**Kaunas University of Technology**

Faculty of Civil engineering and architecture

# Properties Research of Ultra-High-Performance Concrete

Master's Final Degree Project

**Ahmad Al Dahabi**

Project author

**Lekt. Šerelis Evaldas**

Supervisor

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Structural and Building Products Engineering (6211EX008)

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**Lekt. Šerelis Evaldas**
Supervisor

**Dr. Algirdas Augonis**
Reviewer

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Ahmad Al Dahabi

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## Declaration of Academic Integrity

I confirm that the final project of mine, Ahmad Al Dahabi, on the topic "Properties and Technology of Ultra-High-Performance Concrete" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

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## ABBREVIATIONS

**HSC, HPC –** High strength concrete, High performance concrete;

**UHPC –** Ultra-high-performance concrete;

**UHPFRC –** Ultra-high-performance fiber reinforcement concrete;

**ULWC –** Ultra-lightweight concrete;

**SAC –** Semi-Adiabatic Calorimetry;

**PUS** – Power Ultrasound;

**$C_2S$ –** Dicalcium silicate (belite);

**$C_3S$ –** Tricalcium silicate (alite);

**$C_3A$ –** Tricalcium aluminate;

**$C_4AF$ –** Tetracalcium aluminoferrite;

**W/C** – Water-Cement Ratio;

**US -** xSec – Ultra-sound (where x is time for use sonicator), Second (sec);

**C 735 –** Cement (735 quantity of cement in 1$m^3$ of concrete mix), kg;

**QS (x) –** Quartz Sand (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**OS (x) –** Ordinary Sand (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**$SiO_2$ (x) –** Silica fume (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**$TiO_2$ (x) –** Titanium dioxide (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**GP (x) –** Glass powder (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**SP (x) –** superplasticizer (where x is quantity of quartz sand in 1 $m^3$ of concrete mix), kg;

**L –** Length of concrete prism, mm;

**B –** Width of concrete prism, mm;

**H –** Height of concrete prism, mm;

**d –** Density, kg/$m^3$;

**m –** Mass, kg;

**v –** Volume, $m^3$;

**FS –** Flexural strength, MPa;

**CS –** compressive strength, MPa;

**F –** Force, KN;

**A –** Area, $m^2$;

**l –** Distance between 2 supports in flexural test machine

**WC –** white cement

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**Ahmad Al Dahabi.** Properties and Technology of Ultra-High-Performance Concrete. Master's Final Degree Project / supervisor assoc. lekt. Šerelis Evaldas; Faculty of Civil engineering and architecture, Kaunas University of Technology.

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## Summary

In Final Master project was “Properties Research of Ultra-High-Performance Concrete ”. The main thesis **aim** - research the properties of ultra-high-performance concrete such as mechanical and physical properties and check the effect of materials and ultra-sound on it and on hydration process, to produce ultra-high-performance with a high quality.

Producing many samples of ultra-high-performance concrete with different type of sand and cement and with different amount of mineral admixture (silica fume and glass powder) and comparing the properties.

Last part is economical study, calculating the price of 1 $m^3$ of different sample and comparing the cost of 1 MPa of each one.

**Ahmad Al Dahabi.** Ypač stipraus betono savybių tyrimai. Bakalauro baigiamasis projektas / vadovas lekt. Šerelis Evaldas; Kauno technologijos universitetas, Statybos ir Architektūros fakultetas.
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Kaunas, 2019. 58 p.

## Santrauka

Baigiamojo magistro darbo tema „Ypač stipraus betono savybių tyrimai“. Pagrindinis darbo tikslas – ištirti ypač stipraus betono pagrindines technologines, fizikines ir mechanines savybes, ultragarsiniu dispergatoriumi modifikuojant ypač stipraus betono kietėjimo procesus. Visa tai leido sukurti pažangių savybių ypač stiprų betoną.

Tiriamajame darbe buvo nagrinėjami cementinės tešlos kietėjimo parametrai, įvairių vietinių žaliavų įtaka ypač stipraus betono savybėms, taip pat darbe atlikti ekonominiai skaičiavimai.

Pagaminti ultragarso betono pavyzdžiai su skirtingo tipo smėliu ir cementu bei skirtingu mineralinių priemaišų kiekiu (silicio mikro dulkės ir stiklo milteliai), atliktas jų savybių palyginimas.

Paskutinėje dalyje atlikti ekonominiai tyrimai, apskaičiuojant 1 m3 skirtingų mėginių kainą ir lyginant kiekvienos iš jų 1 MPa kainą.

# INTRODUCTION

History and development of concrete?

The concrete was used in Roman Empire, but history of concrete which we use we can say the history of this concrete is from 1824 when (Joseph Aspdin) find material called Portland cement he get patented for this material, it's the most important material in concrete is the basic of concrete which we mix it with sand and aggregate and water then we have the ordinary concrete this material is good in compressive strength but it's not strong enough in flexure and tensile strength, so in 1853 Francoise Coignet, he was the first person use the reinforcement concrete he use it to build his house. But the strength of this material it wasn't so high so because of that the researcher and Scientists start to develop and increase the properties of concrete. In 1980 they find a relation between the water cement ratio and strength of concrete when the water cement ratio decreasing the strength of concrete increasing according to this information and using fine materials (fine aggregate and sand), they produce a concrete with compressive strength between 50 – 100 MPa the type of concrete called high-strength concrete (HSC or HPC).

Best example of HPC is "Burj Khalifa" in Dubai the concrete used is high-performance concrete guarantee low permeability and higher durability class used isC50, C60 and C80 to arrive to that high (828 m).

## Statement of the Problem

Nowadays the building is become higher and the countries competing which one will build the highest building or tower in the world so to achieve that we need concrete which can resist all this high load.

This new type of concrete is called Ultra-high-performance concrete (UHPC).

What is (UHPC)?

Ultra-high-performance concrete which is symbolic by (UHPC) is Building material so it's a spatial type of concrete is founding in century 20 in (1990) the idea of (UHPC) is producing new type of concrete with low Porosity, high strength and high durability to produce this type they use very fine materials (Silica fume, Glass powder and Fly ash) and they decrease the water cement ratio so much by using (superplasticizer).

This concrete type is possible to be increasing the flexural strength by adding fiber steel is symbolling by (UHPFRC) Ultra-high-performance fiber reinforcement concrete.

Properties of this concrete are:

- Compressive strength higher than 100 – 120 MPa
- Flexural strength 10 times higher than ordinary concrete.
- Self-compacting concrete mix

The Shawnessy Light Rail Transit (LRT) Station, constructed during 2003 and 2004, forms part of a southern expansion to Calgary's LRT system and is the world's first LRT system to be constructed with ultra-high-performance concrete (UHPC).

**Aim of work**

Research the properties of ultra-high-performance concrete such as mechanical and physical properties and check the effect of materials and ultra-sound on it and on hydration process, to produce ultra-high-performance with a high quality.

**Objectives**

- Research main workability and mechanical properties of UHPC.
- Research the effect of ultra-sonic activation on cement paste and concrete.
- Research the effect of ultra-fine materials and chemical admixture on properties of UHPC
- Develop eco-friendly, economic with good mechanical and durability properties UHPC.

# 1. LITERATURE REVIEW

## Cement hydration process

To know the cement hydration reaction process first should know the compounds of cement, the cement compound is Dicalcium silicate ($C_2S$), Tricalcium silicate ($C_3S$), Tricalcium aluminate ($C_3A$), Tetracalcium alumino ferrite ($C_4AF$) and gypsum.

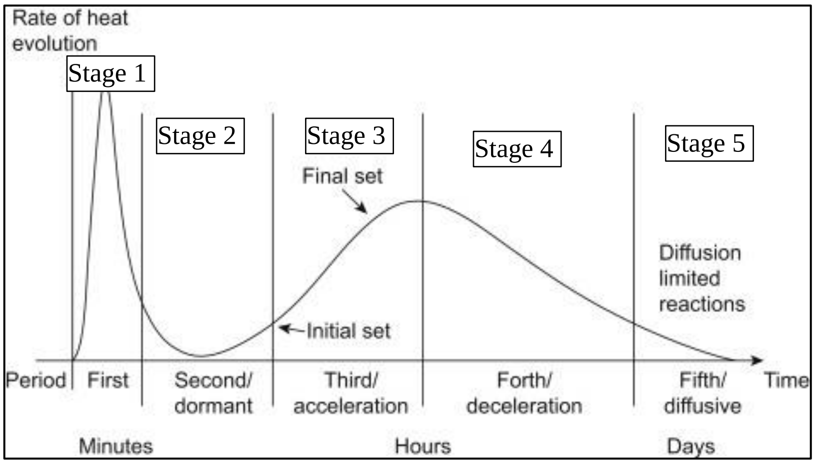


**Fig. 1.1** Stage of cement hydration process [1]

Stage 1: is a fast stage is finish in some minutes (10 – 15 min) in this stage the PH is increasing more than 12 and, in this stage, the tricalcium aluminate react with a gypsum and product ettringite.

If the all the quantity of gypsum is reacted and finish before the tricalcium aluminate so the quantity left of $C_3A$ is begin in hydrate

$C_3A + 6H \rightarrow C_3AH_6$ ($C_3AH_6$ which is stable for cubical crystals, with high sulfate resistance.

Stage 2: this stage is called (dormant period) this stage is complete for an hour (2-4) that why the concrete is remains in plastic state for an hour.

Stage 3: this stage corresponds to acceleration period is staring after dormant stage and staying for (3 - 10h) calcium silicates is hydrate at this stage ($C_3S$) and ($C_2S$).

$2\ C_3S + 6\ H \rightarrow C_3S_2H_3 + 3\ Ca(OH)_2$

$2\ C_2S + 4\ H \rightarrow C_3S_2H_3 + Ca(OH)_2$

The C-S-H is starting formation in this stage and starting crystallization this stage is starting with initial setting time and ending with final setting time which the temperature of reaction is max.

Stage 4: the second Hydration of tricalcium silicate and producing long ettringite and C-S-H which is inner products starts form inside the shell. If silica fume is adding to mixture at this time the SiO2 in silica fume is reacted with CH which is producing from stage 3 and formation more C-S-H which can increase the strength of concrete.

Stage 5: C-S-H is formation, reduction of shell separation.

## 1.1. SEMI-ADIABATIC CALORIMETRY EVALUATION FOR UHPC

The goal of semi-adiabatic test is measuring the heat producing of Reaction and according to the temperature we can know hydration setting time and higher temperature the reaction if it's good or no. The temperature is a catalyzer of reaction and temperature and Reaction are proportional, so higher temperature means better reaction.

- Heat flow is determined with a calibrated temperature transducer
- Heat flow is determined from a cooling factor or coefficient of temperature loss

semi-adiabatic setups of the concrete temperature are registered as a function of time. The semi-adiabatic setup allows for energy losses, which are accounted for in the evaluation process.

- The temperature in the concrete sample and the ambient air are equal when starting the semi-adiabatic measurement.
- The air temperature is constant during the test period.

To ensure these conditions limits are usually specified, e.g. the temperature of the fresh concrete mix should be within ±2°C of the calorimeter temperature [3], and the ambient temperature where the calorimeter is placed should be within the limit 20±1°C. In the laboratory, where the mixing of the constituents of the concrete occurs, the air temperature should be within 20±2°C. The room, where the test is conducted, have the corresponding limit 20±1°C, and the reference temperature should not differ more than ±0,5°C throughout the test [4].

When heat flow is directly measured with a calibrated temperature transducer, the points above are not that important. However, limits are still used, and in the laboratory[5], where the test is conducted and where the mortar constituents are stored, the room temperature should be within 20±2°C. In this paper, heat flow is calculated from the sample temperature, and, our limits are the same as in [5].

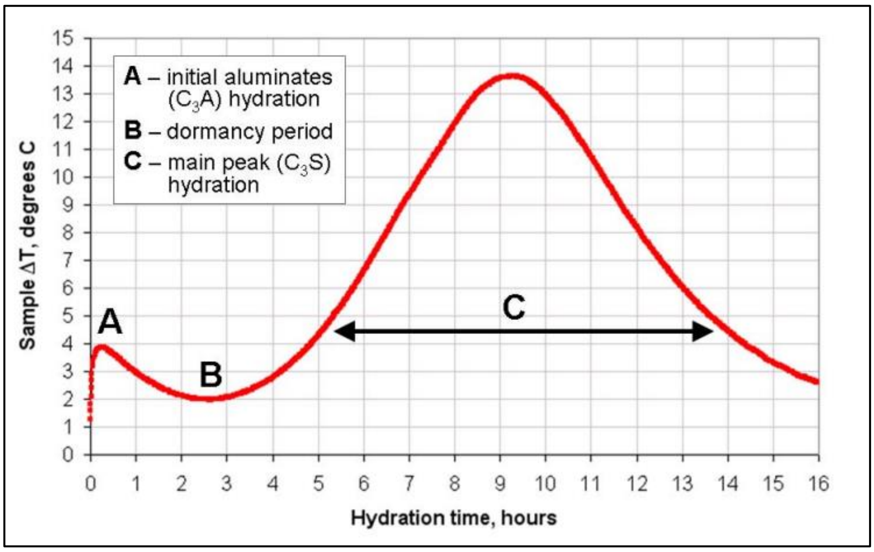


**Fig. 1.2** Semi-adiabatic test of cement hydration process. [6]

## Semi-Adiabatic Calorimetry (SAC).

The Semi-Adiabatic Calorimetry study is study of heat evolution from hydration mixtures this instrument for estimate performance it's not a new. It was used by Lerch in the 1940s to cheque effects of various cement properties on performance (Lerch 1946). Isothermal conduction calorimetry tool was used by many researchers in the last years.[7][8][9]

Isothermal calorimetry, it's better when the results needed is quantitative, firstly a laboratory tool it's an expensive equipment and in general the test part is a small sample of paste, in otherwise it can have similar results with inexpensive equipment in the lab or field with (paste, mortar or concrete).[10][11]

**Fig. 1.3** Solidus Integration thermal system for "coffee cup" calorimetry.[6]

**Fig. 1.4** Grace radical portable field calorimeters.[6]

In **Fig. 1.3.** And **Fig. 1.4.** The 2 method is method are Semi-Adiabatic Calorimetry And they give the same results the most important in isothermal test is isolation to isolate samples from outside temperature and condition should be the same.

