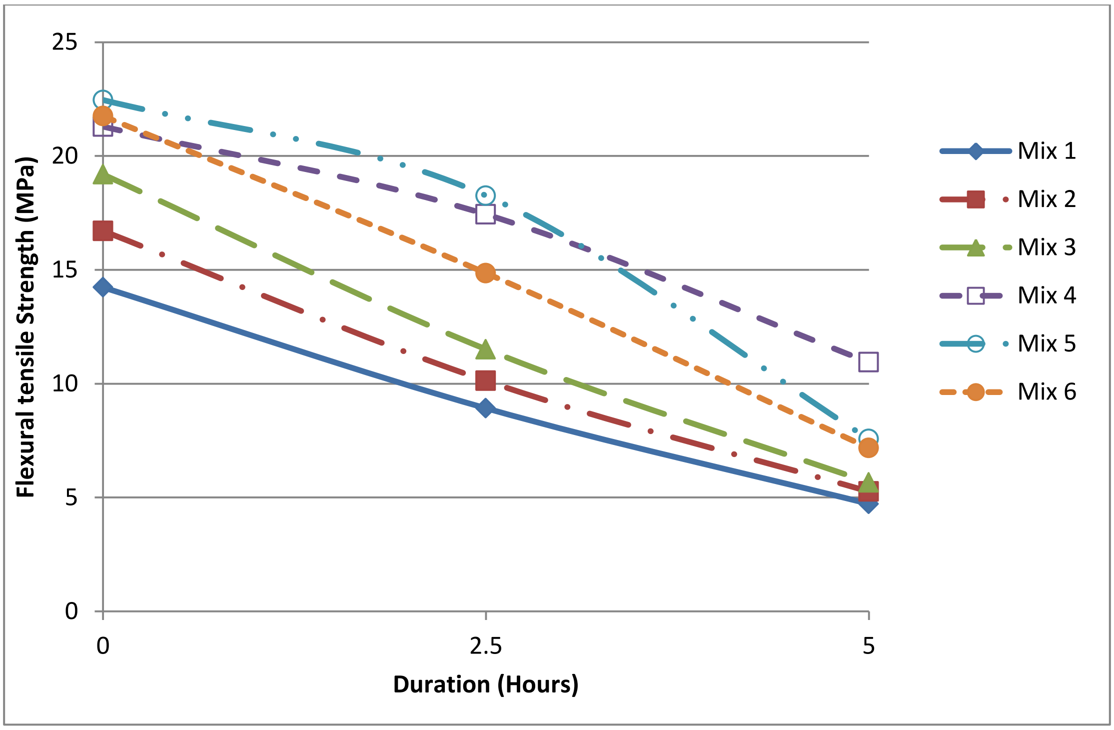


Figure 4.9: Flexural tensile strength results for samples heated to 250 C°.

From Table 4.5 and Figure 4.9, it is noticed that for samples without polypropylene and steel fibers, the reductions in flexural tensile strengths are larger than those with polypropylene and steel fibers. For example the percentage of strength losses for samples with 0.0% PP and 0.0% steel fibers heated at 250°C for 2.5 hours was 37.7 %, and when heated to 5 hours at the same temperature was 66.8%. On the other hand, the loss in tensile strength for samples with 0.75% PP & 16% steel fibers heated at 250°C for 2.5 hours was 18.69% and when heated at 250°C for 5 hours the loss was 66.2 %. For samples with 0.75% PP and without steel fibers heated at 250°C for 5 hours the loss was 68.5%. For samples with 16 % steel fibers and without PP heated at 250°C for 5 hours the loss was only 48%. So from these results, one may conclude that the addition of polypropylene is highly decreasing the loss of concrete tensile strength when it was heated up to 2.5 hours at 250 °C but its not significant when the samples heating to 250°C for 5 hours. But when using the steel fibers in the concrete mix the flexural tensile strengths is highly improved to resist high temperatures for 5 hour heating. and optimum percentage of PP and steel fibers recommended to be used based on this investigation for improving the concrete resistance against fire is 1.5% and 16% by volume of the mix.

Also, it is noticed that PP and steel fibers not only improve the concrete resistance for fire, but also improve its initial strength before heating, as shown in Table 4.2 and Figure 4.2, where the tensile strength increased by 17.4% when 0.75% PP is used, and by 34.8 % when 1.5% PP is used. Also, the compressive strength increased by 49.6% when 16% steel fibers is used only, and when using a combination of PP and steel fibers the compressive strength increased by 57.8% for 0.75% PP and 16% steel fibers and 52.8% for 1.5% PP and 16% steel fibers. Results agree with that of Pliya et al., 2010.

4.3 Effects of polypropylene and steel fibers on concrete unit weight

Table 4.2 and Figure 4.3 summarize the effect of polypropylene and steel fibers on the concrete unit weight. The results show that the density of concrete decreases when increasing the polypropylene fiber percentage in mix, but it increases when the amount of steel fibers increases. Results agree with those of Shihada, 2010 and Arafa et al., 2010.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Chapter 5

Conclusions and Recommendations

5.1 Introduction :

UHPFRC is a relatively new form of concrete which can be used for general applications and especially for rehabilitation works. The main advantages that UHPFRC have over standard concrete are its high compressive strength, relative high tensile and flexural strength, low porosity, high durability and fire resistance properties.

Improving concrete fire resistance is of vital importance since damages caused by fires are one of the most serious problems that face civil engineers specially in countries that are susceptible to wars and enemy fighting such as Gaza Strip.

The objective of this research is to study the effects of adding available materials to the concrete mixes and designing these mixes with optimum amount of polypropylene and steel fibers on improving fire resistance of Ultra High Performance Concrete (UHPC) by decreasing the rate of compressive strength loss and increasing the time of exposure before occurrence of failure. The experimental phase of this research focused on developing UHPFRC and properties for hardened statuses. The laboratory tests determined compressive and flexural tensile strengths of the developed UHPFRC after and before being subjected it to high temperatures. The analytical phase of this research focused and elaborated on the results obtained from the experimental phase.

5.2 Conclusions

In this research, specimens of various concrete compositions were made and subjected to different heating periods. Six concrete groups were formulated without or with polypropylene and/or steel fibers. Concrete mass loss and residual mechanical properties were studied. The following conclusions can be drawn from the experimental results:

- The compressive strength for mix without fibers (Mix-1) were increased by 34.8 % when polypropylene fibers were added only as in (Mix 3) and it was increased by 49.6 % when steel fibers were added only as in (Mix 4), also it was increased by 57.8% when PP and steel fibers were used as in (Mix 5).

- Compared with concretes without fibers (Mix 1), reduction of relative residual strength was observed at 250°C for 5 hours was 33%, and when heated at 500°C for 5 hours was 84.2%. On the other hand, the loss for concrete (Mix 5) heated at 250°C for 5 hours was 7% and when heated at 500°C for 5 hours the loss was 68.7 %. For concrete (Mix 2) heated at 250°C for 5 hours the loss was 14.5% and when heated to 500°C for 5 hours the loss was 76.8%. For (Mix 4) heated at 250°C for 5 hours the loss was 17.79% and when heated to 500°C for 5 hours the loss was 76.2%.
- Compared with concretes without fibers (Mix 1), it is noticed that the reductions in flexural tensile strengths are larger than those with polypropylene and steel fibers. The percentage of strength losses for (Mix 1) heated at 250°C for 2.5 hours was 37.7 %, and when heated to 5 hours at the same temperature was 66.8%. On the other hand, the loss tensile strength for (Mix 5) heated at 250°C for 2.5 hours was 18.69% and when heated at 250°C for 5 hours the loss was 66.2 %. For (Mix 2) heated at 250°C for 5 hours the loss was 68.5%. For (Mix 4) heated at 250°C for 5 hours the loss was 48%.
- The masses of the different groups of concretes decrease with temperature. An additional mass decrease is noticed with the concrete incorporating polypropylene fibers. After the heating at 250 ºC and 500 ºC, the mass loss of fibers (PP and Steel Fibers) concretes is lower than that of concretes with and without PP but is higher than that of Steel fibers concretes.
- All of concrete mixes prepared in this research achieved high workability and flowability, and may it can use it as a self compacting concrete.