## 1.2. THE INFLUENCE OF POWER ULTRASOUND

"In general sound is defined as waves of compression and expansion crossing gases, liquids or solids. Talking about ultrasound these sound waves possess frequencies above human hearing" (approximately 20 kHz to 100 kHz). [16][12][13] "To generate ultrasound most commonly a piezoelectric ceramic is exposed to a high altering electric current. In this electrical field the piezoelectric ceramic expands and contracts. Consequently, occurring mechanical vibrations are transferred e.g. via an amplifying horn into the medium. In 1894 fatal vibrations were noticed by Thornycroft and Barnaby for the first time. They observed significant erosions on the screw – propeller of British destroyers. Later (1917) Lord Rayleigh evolve a first mathematical model in order to calculate the pressure in a fluid during cavitation collapse".[14] "The chemical effects of ultrasound were first investigated by a group around Alfred Lee Loomis in 1927". [15] "Besides the description of discharging effects due to irradiation as well as "atomizing" effects they also call for attention to the fact that the temperature raises due to energy absorption. Among other things they could evidence the de-airing effect of PUS as well as the acceleration of certain chemical reactions". [15]

In following years Patents on cleaning (1943, DE 733470C) and emulsification (Swiss Patent 394.390) were granted. Since the 1950´s research in the field of ultrasound and cavitation becomes intensified.

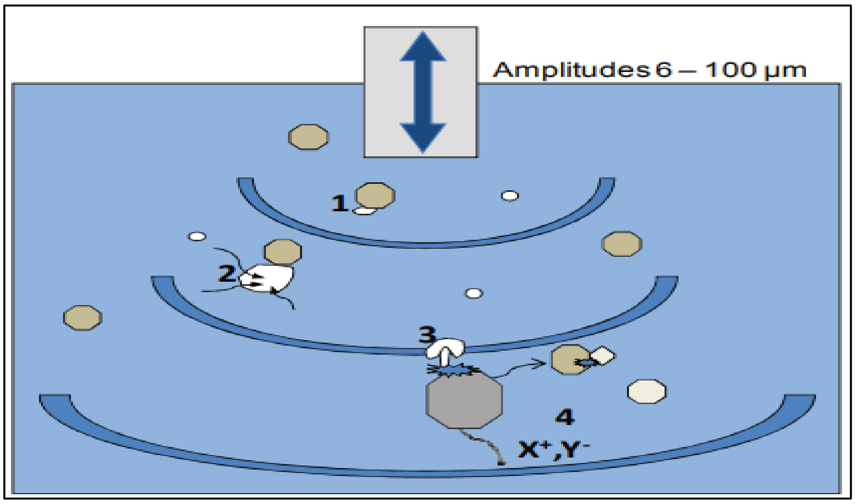


**Fig. 1.5** Principle life of cavitation bubbles in the presence of a high intensity sound wave field. 1: Bubble formation. 2: Bubble growth, energy adsorption. 3: Bubble collapse. 4: Formation of "jet streams" and shock waves. [17]

the cavity during a sonication in an aqueous solution containing a very small number of particles. For the period of rarefaction cycle, the small bubbles of gas are released into solution out of crevices of particles due to gas expansion in the negative pressure field (no. 1, **Fig. 1.5**). Subsequently altering compression and expansions cycles cause the cavity bubble to grow. Meanwhile the cavitation bubble absorbs energy from the system (no. 2, **Fig. 1.5)**. However, the process of bubble growth depends on the intensity of sound. [16]

**evolution of temperature**

The temperature of hydration reaction of mortar is measured by semi adiabatic method to cheque

the changing of temperature and what is the influences of US on hydration reaction the steps of semi adiabatic test is as showing semi adiabatic part.

**Influence of PUS on microstructure**

Development of microstructure in dependence of hydration time and PUS application was examined by high resolution SEM imaging (Nova NanoSEM 230, FEI, Netherlands).

The images are recorded at initial setting time of cement hydration reaction (unsonicated and sonicated) cement suspensions 3 different period first is at 3hours and 30 min second at 5 hours and the last at 6hours and 30 min. [17]

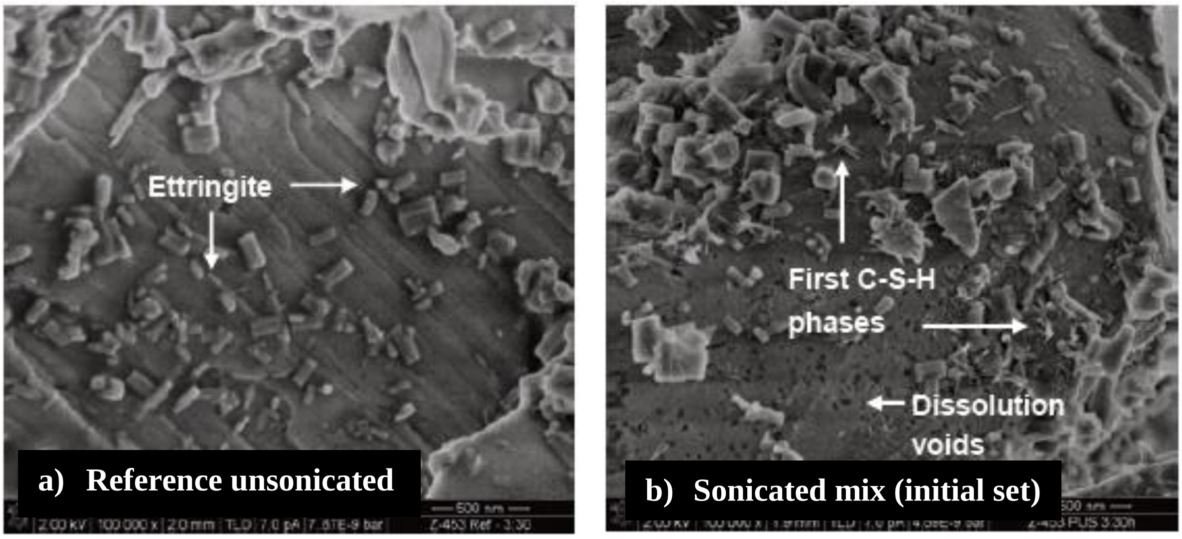


**Fig. 1.6** Microstructure of cement suspension at 3h 30 min hydration. [17]

From the Fig 5a it's clearly only the ettringite can be observed in the reference mix sample in first period after 3hours and 30 min of hydration. In otherwise at same time in Fig 5b which the sample is sonicated it's visible on $C_3S$ surfaces the first C-S-H phases are formation and seen in Fig 5b.

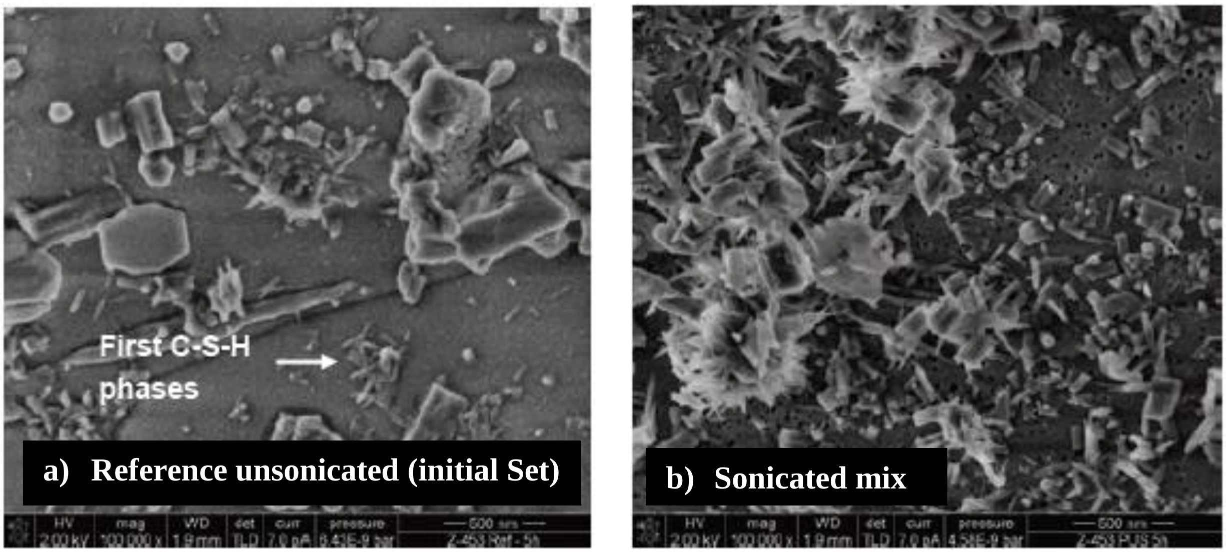


**Fig. 1.7** Microstructure of cement suspension after 5h of hydration. [17]

From Fig. 6a reference mix the first C-S-H is formed after 5 h from starting the hydration reaction which is late 1.5 h on the first formation of C-S-H in the mix which the US is used in Fig 6b the formation of C-S-H is too much bigger than formation in reference mix. So, the US is affecting on hydration process is enhances the dissolution of C3S and accelerates the growth of C-S-H phases, increasing the formation of C-S-H and that is so clearly after 6 h 30 min of hydration reaction in the Fig 7b coMParing with Fig 7a formation of C-S-h in mix sonicate after 5h in Fig. 6b is higher than formation of C-S-H in reference mix after 6h 30 min in Fig 7a.

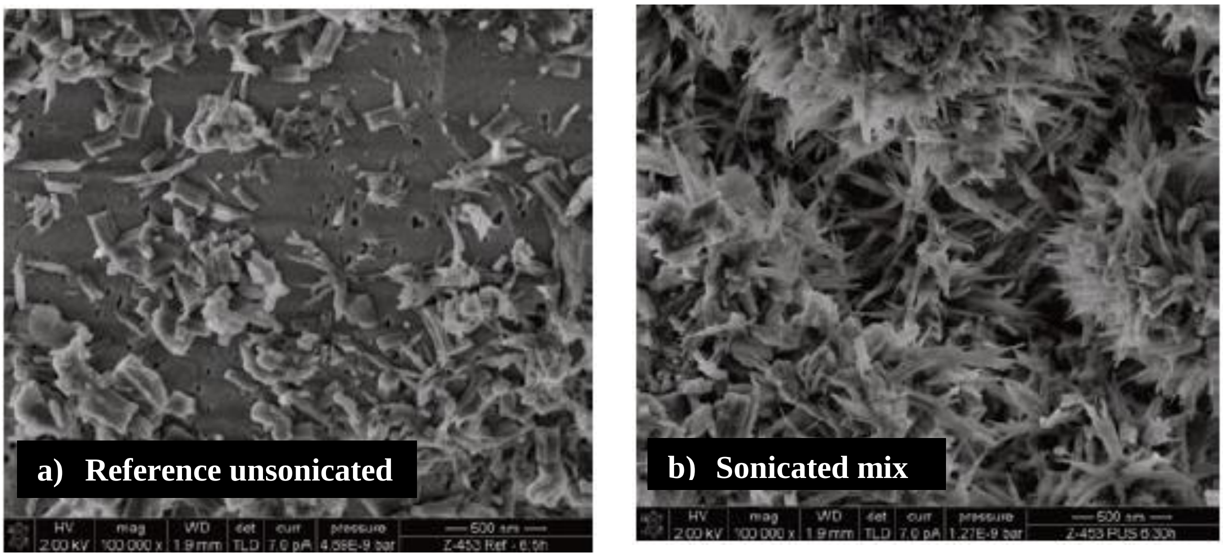


**Fig. 1.8** Microstructure of cement suspension after 6h 30min of hydration. [17]

So, US is accelerating the initial setting time of hydration process and accelerated the alite of hydration and enhanced the heat released.

### 1.3. FLOWABILITY

The flowability test is a means the rating of concentration or consistency of fresh concrete and this test is used to cheque if the amount of water is Consistent with the mix or not because if the amount of water is higher than needed then the mix will segregate and if it's lower than needed so the mix will be not compacting in the shape between the reinforcement and this test is testing according to standard flow test by EN 459-2, 1015-3 A it's 4 -inch cone.

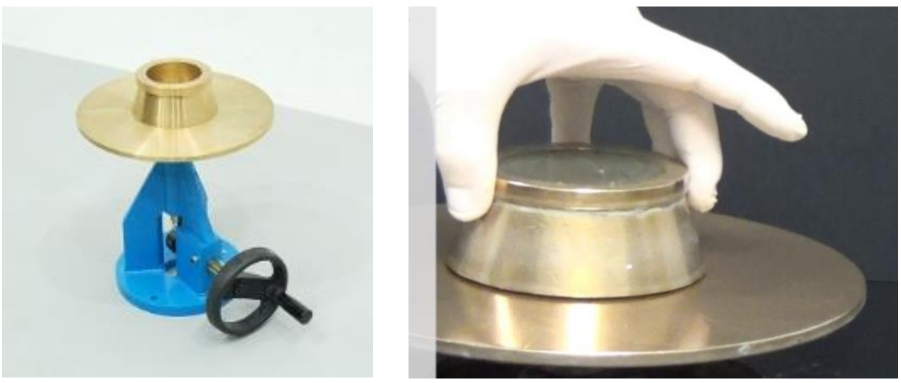

**Fig. 1.9.** Brass flow table test. [47]

There are two models of mortar and cement past flow table according to EN and ASTM standards. These 2 standards are describing by **Table 1**.

**Table 1.1** Flow table standards.

| | ASTM, Standards | EN, Standards. |
|---|---|---|
| **Table diameter** | 254 mm | 300 mm |
| **Cone Base/ Top Diameter** | 100 mm / 70 mm | 100 mm / 70 mm |
| **Cone Height** | 50 mm | 60 mm |
| **Drop Height** | 12.7 mm | 10 mm |

Flow table equipment will consist of a complete cast solid iron structure (frame) a circular rigid table with 25.4 mm or 300 mm of diameter, with a shaft attached perpendicular to the table as showing in the **Fig. 1.9.** The flow is calculated by radius or diameter of circle of mortar which is flowing on the metallic table which has an eight equidistant line with distance 68 mm . "extending from outside of circumference toward the center of the table". **[18]**

## 1.4. DENSITY

In general concrete is not a natural material which can find it in nature. Concrete is a fabricate material which is mad it from different materials, essentially materials for mad concrete are: Portland cement, aggregate, sand, water and air and some spatial type of concrete other materials are used. All these materials are collecting to each other by a chemical reaction called hydration reaction which is between a cement water and air. **[19]** Concrete is transfer from plastic to hard solid material. Density of concrete is affected by different several materials which is made a concrete such as density of aggregate or sand, type of cement. **[20]** Applying the correct treatment (curing) has a significant effect on the density and compressive strength of the concrete **[21]**.

The density or mass volumetric for liquid one of properties of materials is symbolic by (d or ρ) the unit of density in system international is ($Kg/m^3$) and the materials has different density and when the density is higher that mean the material it's more heavy and stronger.

To calculate the density of material we should calculate the mass and volume of material and then divide the mass on volume: $d = \frac{m}{V}$ ($Kg/m^3$).

Density of concrete related so much with density of aggregate. There is lightweight concrete which is defines by density, $800 \leq d \leq 2000$ Kg/ $m^3$, Nevertheless, it does not specify and thus is not applicable to concretes having the dry densities lower than 800 kg/m3 . One novel type of concrete that falls under this density class has been developed recently in the Netherlands, called “Warmbeton”. [22] [23] [26] Otherwise there is other type of concrete has density d ≤ 800 Kg/ $m^3$ which called ultra-lightweight concrete. [24] [25] [26]

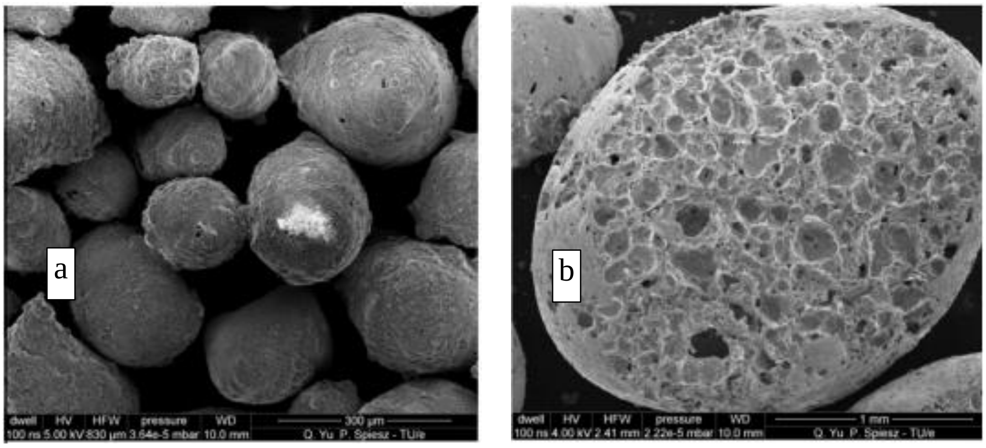


**Fig. 1.10** Light weight aggregate. a ) external surface of LWA,b) internal surface LWA [27]

In concrete we have different types, so we have different density and the strength of concrete also is related with the density of concrete and the density of concrete is related with the density of materials which is used in the concrete mix such as density of (sand, aggregate, cement, etc.)

So, we have high concrete density which has density d ≥ 2600 kg/m3 this concrete is called heavy concrete.

Ordinary concrete has density 2100 ≤ d ≤ 2400 Kg/$m^3$.

And the light weight concrete 800 ≤ d ≤ 2000 Kg/ $m^3$.

The ultra-light weight concrete has density 100 ≤ d ≤ 800 Kg/ $m^3$.

Normal ordinary concrete density is between 2000 to 2200 Kg/$m^3$.

**Ultra-high-performance concrete**

Ultra-high-performance density is higher than normal concrete because of small particles (micro size) like silica fume glass powder (quartz powder). Density of UHPC is between 2200 – 2400 Kg/$m^3$.

**Table 1.2** Typical composition of UHPC.[28]

| UHPC constituents | Range (% by weight) |
|---|---|
| Cement | 27 – 40 |
| Silica fume | 6 – 12 |
| Quartz powder | 7 – 14 |
| Sand | 35 – 45 |
| Water | 0.5 – 3 |
| Superplasticizer | 4 – 10 |
| Steel fiber | 0 – 8 |

**High-Density Concrete**

Most time high-density concrete is used to save from radiation in station like nuclear station to save from radiation because high-density concrete has more durability of normal concrete which can prevent the radiation from cross Through because of high density materials inside it. There is a lot of other used for high-density concrete where we need heavy materials like in tower crane or in the see to save from waves on cable and so on. The density of high-density concrete is higher than 2600 $Kg/m^3$.[29]

## 1.5. FLEXURAL STRENGTH

Flexural strength is the ability of the slab or beam to resist the load which is affected on it (resist failure in bending).

It's measuring by applying a load on unreinforced concrete beam with spatial dimension some time (150 x 150) with length usually 450 mm 3 time the depth or(140 x 140), (100 x 100) it's depended of machine used. The unit of flexural strength is MPa or ($N/mm^2$) in European standards.

Flexural strength is almost 10 – 20 % of compressive strength, there is 2 way to do flexural strength as showing in **Fig.10**. [30]

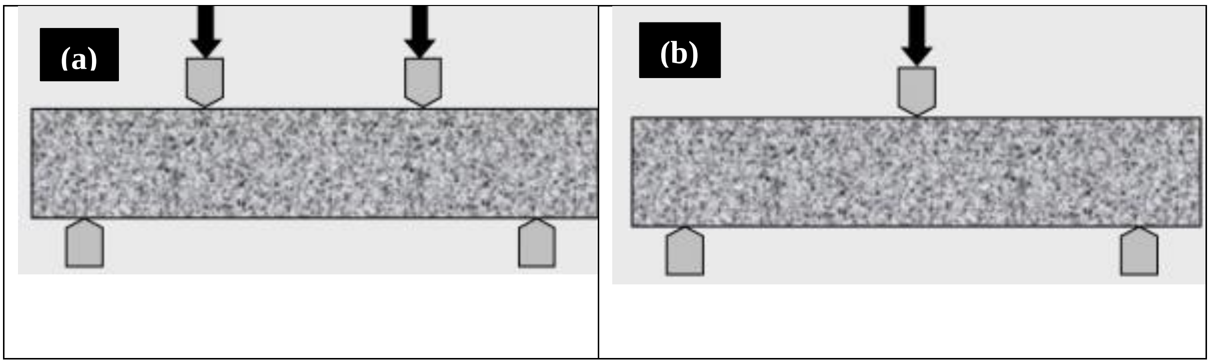


**Fig. 1.11** Flexural strength **a)** The load is applied at two points. **b)**The load is applied at 1 point [30]

Usually strength of concrete is related with 2 variant tensile or flexural strength and compressive strength every type concrete has range of strength which is specific this type of concrete for example normal concrete has flexural strength 3 – 5 MPa and compressive strength 20 – 40 MPa.

The ultra-high-performance concrete has flexural and compressive strength higher than normal concrete can be 3 – 10 time higher or even higher in some spatial condition. [31]

“ultra-high-performance concrete, most of stress-strain relation shapes are triangular under compression. Therefore, under compression, triangular stress block may be used for the design of ultra-high-performance concrete flexural members”. [32]

## 1.6. COMPRESSIVE STRENGTH

Compressive strength of concrete cube test provides an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. Concrete compressive strength for general construction varies from 20 MPa to 40 MPa and higher in commercial and industrial structures.

According to compressive strength the concrete is classified in 5 type from the lower compressive strength to higher: - ultra-lightweight concrete, lightweight concrete, normal or ordinary concrete, high strength concrete and ultra-high-performance concrete.

Ultra-lightweight concrete has prospect enforcement as natant structure and architectural elements. ULWC is a good insulating because of air bubble inside it and it’s a fire resistant. Lightweight concrete was available since 1950s and it was useful in high building. [33] ULWC has low compressive strength which is lower than 10 MPa.

Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, quality control during production of concrete etc.

Light weight concrete is called also light strength concrete has strength lower than 20 MPa. [34] [26]

high strength concrete $50 \geq C.S \geq 100$ MPa and ultra-high strength concrete $C.S \geq 100$ MPa.

Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test.

Compressive strength calculated according to formula C.S = F/A (where F is the force to break the sample of concrete unit in KN and A is the area where is the force applied unit in $mm^2$).

### Ultra-high-performance concrete

(UHPC) ultra-high-performance concrete it's one of most type of concrete researching at recent days because it can be most economical and has long life because it has high durability. [35] [36] The research which made it on (UHPC) led to improve the quality and properties (strength) of (UHPC). [36] [37] [38]

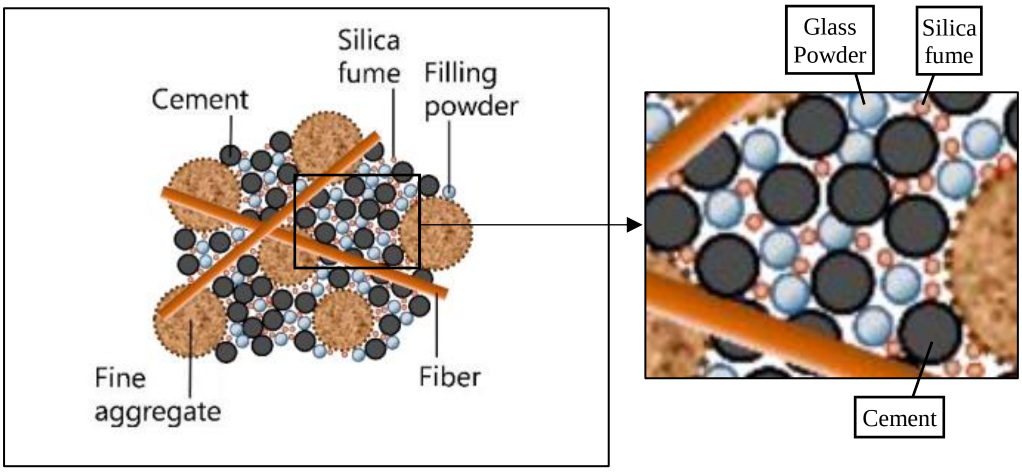


**Fig. 1.12** Distribution of particles in (UHPC). [38]

The increasing of compressive strength in concrete is much more related with water cement ratio and is related with quantity of silica fume which is replacement with cement. Compressive strength is increase with silica fume content up to 20% and it's arrived at maximum for a 10 to 15% sf quantity according to cement quantity. [39]

Compressive strength of UHPC with cement ratio W/C = 0.2 and curing in oven 48 h under temperature 90 °C it's 201 MPa. [38] [39]

### Durability and Practical application of UHPC

Ultra-high-performance concrete not only better than normal concrete in strength, but it's also better in durability. Durability of concrete is more related with the microstructure of concrete and specially pore structure and absorbing the water is harmful element in concrete because inside water there is sulfate and chloride which can make damage in concrete with time and absorbing water can exposing concrete to the risk of frost. [40]

Frost resistance test of concrete is test to cheque how much the concrete can resist the freezing. Frost resistance test is generally evaluated by measurement of mass of materials in ($Kg/m^2$) which is represent concrete slab after 56 freeze-thaw cycles. Frost resistance is F112 which mean 112 cycles. [41]

The places where can use UHPC is bridges, railway, building the reason of using the UHPC in these places is because UHPC has high compressive strength (100 – 150 MPa) even higher and higher flexural strength (15 – 25 MPa), example about UHPC Shawnessy Light Rail Transit Station, Calgary, Canada, Fondation Louis Vuitton pour la Creationin, Paris, France, Sakata-Mirai bridge, Sakata, Japan, bridge in Wapello county United States of America. [41] [42] [43]

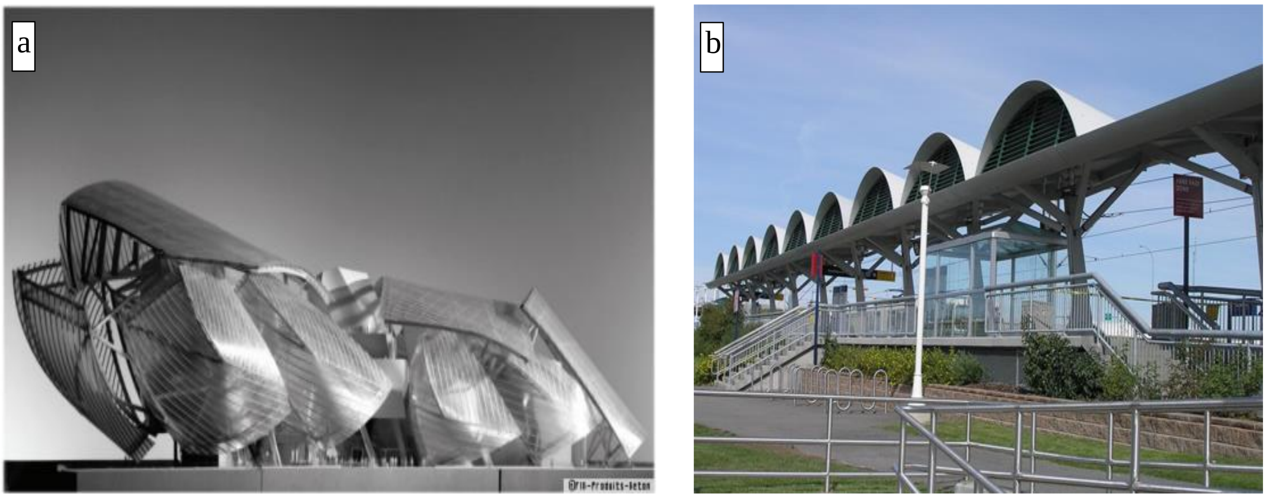


**Fig. 1.13** UHPC construction a) Fondation Louis, Paris, France b) Shawnessy Light Rail Transit Station, Calgary,Canada. [40]

**Conclusions of literature review**

- According to literature review it was not clearly how the workability and mechanical properties of UHPC affect.
- It was not clearly in literature review how the ultrasonic effecting on cement hydration process and on UHPC properties .
- In literature review it was not clearly how the fine materials effect on cement hydration process and UHPC properties
- How to create or develop UHPC with a low price and good properties .