5.3 The following recommendations are proposed for further research

❖ **The effect of Material Property**

  - The influence of cement type and steel fibers shape on the mechanical property of UHPFRC need to be studied.
  - The effect of other types of fibers (Carbon, Glass …etc.) addition on the mechanical properties of UHPFRC need to be investigated for further research.
  - The influence of superplastisizer type on the mechanical property of UHPFRSCC need to be studied.

❖ Durability of UHPFRC

Further investigations have to be carried out on the following:

- Pore structure and permeability.
- Mechanism of strength development.
- Chemical resistance.
- Fire resistance for other temperatures and periods.

❖ Short term mechanical properties

Further testing and studies on short term mechanical properties of UHPFRC have to be carried out on the following:

- Drying shrinkage and creep.
- The stress – strain behavior in compression.
- The stress – strain behavior in tension.
- Static and dynamic modulus.

❖ Using UHPFRC in the Rehabilitation Works

Further testing and studies needed to be carry out to test the behavior of UHPFRC when used as a repair material, and derive proper equations when we use it to repair the different deteriorated structural elements such as beams, columns, slabs, footings, shear walls … etc.

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APPENDICES

APPENDICES

APPENDIX I :

Concrete Mixes Used in This Research

Mixes proportions of UHPFRC by weight of cement

Ingredient/Cement Content (%)

Mix No.	Cement	Silica Fume	Quartz Sand	Super-plasticizer	Steel Fibers	PP Fiber	Water
Mix-1	1.00	15 %	125%	3%	0 %	0%	24%
Mix-2	1.00	15 %	125%	3%	0 %	0.75%	24%
Mix-3	1.00	15 %	125%	3%	0 %	1.50%	24%
Mix-4	1.00	15 %	125%	3%	16%	0%	24%
Mix-5	1.00	15 %	125%	3%	16%	0.75%	24%
Mix-6	1.00	15 %	125%	3%	16%	1.50%	24%

Ingredient (Kg/m^3)

Mix No.	Cement	Silica Fume	Quartz Sand	Super-plasticizer	Steel Fibers	PP Fiber	Water
Mix-1	900	135	1125	27	0 %	0%	216
Mix-2	900	135	1125	27	0 %	6.75	216
Mix-3	900	135	1125	27	0 %	13.50	216
Mix-4	900	135	1125	27	144	0%	216
Mix-5	900	135	1125	27	144	6.75	216
Mix-6	900	135	1125	27	144	13.50	216

APPENDIX II :

Compressive strength

Test Results for all of Research Samples

Note: D1: Without heating, D2: 2.5 hour, D3: 5.0 hour.

T1: Room temperature, T2: 250 °C, T3: 500 °C.

Sample code	Density (Kg/m^3)	Compressive Strength (MPa)	Average Density (Kg/m^3)	Average Compressive Strength (MPa)
Mix1-D1-T1-1	2355.00	133.73	2335	138.18
Mix1-D1-T1-2	2327.00	140.86		
Mix1-D1-T1-3	2323.00	139.94		
Mix1-D2-T2-1	2329.00	115.21	2319	113.31
Mix1-D2-T2-2	2294.00	111.56		
Mix1-D2-T2-3	2334.00	113.15		
Mix1-D3-T2-1	2295.00	37.34	2304.33	40.07
Mix1-D3-T2-2	2299.00	42.64		
Mix1-D3-T2-3	2319.00	40.22		
Mix1-D2-T3-1	2315.00	87.51	2308	92.58
Mix1-D2-T3-2	2297.00	93.11		
Mix1-D2-T3-3	2312.00	97.13		
Mix1-D3-T3-1	2292.00	23.07	2292	21.83
Mix1-D3-T3-2	2295.00	21.49		
Mix1-D3-T3-3	2289.00	20.93		
Mix2-D1-T1-1	2318.00	152.37	2320	150.57
Mix2-D1-T1-2	2325.00	148.21		
Mix2-D1-T1-3	2317.00	151.14		
Mix2-D2-T2-1	2296.00	144.23	2302	145
Mix2-D2-T2-2	2299.00	145.65		
Mix2-D2-T2-3	2311.00	145.11		
Mix2-D3-T2-1	2295.00	69.30	2294.33	69.26
Mix2-D3-T2-2	2299.00	70.35		
Mix2-D3-T2-3	2289.00	68.12		
Mix2-D2-T3-1	2297.00	131.19	2296.33	128.73
Mix2-D2-T3-2	2300.00	126.97		
Mix2-D2-T3-3	2292.00	128.02		
Mix2-D3-T3-1	2292.00	34.92	2288	34.93
Mix2-D3-T3-2	2285.00	35.33		
Mix2-D3-T3-3	2287.00	34.54		