**Task**

- Check the workability and mechanical properties of UHPC.
- Check the effect of ultrasonic activation on cement paste and concrete.
- Check the effect of ultra-fine materials and chemical admixtures on properties of UHPC.
- Develop eco-friendly, economic with good mechanical and durability properties UHPC.

# 2. USED MATERIALS

## 2.1. CEMENT

Grey Portland cement: (chemical composition)

The Portland cement used in these experiments is CEM I 52.5 R (EN 197-1:2011/P:2013) [44]. Density is 3150 kg/ $m^3$. The specific surface is 4840 $cm^2/kg$ (by Blaine). The setting time is between (initial setting time 60 min/ final setting time 600 min). The compressive strength after 28 days is between 20/60 MPa. The percentage of mineral composition could be quantitatively expressed as: $C_3S$ – 68.70 %; $C_2S$ – 8.70%; $C_3A$ – 0.20%; $C_4AF$ – 15.90%.

White Portland cement:

White cement (EN 197-1:2011/P:2013 CEM I 52.5 R; The density of cement is 3150 $kg/m^3$). The specific surface is (fineness) 395 $m^2/kg$ (by Blaine). The setting time is 100 min. The compressive strength after 28 days is between 20/60 MPa.

## 2.2. MINERAL ADMIXTURE

Silica fume:

This material is also called micro-silica (EN 13263-2:2005+A1:2009) [45] this name is because of the size of silica fume in micrometer and the density of this material 1350 $kg/m^3$ and pH – 5.3. The specific surface of silica fume (fineness) is. Silica fume has big amount of Silicon $SiO_2$ > 85%. Specific gravity is 2.2 $g/cm^3$.

Glass Powder:

Glass powder is used in these experiments and the properties of (GP) are density d=2528 $kg/m^{3;}$ the average particle size of glass powder is 26 µm. The perimeter surface is 335 $m^2/kg$ (by Blaine).

## 2.3. AGGREGATE

Quartz Sand:

In these experiments the quartz sand is used with properties fraction equals 0/0.5; density 2650 $kg/m^3$ and specific surface is 9.1 $m^2/kg$ (by Blaine).

Grinded sand:

Fraction of sand is 0.2 mm, was used. The specific density is 2390 $Kg/m^3$. Specific particles surface area of 1103 $cm^2/g$. the average particle size – 691.17 µm.

**Table 2.1** Chemical composition of Portland cement. Silica fume and glass powder

| **Components** | **Portland cement** | **Silica Fume** | **Glass Powder** |
|---|---|---|---|
| | **(CEM I 52.5R) %** | **(%)** | **(%)** |
| $SiO_2$ | 21.10 | 93.2 | 72.76 |
| $Al_2O_3$ | 3.42 | 0.44 | 1.67 |
| $TiO_2$ | 0.22 | - | 0.04 |
| $Fe_2O_3$ | 5.23 | 0.2 | 0.79 |
| MnO | 0.05 | 0.81 | 0.02 |
| MgO | 0.79 | - | 2.09 |
| CaO | 66.40 | - | 9.74 |
| $SO_3$ | 1.93 | - | 0.1 |
| $Na_2O$ | 0.19 | - | 12.56 |
| $K_2O$ | 0.38 | 0.49 | 0.76 |
| $P_2O_5$ | 0.28 | - | 0.02 |
| $Na_2O_{ekv.}$ | 0.44 | - | 13.06 |

## 2.4. CHEMICAL ADMIXTURE

superplasticizer:

(SP) (EN 934, EN 480) [46] is used in these experiments which is based on polycarboxylic ether; the (SP) is dark brown liquid with pH value 7 ± 1; it had 60.1 % chloride content and 65% alkali content. its specific gravity measured 1.08 ± 0.02 g/cm3 at temperature (20 C).

## 2.5. TITANIUM DIOXIDE

Titanium dioxide:

In the experiment titanium dioxide was used. The main properties of titanium dioxide are: standards (EN 71-3 2013) chemical composition is 59.93% titanium and 40.55% oxygen with pH=7.

Distribution of materials

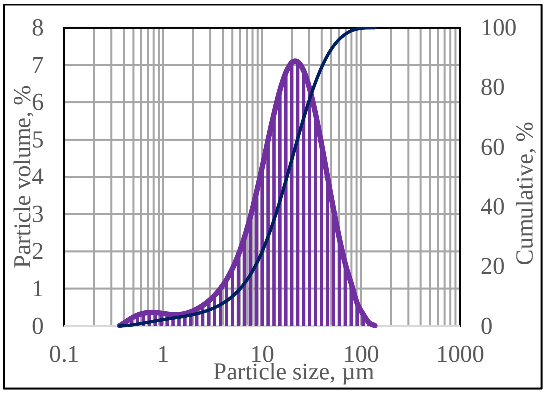


**Fig. 2.1** Distribution of cement particles

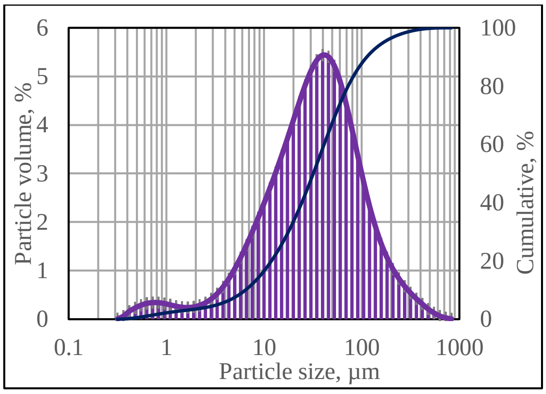


**Fig. 2.2** Distribution of $SiO_2$ particles

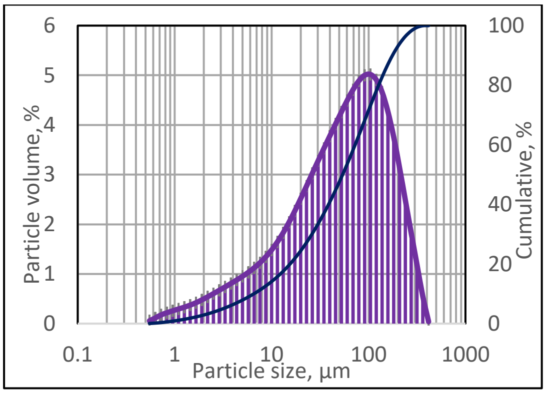


**Fig. 2.3** Distribution of $SiO_2$ particles

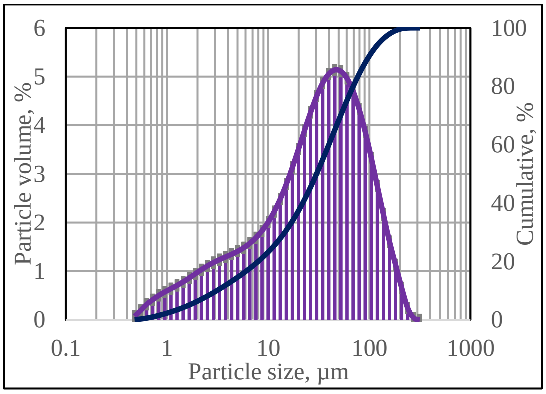


**Fig. 2.4** Distribution of Sand particles

# 3. METHODS

## 3.1. PARTICLE SIZE DISTRIBUTION

(specific surface area).

The particle size distribution was measured with a ‘‘Mastersize 2000” instrument.

The specific surface area of materials was measured by using Blaine instrument, according to the EN 196-6:2010 standard.

## 3.2. CEMENT PAST

**Table 3.1** Cement paste with different amount of superplasticizer, unit is (Kg per $1m^3$).

| Mix | Notation of mix | C (Kg) | SP (Kg) |
|---|---|---|---|
| **1** | C 735, SP 0 | 735 | - |
| **2** | C 735, SP 29.4 | 735 | 29.4 |
| **3** | C 735, SP 36.75 | 735 | 36.75 |
| **4** | C 735, SP 44.1 | 735 | 44.1 |
| **5** | C 735, SP 51.45 | 735 | 51.45 |

**Table 3.2** Cement paste with different amount of silica fume, unit is (Kg per $1m^3$).

| Mix | Notation of mix | C (Kg) | SIO2 (Kg) | SP (Kg) |
|---|---|---|---|---|
| **6** | C 735, SP 0, SIO2 0 | 735 | - | 36.75 |
| **7** | C 735, SP 36.75, $SiO_2$ 36.75 | 735 | 36.75 | 36.75 |
| **8** | C 735, SP 36.75, $SiO_2$ 73.5 | 735 | 73.5 | 36.75 |
| **9** | C 735, SP 36.75, $SiO_2$ 110.25 | 735 | 110.25 | 36.75 |
| **10** | C 735, SP 36.75, $SiO_2$ 147 | 735 | 147 | 36.75 |

**Table 3.3** Cement paste with different amount of titanium dioxide, unit is (Kg per $1m^3$).

| Mix | Notation of mix | C (Kg) | SP (Kg) | TIO2 (Kg) |
|---|---|---|---|---|
| **11** | C 735, SP 36.75, $TiO_2$ 0 | 735 | 36.75 | - |
| **12** | C 735, SP 36.75, $TiO_2$ 14.7 | 735 | 36.75 | 14.7 |
| **13** | C 735, SP 36.75, $TiO_2$ 36.75 | 735 | 36.75 | 36.75 |
| **14** | C 735, SP 36.75, $TiO_2$ 51.45 | 735 | 36.75 | 51.45 |
| **15** | C 735, SP 36.75, $TiO_2$ 73.5 | 735 | 36.75 | 73.5 |

**Table 3.4** Ultra-sonic activation according cement paste mix, unit is (Kg per $1m^3$;second).

| Mix | Notation of mix | C (Kg) | SP (Kg) | US-(Sec) |
|---|---|---|---|---|
| **16** | C 735, SP 36.75, US-0 Sec | 735 | 36.75 | - |
| **17** | C 735, SP 36.75, US-5 Sec | 735 | 36.75 | 5 |
| **18** | C 735, SP 36.75, US-10 Sec | 735 | 36.75 | 10 |
| **19** | C 735, SP 36.75, US-20 Sec | 735 | 36.75 | 20 |
| **20** | C 735, SP 36.75, US-30 Sec | 735 | 36.75 | 30 |

**Table 3.5** Mixes with and without ultra-sonic activation, unit is (Kg per $1m^3$; second).

| Mix | Notation of mix | C (Kg) | SIO2 (Kg) | GP (Kg) | SP (Kg ) | U-S (Sec) |
|---|---|---|---|---|---|---|
| **21** | C 735, GP 412, SP 36.75, US-0 Sec | 735 | - | 412 | 36.75 | - |
| **22** | C 735, GP 412, SP 36.75, US-10 Sec | 735 | - | 412 | 36.75 | 10 |
| **23** | C 735, SIO2 99, SP 36.75, US-0 Sec | 735 | 99 | - | 36.75 | - |
| **24** | C 735, SIO2 99, SP 36.75, US-10 Sec | 735 | 99 | - | 36.75 | 10 |

**Table 3.6** Explain the notation in Tables

| Notation | Meaning of notation |
|---|---|
| **C735** | Quantity used of cement in 1 $m^3$ of concrete mix is 735 kg. |
| **$SiO_2$99** | Quantity used of silica fume in 1 $m^3$ of concrete mix is 99 kg. |
| **GP412** | Quantity used of glass powder in 1 $m^3$ of concrete mix is 412 kg. |
| **$TiO_2$73.5** | Quantity used of titanium dioxide in 1 $m^3$ of concrete mix is 73.5 kg. |
| **SP 36.75** | Quantity used of superplasticizer in 1 $m^3$ of concrete mix is 36.75 kg. |
| **US-10 Sec** | The time to use Ultrasonic Probe Sonicate is 10 second. |

### 3.2.1. MIX PROCEDURE:

After balancing the materials put the dry materials (cement, silica fume and glass powder) in vessel and mix till the materials is mixed, then add the liquid materials (water and superplasticizer) (water cement ratio is W/C = 0.3), and mix the materials together for the first minute of mix the materials is became darker then after 2 min the materials is joining and the mix became like mingled and denser, after 3-4 min of mixing the mix is mixed good and have the final form of concrete mix.

In semi adiabatic test the temperature it's the variable so because of that in could country we made this test in winter when the temperature of the room is approximately constant because of heating but the problem in winter the water is so cold to solve this problem we put the water in bottle and we put it in the room 1 day before the test to take the same temperature of room.

During the mixing time all the mix should has the same condition for example the vessel where we mix should be dry in all the mix.

### 3.2.2. HIGH-INTENSITY SONICATION:

In the part of effect of ultra sound on cement paste. When the mixes are ready (mix16 till mix24) which they are showing in the **Tables** (3.4 – 3.5), now we use the sonicate, we put the horn of sonicate in the middle of mix and we start moving the mix carefully without touching the border or bottom of vessel to be sure the ultra sound is moving in the mix. When the sonicate is used we can hear noise sound and feel like vibration.

### 3.2.3. SEMI-ADIABATIC CALORIMETRY

When the cement paste concrete mix is ready at this moment the computer should be turned on and connected with the reader which is connected by cables from other side and the system of program should be activated and ready to start and we cheque all the cable if it's working correctly and reading temperature.


**Fig. 3.1** Semi-Adiabatic Calorimetry test sample preparation.

Then we put the mix in tube which is smutch by oil the aim of oil is to be easy cleaning later after the hardening of mix. We start program then put the cable which has at the tip copper to read the temperature, and we put this cable in small Rubber tube which is closed in the border to not allow the concrete or air to enter to this cable then we put this tube in the middle of mix which is in the big tube then we cover the plastic tube by plastic cover then after that we add mix by mix in the same way and the program is activated. When all the mixes are put it in the tubes and connected with the system, we put the tube in insulation in this lab is polystyrene insolation and we covered also by polystyrene isolation the isolation should cover all the tubes mixes from every side the idea of isolation is to isolate the reaction temperature to outside temperature as we see in **Fig. 3.1**

## 3.3. CONCRETE

### 3.3.1. MIX PROCEDURE:

Preparing the materials balancing according the Tables the liquid materials (water and superplasticizer) also balanced, then put the dry materials (cement, sand, silica fume, glass powder and titanium dioxide) in the EIRICH R02 mixer then turn on the mixer on slow mode and mix for 1 min (the time is cheque it by the timer) till the dry materials is mix, add the half quantity of water and mix for a min after that take a break for min then add the half quantity of superplasticizer to mixture and mix for a min at this time we can see the mixture color is became darker, then take break for 4 min then add the remaining quantity of water and superplasticizer to mixture and mix on fast mode of mixer till have a good mixture mixing good together.

When the ordinary sand the mix time is increasing comparewhen the quartz sand is used and specially when the high amount of silica fume is used in the mix 5 in **Table 3.7** the mix operation is taking a long time for example in the last part of mix operation instead of taken 3 or 4 min of mix it take like between 8-12 min.

The steps of transforming of concrete mix are:

The color of concrete mixer is becoming darker after adding the half quantity of superplasticizer the after adding the remain quantity of water and superplasticizer the mixture and mix for a 2 min is become like small balls then after a min is became like dense cream mix then after that mix for a 2 min and we will have the final coherent mixture with a good flowability.

In the concrete mix the part of researching is about (affecting of materials and ultra-sound on concrete properties )

**Table 3.7** Use ordinary sand, unit is (Kg in $1m^3$).

| **Mix** | **Notation of mix** | **C (Kg)** | **QS (Kg)** | **OS (Kg)** | **SIO2 (Kg)** | **GP (Kg)** | **SP (Kg)** |
|---|---|---|---|---|---|---|---|
| **1** | C735, QS962, $SiO_2$99, GP412, SP36.75 | 735 | 962 | - | 99 | 412 | 36.75 |
| **2** | C735, OS 1374, $SiO_2$99, SP36.75 | 735 | - | 1374 | 99 | - | 36.75 |
| **3** | C735, OS962, $SiO_2$99, GP412, SP36.75 | 735 | - | 962 | 99 | 412 | 36.75 |
| **4** | C735, OS962, GP511, SP36.75 | 735 | - | 962 | - | 511 | 36.75 |
| **5** | C735, OS962, $SiO_2$150, GP412, SP36.75 | 735 | - | 962 | 150 | 412 | 36.75 |

**Table 3.8** Use ultrasound, unit is (Kg in $1m^3$).

| **Mix** | **Notation of mix** | **C (Kg)** | **QS (Kg)** | **OS (Kg)** | **SIO2 (Kg)** | **GP (Kg)** | **SP (Kg)** | **US-(Sec)** |
|---|---|---|---|---|---|---|---|---|
| **6** | C735, QS962, $SiO_2$99, GP412, SP36.75, US-10Sec | 735 | 962 | - | 99 | 412 | 36.75 | 10 |
| **7** | C735, OS1374, $SiO_2$99, SP36.75, US-10Sec | 735 | - | 1374 | 99 | - | 36.75 | 10 |
| **8** | C735, OS962, $SiO_2$99, GP412, SP36.75, US-10Sec | 735 | - | 962 | 99 | 412 | 36.75 | 10 |
| **9** | C735, OS962, GP511, SP36.75, US-10Sec. | 735 | - | 962 | - | 511 | 36.75 | 10 |
| **10** | C735, OS962, $SiO_2$150, GP412, SP36.75, US-10Sec | 735 | - | 962 | 150 | 412 | 36.75 | 10 |

**Table 3.9** Use titanium dioxide, unit is (Kg in 1m$^3$).

| Mix | Notation of mix | C (Kg) | QS (Kg) | SIO2 (Kg) | GP (Kg) | SP (Kg) | TIO2 (Kg) |
|---|---|---|---|---|---|---|---|
| **11** | C735, QS962, $SiO_2$99, GP412, SP36.75 | 735 | 962 | 99 | 412 | 36.75 | - |
| **12** | C735, OS1374, $SiO_2$99, SP36.75, $TiO_2$14.7 | 735 | 962 | 99 | - | 36.75 | 14.7 |
| **13** | C735, QS962, $SiO_2$99, GP412, SP36.75, $TiO_2$36.75 | 735 | 962 | 99 | 412 | 36.75 | 36.75 |
| **14** | C735, QS962, GP511, SP36.75, $TiO_2$51.45 | 735 | 962 | - | 511 | 36.75 | 51.45 |
| **15** | C735, QS962, $SiO_2$150, GP412, SP36.75, $TiO_2$73.5 | 735 | 962 | 150 | 412 | 36.75 | 73.5 |

**Table 3.10** Use white cement, unit is (Kg in 1m$^3$).

| Mix | Notation of mix | C (Kg) | QS (Kg) | SIO2 (Kg) | GP (Kg) | SP (Kg) | TIO2 (Kg) |
|---|---|---|---|---|---|---|---|
| **16** | WC735, QS962, $SiO_2$99, GP412, SP36.75, $TiO_2$51.45 | 735 | 962 | 99 | 412 | 36.75 | 51.45 |
| **17** | WC735, QS962, $SiO_2$99, GP412, SP36.75 | 735 | 962 | 99 | 511 | 36.75 | - |
| **18** | C735, QS962, $SiO_2$99, GP412, SP36.75, $TiO_2$51.45 | 735 | 962 | 99 | 412 | 36.75 | 51.45 |
| **19** | C735, QS962, $SiO_2$200, GP412, SP36.75, $TiO_2$51.45 | 735 | 962 | 200 | 412 | 36.75 | 51.45 |

### 3.3.2. HIGH-INTENSITY SONICATION:

In the part of effect of ultra sound on concrete in the mixes (6 till 10 in the Table 3.8 ). When the concrete mixes are ready, now using the sonicate, put the horn of sonicate in the middle of mix and start moving the mix carefully without touching the border or bottom of mixer vessel to be sure the ultra sound is moving in the mix. When the sonicate is used it make like noise sound and like vibration.


**Fig. 3.2** Bandelin Electronic Ultrasonic Homogenizer UW 3400.

The period time to use ultra sound in this part is 10 S all the step after mixing should be fast because the cement ratio of concrete mix is low W/C = 0.3 so will hardening fast.

### 3.3.3. FLOWABILITY

The main idea of flowability test of concrete mix is to determine the consistence of fresh concrete, in this test the method used is Brass flow table test C-1437 as directed by EN 1015-3 A it's 4 -inch cone which is used for a mortar mix flow test.

The procedure of test:

When the fresh concrete is mixed, the cone should be put it on the middle of Smooth surface and when we make this test the condition should be the same to all test part for example if the surface is wet should be wet in all test part or if it's dry should be dry in all part, so after that flow the fresh concrete in the cone till top carefully without moving the cone or flowing out the mixture, then lift the cone and the fresh concrete will flow on the surface, and when the flowing is stopping, should measure the diameter of the circle of mixture such as showing in the **Fig. 3.2**

The measuring of diameter should be taken by 2 different direction then adding the 2 number and divided by 2 this way is to be the result is more precising.

**Fig. 3.3** Flowability of fresh concrete( W/c = 0.3)

This step should be doing fast as possible do not hardening the concrete because in this type of concrete the cement ratio is too low, then flow back the mixture in the mixer and mix for a some second and after that flow in the metallic formwork.

### 3.3.4. FORMING CONCRETE SAMPLE

One of advantage of concrete building material is the Formed, the concrete is can take any form of by putting the fresh concrete in form and after hardening of concrete mix the concrete will take the form of shape.

The sample preparing in this test is for next test is prism of concrete with dimension (L = 160 mm, B = 40 mm and H = 40 mm). The way to preparing this samples is to put it in metallic form which is can it expands to 3 prisms.

Before flow the concrete mixture in the shape this shape should be so cleaning and smutched by special type of oil (spray oil) the object of using oil it's to have a good and smooth concrete surface and when we take out the prism from the shape the concrete will not be connect with the metallic border because the oil make like an isolate layer.

In general, when we put the normal concrete mixture, we should vibrate the shape to not have any air bubbles inside the prisms after hardening but in this type of concrete this step it's not so necessary because this concrete type it's self-compacting. The air bubble decreasing the resistance of concrete so it's decreasing the compressive and flexural strength.

The next step is the covering, put cover on the shape it's necessary to save the water inside the fresh concrete from evaporation which is so important to hydration reaction and specially if the cement ratio it's very low the covering it can be by plastic or glass and upper closed from sun if in place where is sun light.

Second day after the concrete mixes are hardening, take out the prism from the metallic shape and put it in the water then waiting for 28 days to take the hardening because after 28 days of concrete mix when we put the concrete in the water the concrete will have like 90 % of maximum hardening. sometime in lab there is other way to accelerate this step the way is:

Put the prism in container then adding the water upper than level of prism that mean the prisms should be under water and put it in spatial type of oven on (80-90 $^{o}$C) and Leaves on this case for 2-3 days and after that take it out from the oven and put it in the room temperature to second day to have the same room temperature2/ then the prism have the same condition of concrete which put it in water for 28 days without oven the water is important to not allow the evaporation of water inside the concrete prism.

### 3.3.5. DENSITY TEST

The density test is testing to calculate the density of concrete by measuring the dimension and the mass of the concrete prism then from this data we can calculate the density of concrete the way is:

By special ruler which has two metallic poles put it in the border and it's so precise by millimeter and decimal of millimeter which is used to measure the dimension as showing in the **Fig. 3.3** measuring the length, width and high of prism to calculate the volume.

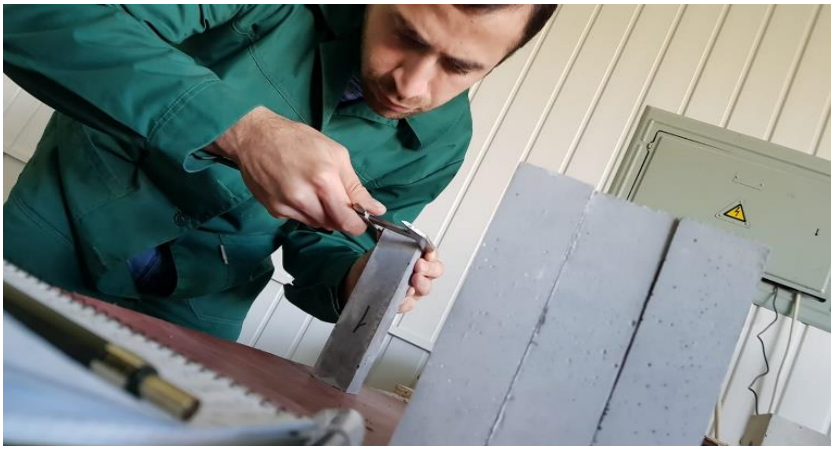

**Fig. 3.4** Calculate the concrete density of samples.

After measuring the dimension of prism should take the mass of it by balance and according to the formula d = m / V (where is d: density (Kg/$m^3$), m: mass (Kg) and V: volume ($m^3$).

### 3.3.6. FLEXURAL STRENGTH TEST

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an un-reinforced concrete beam or slab to resist failure in bending.

The flexural strength is the first destructive test which is broke the prism the way is put the prism on the 2 support which should be put it horizontal on the border then start the test, the machine will start press the prism in the middle and the force applied on the prism will increase till break the prism (the distance between the 2 support it’s 100 mm and pressing in the middle, and the force needed to break the prism will be marked on the screen as showing in **Fig. 3.4**


**Fig. 3.5** Flexural strength test.

Flexural strength calculated according to the Formula: F.S = 3(Fxl)/(2xbx(h)^2) (where F, is the force to break the prism; L is the distance between the 2 supports 100 mm; b is the width of the prism and h is the high of the prism) .

The unit of the flexural strength is (N/mm$^2$ or MPa which is the same (1MPa = 1 N/mm$^2$). Now the prism will be break to 2 parts which will be used to calculate the compressive strength of the concrete.

### 3.3.7. COMPRESSIVE STRENGTH TEST

what is compressive strength?

Compressive strength is the ability of the material to support or carry the load on it without any deflection or crack. In the test of compressive strength, and after flexural strength the area of 2 division of prism is unknown so because of that in this case we use 2 metallic plate with knowing area and dimension (4x4 cm) and we put the half of prism between these 2 plates and put it in compressive machine and starting the test and when the sample is break then on the screen the load to break this sample is marked.