Sample code	Density (Kg/m^3)	Compressive Strength (MPa)	Average Density (Kg/m^3)	Average Compressive Strength (MPa)
Mix3-D1-T1-1	2310.00	168.57	2315	171.39
Mix3-D1-T1-2	2317.00	174.00		
Mix3-D1-T1-3	2318.00	171.61		
Mix3-D2-T2-1	2308.00	170.57	2310.67	168.74
Mix3-D2-T2-2	2310.00	166.68		
Mix3-D2-T2-3	2314.00	168.96		
Mix3-D3-T2-1	2308.00	62.28	2303.67	63.58
Mix3-D3-T2-2	2301.00	60.85		
Mix3-D3-T2-3	2302.00	67.61		
Mix3-D2-T3-1	2298.00	144.20	2294.67	140.9
Mix3-D2-T3-2	2292.00	137.43		
Mix3-D2-T3-3	2294.00	141.07		
Mix3-D3-T3-1	2288.00	39.82	2288.67	37.8
Mix3-D3-T3-2	2293.00	35.17		
Mix3-D3-T3-3	2285.00	38.41		
Mix4-D1-T1-1	2399.00	170.92	2395	173.14
Mix4-D1-T1-2	2390.00	175.16		
Mix4-D1-T1-3	2396.00	173.35		
Mix4-D2-T2-1	2389.00	176.93	2390.67	179.2
Mix4-D2-T2-2	2390.00	178.82		
Mix4-D2-T2-3	2393.00	181.85		
Mix4-D3-T2-1	2389.00	77.31	2388.67	74.45
Mix4-D3-T2-2	2386.00	70.83		
Mix4-D3-T2-3	2391.00	75.22		
Mix4-D2-T3-1	2389.00	143.87	2389.67	145.44
Mix4-D2-T3-2	2389.00	140.52		
Mix4-D2-T3-3	2391.00	151.93		
Mix4-D3-T3-1	2385.00	44.30	2385.67	41.2
Mix4-D3-T3-2	2389.00	39.21		
Mix4-D3-T3-3	2383.00	40.10		

Sample code	Density (Kg/m^3)	Compressive Strength (MPa)	Average Density (Kg/m^3)	Average Compressive Strength (MPa)
Mix5-D1-T1-1	2375.00	180.33	2372	176.93
Mix5-D1-T1-2	2371.00	172.82		
Mix5-D1-T1-3	2370.00	177.64		
Mix5-D2-T2-1	2370.00	168.54	2369.33	170.21
Mix5-D2-T2-2	2367.00	171.31		
Mix5-D2-T2-3	2371.00	170.79		
Mix5-D3-T2-1	2366.00	99.56	2366	102.62
Mix5-D3-T2-2	2361.00	104.21		
Mix5-D3-T2-3	2371.00	104.10		
Mix5-D2-T3-1	2362.00	157.33	2365	164.55
Mix5-D2-T3-2	2362.00	170.51		
Mix5-D2-T3-3	2371.00	165.82		
Mix5-D3-T3-1	2362.00	60.23	2364.67	55.38
Mix5-D3-T3-2	2365.00	52.43		
Mix5-D3-T3-3	2367.00	53.49		
Mix6-D1-T1-1	2344.00	174.42	2345	171.36
Mix6-D1-T1-2	2350.00	171.43		
Mix6-D1-T1-3	2341.00	168.22		
Mix6-D2-T2-1	2339.00	165.80	2339	166.9
Mix6-D2-T2-2	2341.00	167.21		
Mix6-D2-T2-3	2337.00	167.70		
Mix6-D3-T2-1	2339.00	84.96	2338.33	83.96
Mix6-D3-T2-2	2337.00	85.85		
Mix6-D3-T2-3	2339.00	81.07		
Mix6-D2-T3-1	2340.00	146.92	2336	151.51
Mix6-D2-T3-2	2335.00	157.13		
Mix6-D2-T3-3	2333.00	150.47		
Mix6-D3-T3-1	2333.00	45.44	2334.67	46.43
Mix6-D3-T3-2	2337.00	47.65		
Mix6-D3-T3-3	2334.00	46.19		