So, to calculate the compressive strength of this concrete sample is C.S = F/A (where C.S is compressive strength, F load on the concrete sample and A is the cross-section area of metallic plate which is put it on sample where the load is applied as showing in the **Fig. 3.5**

**Fig. 3.6** Compressive strength test.

This compressive strength test is a destructive test because the sample will be broken after this test or cracked at this point the load needed to break it is the compressive strength of the concrete.

# 4. TESTS EXPERIMENTS RESULTS

## 4.1. HYDRATION PROCESS OF UHPC.

### 4.1.1. EFFECT OF SUPERPLASTICIZER ON HYDRATION PROCESS

The effect of superplasticizer on hydration reaction of cement, in the **Fig. 3.6**, which showing in the mixes (1 till 5) in the **Table 3.1**. The curve of the Mix 1 is showing the hydration reaction of cement with water without any admixture. The hydration reaction without SP is marked the higher temperature which is 52.62(°C). The setting times is also starting early start at min 108 and finish at 446 min so setting time is (338 min) this is the setting time for cement past in otherwise when the superplasticizer is used the maximum temperature is decreasing and the starting and ending of setting time is change it.

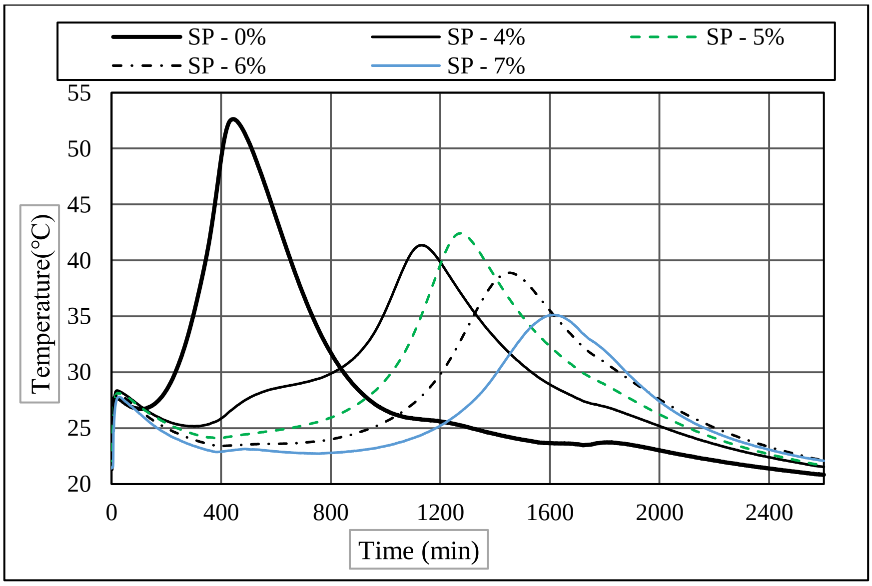


**Fig. 3.7** Effect of superplasticizer on hydration process mixes C735, (x%) SP and (W/C=0.3).

Mix 2 where the percentage of SP is 4% the maximum temperature marked is 40.96 ($^0$C) the setting time is starting at 308 min and finish at 1133 min so setting time is (825 min) the change of setting time is increasing 487 min the percentage of setting time increasing is 144% compare with Mix 1 and the temperature is decreasing 11.66 ($^0$C) percentage of decreasing is 22.15 % compare with Mix 1.

Mix 3 where the percentage of SP is 5% the maximum temperature marked is 41.36 ($^0$C) the setting time is starting at 391 min and finish at 1233 min, setting time is (842 min) which mean the setting time is increasing 504 min and temperature is decreasing 11.26 ($^0$C) compare with Mix 1.

For mix 4 and 5 settings times are 1052 min and 1227 min increasing of setting time are 715 min and 889 min which marked higher decreasing percentage in Mix 5 which is 261.5 % compare with Mix 1 and the temperature is decreasing 13.73 ($^0$C) and 17.5 ($^0$C) the percentage of temperature decreasing in Mix 5 is 33.25 % compare with Mix 1.

The cause to retard of hydration reaction is because of SP is Distribute on the surface of cement particle and cover it which make the contacting between the water and cement particles need more time and when the quantity is bigger the time is increasing.

### 4.1.2. EFFECT OF SILICA FUME ON HYDRATION PROCESS

The effect of silica fume on hydration reaction of cement, in the **Fig. 3.7**, which showing in the mixes (6 till 10) in the **Table 3.2.**

**The curves of:** Mix 6 is showing the hydration reaction of cement without any mineral admixture. The Setting time is 621 min and maximum temperature is 47.82 ($^0$C)

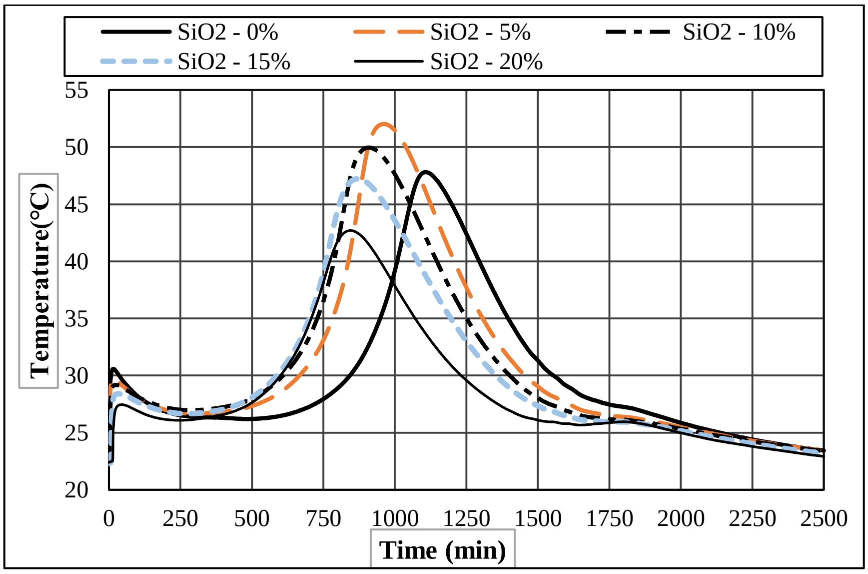


**Fig. 3.8** Effect of silica fume on hydration process mixes C (735), SP (36.75)

Mix 7 quantity of silica fume is 5%. The hydration reaction is starting early and setting time is 627 min percentage of increasing is 0.9 % almost no change in setting time, but the maximum temperature is increasing till 52.03 ($^0$C) the increasing of temperature is 8.8%

Mix 8 quantity of silica fume is 10%. setting time is 606 min setting time decreasing 2.4% compare with Mix 6 and the maximum temperature is increasing till 49.96 ($^{0}$C) the increasing is 4.4 %.

Mix 9 quantity of silica fume is 15%. setting time is 609 min setting time decreasing 1.9% compare with Mix 6 and the maximum temperature is decreasing till 47.23 ($^{0}$C) the decreasing is 1.2 %.

Mix 10 quantity of silica fume is 20%. setting time is 594 min setting time decreasing 4.3% compare with Mix 6 and the maximum temperature is decreasing till 42.71 ($^{0}$C) the decreasing is 10.6 %.

The silica fume it's not effecting so much on setting time period it's just makes it start and finish early otherwise when the percentage of silica fume is 5% the temperature is increasing 8.8 % and it's decreasing 10.6 % when we increase the quantity of silica fume till 20 %.

### 4.1.3. EFFECT OF TITANIUM DIOXIDE ON HYDRATION PROCESS

Effect of titanium dioxide on cement hydration reaction is showing in **Fig. 3.8** in Mix (11-15) which is in the **Table 3.3.** The curve of Mix 11 is curve of mix without any amount of titanium dioxide this mix is the reference Mix which is the other Mixes will compare with.

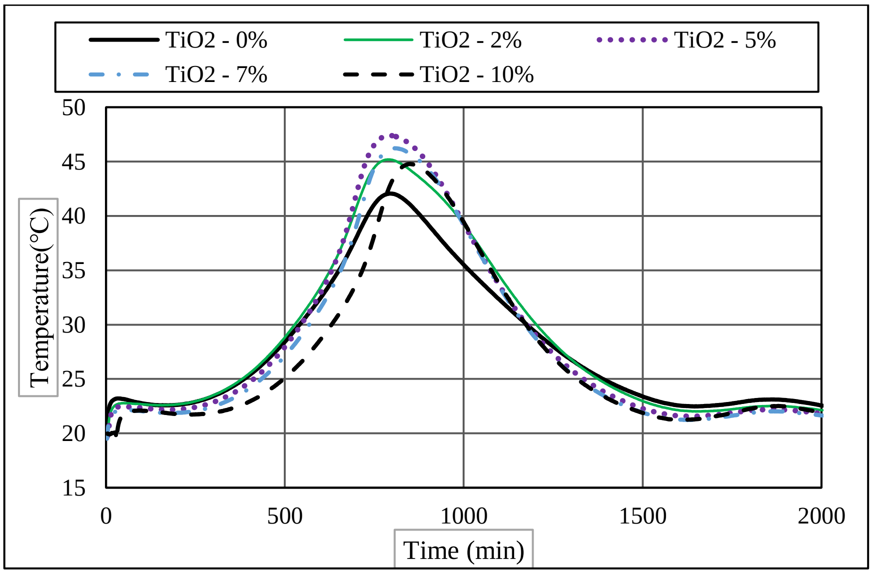


**Fig. 3.9** Effect of titanium dioxide on hydration process mixes (C735, SP36.75)

Mix 11 initial setting time of Mix with 0% titanium dioxide is 162 min and the final setting time is 791 min so setting time is 629 min and the maximum temperature marked is 42.06 ($^{0}$C).

Mix 12 quantity of titanium dioxide used is 2% the setting time is 633 min is increasing just 4 min almost no change in otherwise the temperature is increasing to 45.19 ($^0$C) is increasing 7.4 %.

Mix 13 quantity of $TiO_2$ used is 5% the setting time decreasing to 613 min the decreasing is 2.5 % and the temperature is increasing till 47.4 ($^0$C) percentage of increasing is 12.6 %.

For Mix 14 and Mix 15 quantity of $TiO_2$ used is 7% and 10%. The setting time is decreasing till 622 min and 608 min percentage of decreasing is 1.1% and 3.3 % in otherwise the temperature is increasing till 46.23 ($^0$C) and 44.78 ($^0$C) percentage of increasing is 9.9 % and 6.4 %.

In the **Fig. 3.8** the higher temperature marked is 47.4 ($^0$C) where the quantity of $TiO_2$ used is 5% and the lower setting time is Mix with 10 % of $TiO_2$ is used.

### 4.1.4. EFFECT OF ULTRA- SONIC ON HYDRATION PROCESS

Effecting of ultra sound on hydration reaction is showing in mixes (16- 20) in **Table 3.4**. Ultra sound used with different time as showing in **Fig. 3.9.**

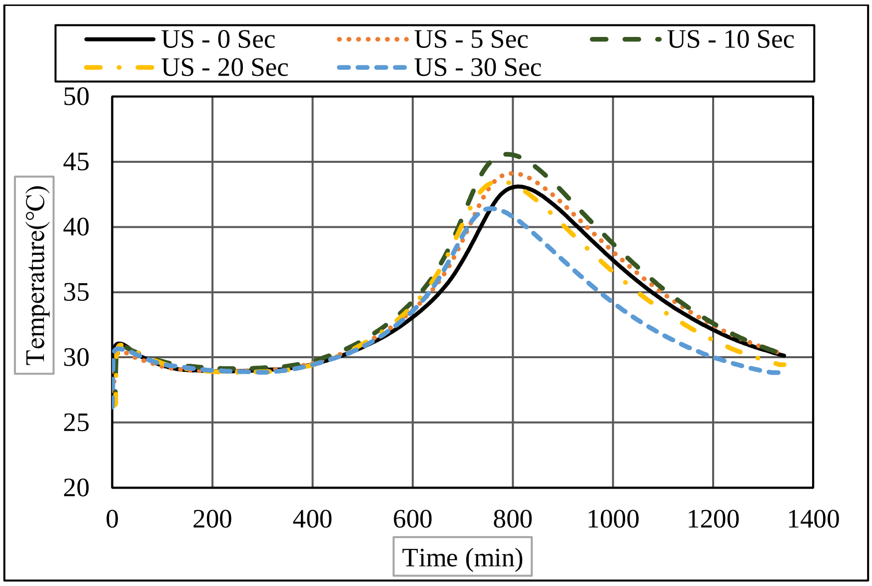


**Fig. 3.10** Effect of Ultra-Sound on hydration process mixes (C (735), GP (412), SiO2(99), SP (36.75) and (x S) U-S)

Mix 16 the time of ultra sound used is 0S this mix is the reference mix of this part of test. Setting time is 606 min and maximum temperature is 43.1 ($^0$C).

Mix 17 ultra-sound used 5S in this mix the setting time is decreasing to 573 min percentage of decreasing is 5.4 % and the maximum temperature is increasing to 44.11 ($^0$C) percentage of increasing is 2.3 %.

Mix 18 ultra-sound used 10S in this mix the setting time is decreasing to 530 min percentage of decreasing is 12.5 % and the maximum temperature is increasing to 45.57 ($^0$C) percentage of increasing is 5.7%.

Mix 19 ultra-sound used 20S in this mix the setting time is decreasing to 504 min percentage of decreasing is 16.8 % and the maximum temperature is increasing to 43.51 ($^0$C) percentage of increasing is 0.9%.

Mix 20 ultra-sound used 30S in this mix the setting time is decreasing to 450 min percentage of decreasing is 25.75 % and the maximum temperature is decreasing to 41.41 ($^0$C) percentage of decreasing is 3.9%.