APPENDIX III :

Sika fume
Manufacture data sheet

Product Data Sheet
Edition 04/2006
Identification no:
02 01 01 05 000 0 000019
Sika®-Fume

Sika® -Fume

Additive for Durable and High Ultimate Strength Concrete

Description

Sika-Fume is a new generation concrete additive in loosely agglomerated particles form based on silica fume technology. It is a highly effective additive for the production of high performance concrete.

Uses

Sika-Fume is used to increased the durability and strength of concrete, improve abrasion resistance as well as reduce the permeability of concrete.

Characteristics / Advantages

Sika-Fume improve the performance characteristics of concrete in the following ways:

- Produces high ultimate strength concretes thereby allowing the dimension reduction of structural members.
- Improves hardened properties of concrete such as density, impermeability, resistant to abrasion and attack by aggressive environments.
- Enhances cohesiveness and reduces bleeding of fresh concrete.
- Reduces rebound and increase build-up in shotcreting operations.
- Improve pumpability and flow of concrete, reducing wear on pump equipment, concrete mixers, shotcrete equipment, moulds, etc.
- Increase corrosion and electrical resistance of concrete.
- Reduces effect of alkali aggregate reaction and the like hood of efflorescence.

Storage Conditions / Shelf life

When stored in unopened sealed bags, the product's effectivity will last for at least one (1) year.

Instruction For Use Or Dispensing

1. Add approximately 75% of mixing water, Sika-Fume, aggregate and sand.
2. Allow to mix for at least 1 minute.
3. Add cement, remaining water and required admixtures.
4. For optimum results in concrete, Sika-Fume is always used in conjunction with a super plasticizer admixture.
5. More mixing time is necessary with silica fume compared to conventional OPC concrete.

Technical Data

Form	Agglomerated particles
Appearance / Colour	Grey
Specific Gravity	2.20 (approximately)
Chloride Content	Nil
Dosage	5%-15% by weight of cement
Suitability	Compatible with Portland base cements including sulphate resisting cement
Packaging	20 kg/bag

- Sika-Fume may have some fine powder associated with agglomerated particles
- Wearing of dust mask may therefore be advisable when pouring the product into the mixer.
- Under relevant health and safety codes, Sika-Fume is classified as non-toxic.

Construction

Legal Notice

Sika Philippines, Inc.
Unit A & B
888 Marcos Alvarez, Ave.
Talon, Las Piñas City 1747
Philippines

Tel.no. : 800 1818
Fax. no : 806 2378
www.sika.com.ph

APPENDIX IV :

Sika ViscoCrete
Manufacture data sheet

Product Data Sheet
Edition: 6 - 2010
Version no. 01.10

Sika ViscoCrete® -10

Concrete Admixture

Construction

Product Description

Sika ViscoCrete® -10 is a fourth generation super plasticizer for concrete and mortar. It meets the requirements for super plasticizers according to SIA 162 (1989) prEN 934-2 and ASTM-C-494 Types G and F .

Uses

Sika ViscoCrete® -10 is suitable for production of concrete.

Sika ViscoCrete® -10 facilitates extreme water reduction, excellent flowability at the same time optimal cohesion and hightest self compacting behaviour.