The ultra-sonic is decreasing the setting time till 25.75 % when the time used is 30 S the reason of this decreasing is because of sonic waves which has energy can remove the air bubble from the mix and can allow the water and cement particles contact faster and reacting and can increase the maximum temperature till 5.7 % when the Ultra-sonic time used is 10 S.

### 4.1.5. Effect of 10S of ultra-sonic on different mixes compound

In **Fig. 3.10** checking the effective of 10 S ultra sound on hydration process of cement with glass powder and silica fume with US – 0 Sec and US – 10 Sec.

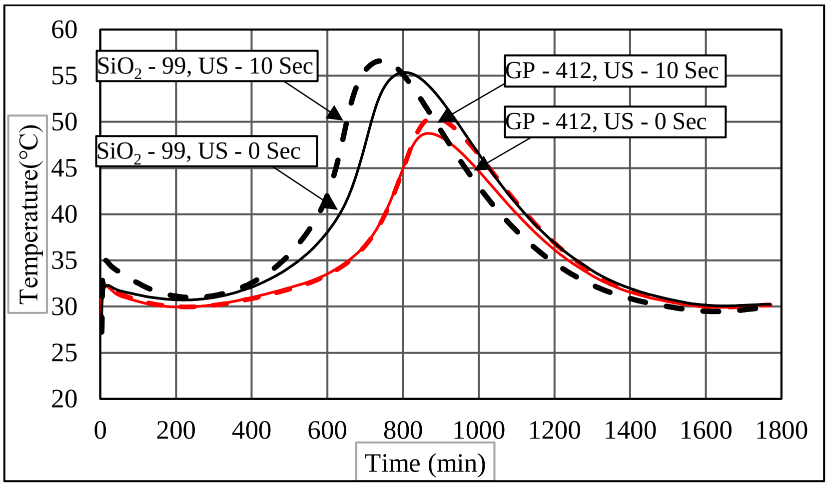


**Fig. 3.11** Effect of glass powder, Silica fume and ultra-sonic on Portland cement hydration process.

Mix 21 is the mix (C (735), G (412), SP (36.75) and U-S (0 S) the setting time is 651 min and the maximum temperature is 48.76 ($^0$C).

Mix 22 the mix (C (735), G (412), SP (36.75) and U-S (10 S) the setting time is the same 651 min, but the maximum temperature is 50.48 ($^0$C) The increasing of temperature is 1.72 ($^0$C), percentage of increasing is 3.5 %.

Mix 23 is the mix (C (735), $SiO_2$ (99), SP (36.75) and U-S (0 S) the setting time is 580 min and the maximum temperature is 55.36 ($^0$C).

Mix 24 the mix (C (735), $SiO_2$ (99), SP (36.75) and U-S (10 S) the setting time is decreasing to 502 min percentage of decreasing is 13.4%. Maximum temperature is 56.62 ($^0$C) The increasing of temperature is 1.26 ($^0$C), percentage of increasing is 2.2 %.

**Table 3.11** Semi adiabatic results of cement paste mixes.

| Mix | Composition | Initial setting time (min) | Final setting time (min) | Setting time (min) | Min t($^0$C) | Max t($^0$C) |
|---|---|---|---|---|---|---|
| 1 | C (735), SP (0), (0%) | 108 | 446 | 338 | 26.71 | 52.62 |
| 2 | C (735), SP (29.4), (4%) | 308 | 1133 | 825 | 25.16 | 40.96 |
| 3 | C (735), SP (36.75), (5%) | 391 | 1233 | 842 | 24.1 | 41.36 |
| 4 | C (735), SP (44.1), (6%) | 406 | 1458 | 1052 | 23.4 | 38.89 |
| 5 | C (735), SP (51.45), (7%) | 397 | 1624 | 1227 | 22.82 | 35.12 |
| 6 | C (735), SP (36.75), SIO2 (0), (0%) | 487 | 1108 | 621 | 26.19 | 47.82 |
| 7 | C (735), SP (36.75), $SiO_2$ (36.75), (5%) | 337 | 964 | 627 | 26.69 | 52.03 |
| 8 | C (735), SP (36.75), $SiO_2$ (73.5), (10%) | 300 | 906 | 606 | 26.97 | 49.96 |
| 9 | C (735), SP (36.75), $SiO_2$ (110.25), (15%) | 262 | 871 | 609 | 26.66 | 47.23 |
| 10 | C (735), SP (36.75), $SiO_2$ (147), (20%) | 251 | 845 | 594 | 26.08 | 42.71 |
| 11 | C (735), SP (36.75), $TiO_2$ (0), (0%) | 162 | 791 | 629 | 22.57 | 42.06 |
| 12 | C (735), SP (36.75), $TiO_2$ (14.7), (2%) | 155 | 788 | 633 | 22.59 | 45.19 |
| 13 | C (735), SP (36.75), $TiO_2$ (36.75), (5%) | 177 | 790 | 613 | 22.17 | 47.4 |
| 14 | C (735), SP (36.75), $TiO_2$ (51.45), (7%) | 183 | 805 | 622 | 21.86 | 46.23 |
| 15 | C (735), SP (36.75), $TiO_2$ (73.5), (10%) | 239 | 847 | 608 | 21.73 | 44.78 |
| 16 | C (735), SP (36.75), $SiO_2$ (99), GP (412), US-(0S) | 205 | 811 | 606 | 28.93 | 43.1 |
| 17 | C (735), SP (36.75), $SiO_2$ (99), GP (412), US-(5S) | 227 | 800 | 573 | 28.92 | 44.11 |
| 18 | C (735), SP (36.75), $SiO_2$ (99), GP (412), US-(10S) | 259 | 789 | 530 | 29.13 | 45.57 |
| 19 | C (735), SP (36.75), $SiO_2$ (99), GP (412), US-(20S) | 271 | 775 | 504 | 28.85 | 43.51 |
| 20 | C (735), SP (36.75), $SiO_2$ (99), GP (412), US-(30S) | 308 | 758 | 450 | 28.85 | 41.41 |
| 21 | C (735), GP (412), SP (36.75), US-(0S) | 215 | 866 | 651 | 29.93 | 48.76 |
| 22 | C (735), GP (412), SP (36.75), US-(10S) | 232 | 883 | 651 | 29.96 | 50.48 |
| 23 | C (735), $SiO_2$ (99), SP (36.75), US-(0S) | 227 | 807 | 580 | 30.71 | 55.36 |
| 24 | C (735), $SiO_2$ (99), SP (36.75), US-(10S) | 242 | 744 | 502 | 30.97 | 56.62 |

## 4.2. CONCRETE EXPERIMENTS RESULTS

### 4.2.1. FLOWABILITY

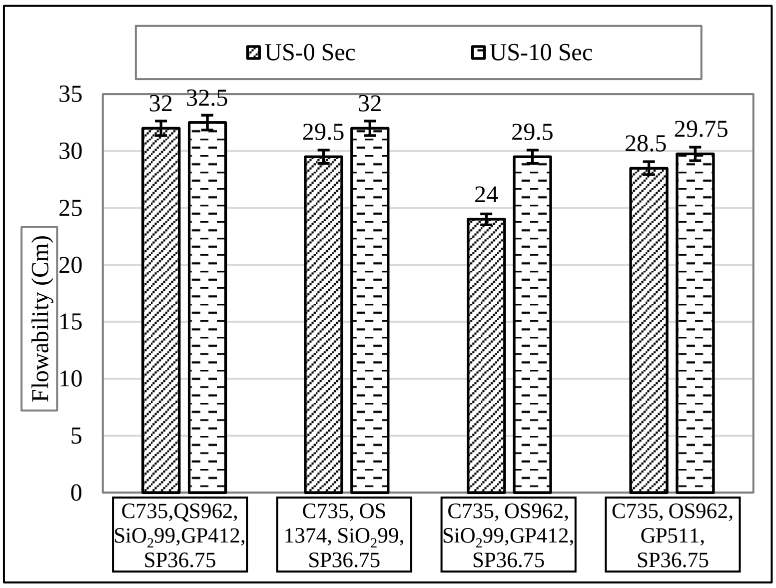


**Fig. 3.13** Effect of ultra-sound on Flowability, W/C = 0.3.

**Fig. 3.12** Flow of Mix

The mixes which is in the ***Fig. 3.11*** is the mixes from **Tables (3.7 – 3.8)**.

Ultra-sound is affecting on the flowability of the UHPC as showing in the Graph above for the Mix 1 (C 735, QS 962, $SiO_2$ 99, GP 412, SP 36.75) flow is increasing 0.5 cm , which is 1.5%. Mix 2 (C 735, OS 1374, $SiO_2$ 99, SP 36.75) flow is increasing from 29.5 to 32 cm the increasing is 2.5 cm, increasing is 8.4%. For Mix 3 (C 735, OS 962, $SiO_2$ 99, GP 412, SP 36.75) the increasing is from 24 cm to 29.5 which is 5.5 cm, percentage of increasing is 22.9%. For Mix 4 flow increase from 28.5 to 29.75 the increasing is 1.25 cm which is 4.3%.

Effect of $SiO_2$ on flow

In the mix 1, mix 5 and mix19 (C 735, OS 962, $SiO_2$[99 – 150 – 200], GP 412, SP 36.75) in **Table 3.7 and Table 3.10** the quantity of silica fume used in mix is small Comparing with the other materials like cement, Sand , but $SiO_2$ can affecting on Flowability of mix as in **Fig. 3.13** . in $SiO_2$ 200 increasing the quantity of $SiO_2$ 33.33% then the Flow decreasing from 24.75 Cm to 17 cm percentage of decreasing is 31.17% .

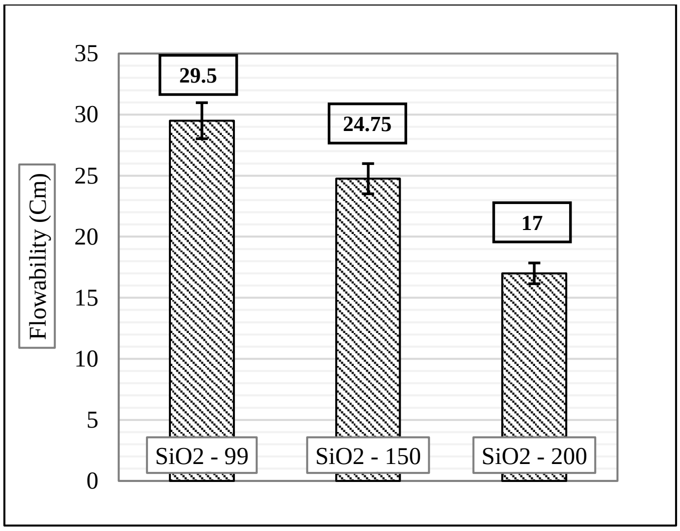


**Fig. 3.14** Effect of $SiO_2$ on Flowability, W/C = 0.3.

### 4.2.2. DENSITY

The mixes in Graph is mixes in (**Tables 3.7 – 3.8**) . there is no a big change in density of concrete because the density of concrete is more related with the density of materials used in producing of concrete this small change is just because of change the quantity of materials as showing in Tables.

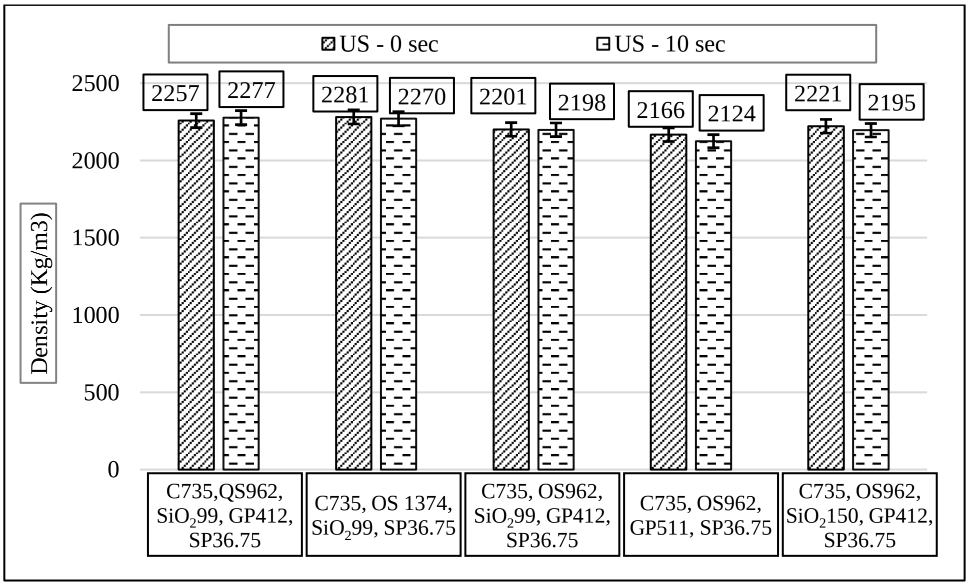


**Fig. 3.15** Density of concrete, W/C = 0.3.

The maximum change is between the mix 2, 4 and 6, 9, in mix 2 density is 2281 $Kg/m^3$ but in mix 4 is 2166 $Kg/m^3$ the different of density is 5% and this is the maximum different.

In mix 6 density is 2277 Kg/m$^3$ but in mix 9 is 2124 Kg/m$^3$ different is 153 kg which is 6.7 %.

### 4.2.3. FLEXURAL STRENGTH

**Curing concrete in water**

The concrete samples should put under water for 28 days to cure and save the inside water from evaporate and will make crack in concrete some time micro crack which decrease the flexural strength of concrete and then not all the bending materials will react with water because of evaporation.

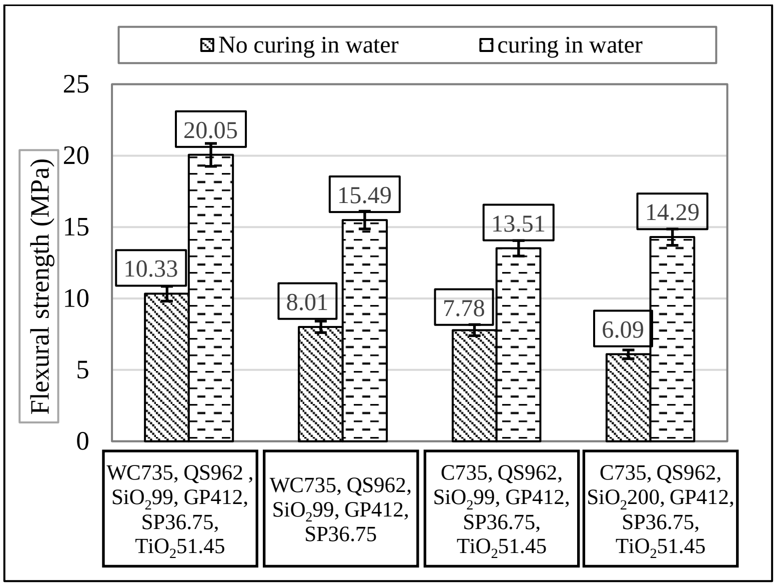


**Fig. 3.16** Flexural strength between curing and no curing concrete samples.(Mix from **Table 3.10** )

W/C = 0.3.

As showing in **Fig.3.15** the flexural strength of sample of Mix 16 which is not put it under water for 28 days is 10.33 MPa in otherwise the sample which is put it under water for 28 days is 20.10 MPa which mean the flexural strength of sample which put it under water and cure is increasing 9.77 MPa so it's increasing 94.54%. For a Mix 17 flexural strength increasing from 8.01 MPa to 15.50 MPa so it's increasing 7.4 MPa which is 91.13%. For Mix 18 flexural strength increasing from 7.78 MPa to 13.50 MPa the increasing is 5.72 MPa, increasing is 73.52%. For Mix 19 Flexural strength increasing from 6.09 MPa to 14.30 MPa the increasing is 8.21 MPa which is 134.81% this is the higher increasing.

### 4.2.4. <u>COMPRESSIVE STRENGTH</u>

**curing concrete in water:** after curing concrete in water for 28 days the compressive strength for first mix is increasing from 139.79 MPa to 150.17 MPa the increasing is 10.38 MPa which is 7.4%.

For second mix compressive strength of concrete sample is increase from 120.59 to 128.97 MPa the increasing is 8.38 MPa which is 6.9%. For third mix compressive strength of concrete is increasing from 126.40 MPa to 135.17 MPa percentage of increasing is 6.9%. for fourth mix compressive strength of concrete is increasing from 126.40 MPa to 131.79 MPa percentage of increasing is 4.2%.

So, curing of concrete sample in water for 28 days increase the compressive strength of this concrete samples between (4.2% and 7.4%).

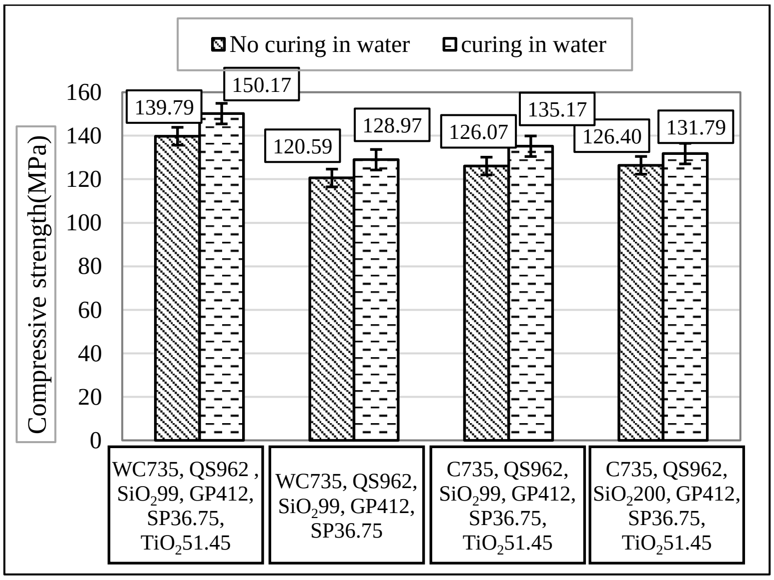


**Fig. 3.17** Compressive strength between curing and no curing concrete samples.(Mix from **Table 3.10**) W/C = 0.3.

**Effect of Ultra-sound on compressive strength:**

For first mix compressive strength is 113.39 MPa, same mix with US – 10 Sec, compressive strength is increasing to 128.35 MPa, the increasing is 14.96 MPa percentage increasing is 13.19%.

Second mix compressive strength is 113.03 MPa, whith US – 10 Sec, compressive strength is increasing to 120.44 MPa, the increasing is 7.41 MPa, percentage of increasing is 6.55 %.

Third mix compressive strength is 100.74 MPa, same mix with US – 10 Sec, compressive strength is increasing to 115.78 MPa, the increasing is 15.04 MPa percentage increasing is 14.92%.

Fourth mix compressive strength is 96.02 MPa, same mix with US – 10 Sec, compressive strength is increasing to 106.84 MPa, the increasing is 10.82 MPa percentage increasing is 11.26 %.

Fifth mix compressive strength is 122.79 MPa, same mix with US – 10 Sec, compressive strength is increasing to 149.39 MPa, the increasing is 26.6 MPa percentage increasing is 21.66 %.

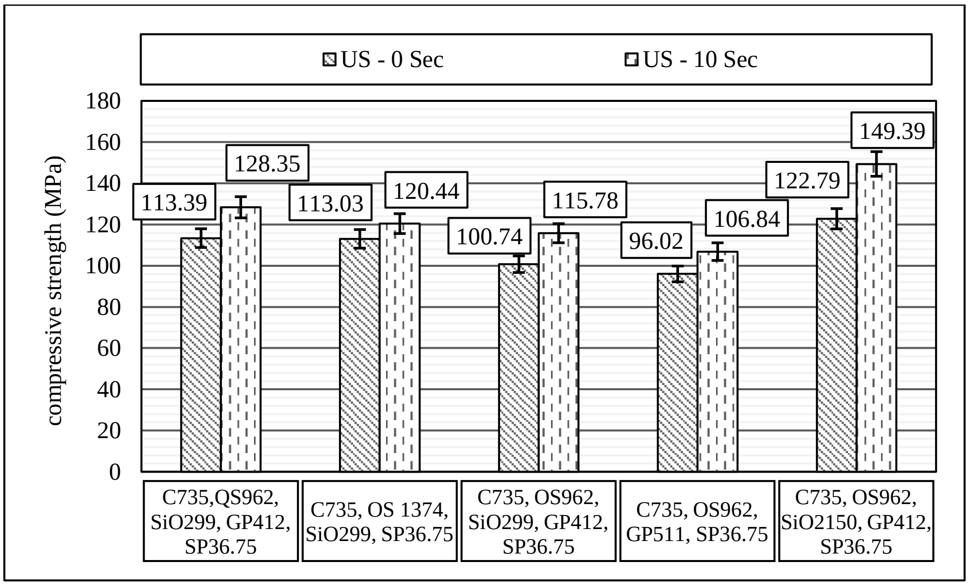


**Fig. 3. 18** Effect of ultra-sound on compressive strength of concrete.(Mix from **Tables 3.7-3.8**) W/C = 0.3.

Ultra-sound increasing the compressive strength because of waves energy which has high energy which allow to extract the air bubbles from the mix which is can be a reason of decreasing the compressive strength.

## 4.3. ECONOMIC STUDY

In economic study the cost of preparing 1 $m^3$ of concrete mix is calculated then after that this cost is divided on compressive strength of concrete and we get price of 1 MPa in each mix.

**Table 3.12** Economic calculation in 1$m^3$ of mix.

| **Mix** | **Notation of mix** | **Price of 1$m^3$ (€)** | **Compressive str. (MPa)** | **Price of 1 MPa** |
|---|---|---|---|---|
| **1** | Cement 735 Kg, Quartz Sand 962 Kg, Silica fume 99 Kg , Glass powder 412 Kg, superplasticizer 36.75 Kg. | 492.61 | 113.39 | 4.34 |
| **2** | Cement 735 Kg, Ordinary Sand 1374 Kg, Silica fume 99Kg , superplasticizer 36.75 Kg. | 269.97 | 113.034 | 2.38 |
| **3** | Cement 735 Kg, Ordinary Sand 962 Kg, Silica fume 99 Kg, Glass powder 412 Kg, Superplasticizer 36.75 Kg | 261.73 | 100.736 | 2.59 |
| **4** | Cement 735 Kg, Ordinary Sand 962 Kg, Glass Powder 511 Kg, Superplasticizer 36.75 Kg | 258.76 | 96.021 | 2.69 |
| **5** | Cement 735 Kg, Ordinary Sand 962 Kg, Silica fume 150 Kg, Glass powder 412 Kg, Superplasticizer 36.75 Kg | 266.83 | 122.793 | 2.17 |
| **6** | White Cement 735 Kg, Quartz Sand 962, Silica fume 99 Kg , Glass powder 412 Kg, Superplasticizer 36.75 Kg | 592.28 | 150.2 | 3.94 |

The cost of 1 MPa in mix 1 is 7.02 **(€)** in otherwise price of 1MPa in mix 2 is just 2.92 **(€)** the different of price it's more than double that different is to big it's possible to produce the same strength by half price at cement ratio W/C = 0.3 and for other mix 3, mix 4, mix 5 and mix 6 the price of 1 MPa is not big change is between 5.27 **(€)** in mix 5 and 5.96 **(€)** in mix 6.

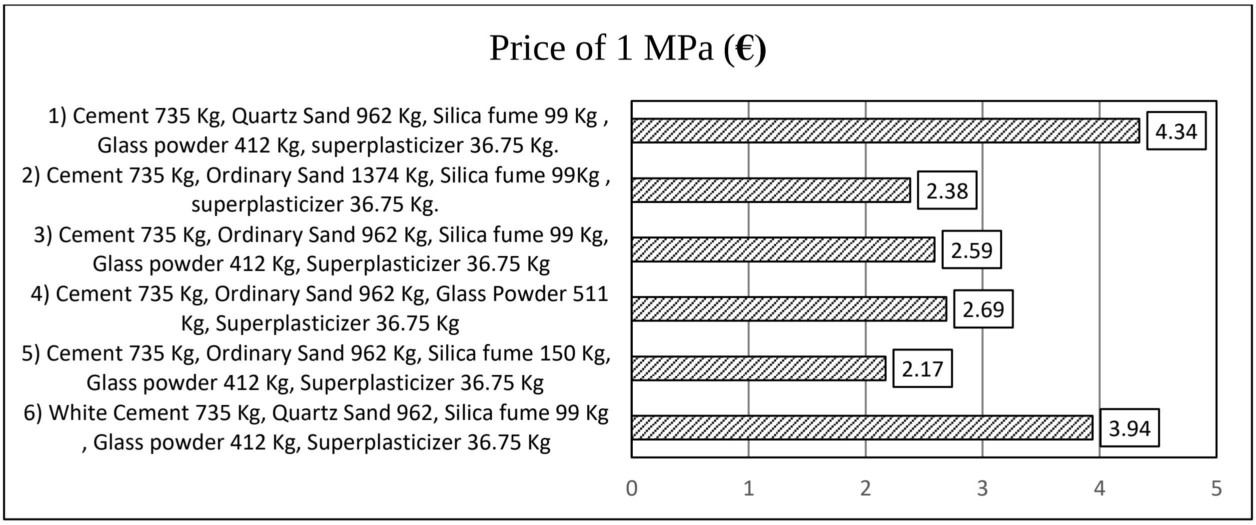


**Fig. 3.19** Cost of 1 MPa in different mixes.

# CONCLUSION

1.1. During research was founded workability of concrete could be increasing by using silica fume between (0-99 Kg in $1m^3$) and it could be decreasing when the amount is between (99 – 200 Kg) when the amount of $SiO_2$ is 99 Kg the flow is 29.5 cm and it's 17 cm when the amount is 200 Kg and in otherwise the glass powder decrease the workability of concrete in all cases.

1.2. Was founded during research that amount of fine materials (silica fume) increase the strength of concrete, it increases the compressive strength from 100.74 MPa to 122.79 MPa 17.95 %.

2.1. During research was founded semi adiabatic calorimetric hydration process of Portland cement was significantly accelerated from 606 min to 450 min 25.74 % accelerated when ultra-sonic activation used for 30 Sec.

2.2. Effect of ultrasonic activation positively influence workability 1.5 % from 32 cm to 32.5 cm in mix (C735,QS962,$SiO_2$99,GP412, SP36.75) and 22.9% from 24 cm to 29.5 cm in mix (C735, OS962, $SiO_2$99,GP412, SP36.75).

2.3. During research was founded ultrasonic activation positively influence the mechanical properties of UHPC, it increases the compressive strength 6.55 % from 113.03 MPa to 120.44 MPa in mix (C735, OS 1374, $SiO_2$99, SP36.75) and 21.66 % from 122.79 MPa to 149.39 MPa in mix (C735, OS962, $SiO_2$150, GP412, SP36.75).

2.4. The density of UHPC it doesn't affect with ultrasonic activation.

3.1. During research it was founded that using titanium dioxide can positively influence the mechanical properties of UHPC, it increases the compressive strength from 120.59 MPa to 139.79 MPa 13.73 %.

3.2. During research it was founded it's necessary to use higher amount of SP in order to get workable concrete, amount of SP is 5% from cement mass fervor increase of SP significantly decrease cement hydration process of Portland cement from 338 min to 842 min 59.85 %. it delays hydration process for 8.4 h.

4. During the research it was created UHPC with recycled materials with prices (266.83 **(€)**– 592.28 **(€)** ) and that price up to 2 time cheaper with other similar product in the market.

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