Sika ViscoCrete® -10 is mainly used for the following applications:

- Pre-cast Concrete
- Ready mix concretes.
- Concrete with highest water reduction (Up to 30%).
- High strength concrete.
- Hot weather concrete.
- Self Compacting Concrete (SCC)

High water reduction, excellent flowability, coupled with high early strengths, have a positive influence on the above mentioned applications.

Characteristics / Advantages

Sika ViscoCrete® -10 acts by different mechanisms. Through surface adsorption and sterical separation effect on the cement particles, In parallel to the hydration process, the following properties are obtained:

- Strong self compacting behaviour. Therefore suitable for the production of self compacting concrete.
- Increase high early strengths development,
- Extremely powerful water reduction (resulting in high density and strengths).
- Excellent flowability (resulting in highly reduced placing and compacting efforts).
- Reduced energy cost for stream cured precast elements.
- Improved shrinkage and creep behaviour.
- Reduced rate of carbonation of the concrete.
- Improved Water Impermeability.

Sika ViscoCrete® -10 does not contain chloride or other ingredients promoting corrosion of steel reinforcement. It is therefore suitable to be used without any restrictions for reinforced and prestressed concrete production.

Technical Data

Base	Aqueous solution of modified Polycarboxylates
Appearance / Colour	Turbid liquid
Density	1.08 kg/lt. ± 0.005
Packaging	5 and 20 kg pails 200 kg drums Bulk Tanks packing available upon request
Storage / Shelf Life	12 months from date of production if stored properly in unopened and undamaged, original sealed packaging, in dry temperatures between +5°C and +35°C. Protected from direct sunlight and frost.

Application Details

Dosage / consumption

Recommended dosage

- For medium workability: 0.2 – 0.8% litre by weight of cement
- For flowing and self compaction concrete (S.C.C.) 0.3 – 2 % litre by weight of cement.

Addition

Sika ViscoCrete® -10 is added to the gauging water or simultaneously with it poured into the concrete mixer. For optimum utilisation of the high water reduction we recommend through mixing at a minimal wet mixing time of 60 seconds.

The addion of the remaining gauging water – to fine tune concrete consistency – may only be started after 2/3 of wet mixing time, to avoid surplus water in the concrete.

Concrete Placing

With the use of Sika ViscoCrete® -10 concrete of highest quality is being produced. The standard rules of good concreting practice (production as well as placing) must also be observed with Sika ViscoCrete® -10 concrete.

Fresh concrete must be cured properly.

Compatibility

Sika ViscoCrete® -10 may be combined with following Sika products:

- Sika Pump®
- Sika® Ferrogard® -901
- Sikafume®
- SikaRapid®
- Sika Retader®

Pre-trials trials are recommended if combinations with the above products are being made. Please consult our technical service.

Important Flowing concrete S.C.C

Sika ViscoCrete® -10 is also used to produce flowing and self compacting concrete (S.C.C) For these, special mix designs are required, contact out Technical Service devision.

Safety Instructions

Safety Precautions

In contact with skin, wash off with soap and water.

In contact with eyes or mucous membrane, rinse immediately with clean warm water and seek medical attention without delay.

Ecology

Residues of material must be removed according to local regulations. Fully cured material can be disposed of as household waste under agreement with the responsible local authorities.

Transport

Non-hazardous

Toxicity

Non-Toxic under relevant health and safety codes.

Legal notes

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

THE END:

وفي الختام .....

فإن هذا هو جهد البشر، فإن أصبنا فبتوفيقٍ من الله وحده، وإن أخطأنا فهذا من نقصِ البشر، ولا يسعنا في هذا المقام إلا ما قاله العمادُ الأصفهانيّ:

" إني رأيت أنه لا يكتب إنسانٌ كتاباً في يومِهِ إلا قال في غدِهِ: لو غُيِّرَ هذا لكان أحسن، ولو زِيدَ هذا لكان يُستحسن، ولو قُدِّمَ هذا لكان أفضل، ولو تُرِكَ هذا لكان أجمل، وهذا من أعظمِ العِبَر، ودليلٌ على استيلاء النقصِ على جملة البشر "

والحمد لله رب العالمين

م. أحمد ماهر صيام

22 ديسمبر 2014