Eng.&Tech.Vol.26,No.8,2008

Properties of High Performance Mortar Using Local Additives

Prof. Dr. Husain M.Husain* Prof. Dr. Zain A. Raouf Dr. Wasan I. Khalil*****

Received on: 12/12/2007

Accepted on:6/3/2008

Abstract

High performance mortar can be produced by using ultrafine particles and superplasticizer admixtures which reduce water – cement ratio (less than 0.3). In this investigation an attempt was made to examine the possibility of replacing a part of weight of sand (10 and 20%) or a part of weight of cement (11.5, 17 and 23%) by low cost locally feldspar powder (FP) without impairing the high strength characteristic of the mortar. The experimental work includes the preparation of the feldspar material as one type of pozzolana, and selection of high performance mortar mix. Finally the properties of the selected mortar (compressive strength, modulus of rupture, density, pulse velocity, static and dynamic moduli of elasticity) at room temperature at 3, 7, 14, 28, 60, 90 and 180 days and after exposure to high temperatures in the range from 150 to 900°C at age 60 days were investigated.

The results show that the incorporation of 17% of feldspar powder as a partial replacement of cement and 4% of superplasticizer by weight of cement to 1:1 cement to sand mortar mix enabled the production of high performance mortar with compressive strength of about 80 N/mm^2 at 28 days. This mix shows significant drop in compressive strength and modulus of rupture of about 45 and 60% respectively, while the reduction in static and dynamic moduli was about 66 and 86% respectively after exposure to 600°C.

خواص المونة عالية الاداء بأستخدام مضافات محلية

من الممكن إنتاج مونةإسمنت عالية الاداء بأستخدام حبيبات فائقة النعومة ومضافات من نوع الملدنات المتفوقة والتي تقال نسبة الماء- الاسمنت (أقل من 3,.). تتضمن هذه الدراسة تحديد إمكانية إستبدال جزء مـن وزن الرمل (10٪ و20٪)أو جزء من وزن الاسمنت (11,5, 17, 23٪) لدقيق الفادسبار المحلـي القليـل الكلفـة وبدون التأثير على خاصية المقاومة العالية لمونة الاسمنت. تضمن البرنامج العملي تحضير مادة الفادسـبار كأحد أنواع البوزولانا وتحديد خلطة المونة عالية الاداء . وأخيرا تم دراست خـواص الخلطـة المحـددة (مقاومة الانضغاط , معاير الكسر , الكثافة , سرعة الذبذبات فوق الصـوتية, معـاملي المرونـة السـتاتيكي والديناميكي) في درجة حرارة الغرفة بعمر 3, 7, 14, 90,60,28, 180 يوم وبعد التعرض لدرجات حرارة عالية تتراوح بين 150الى 900م° وبعمر 60يوم.

أظهرت النتائج إن إضافة 17٪ من دقيق الفادسبار كبديل جزئي للاسمنت و 4٪ من الملدن المتفوق من وزن الاسمنت الى خلطة المونة 1:1(إسمنت :رمل) يساعد على إنتاج مونة عالية الاداء لها مقاومة إنضغاط بحدود 80 نيوتن/مم^{2}بعمر28يوم.أظهرت هذه الخلطة إنخفاضا واضحا في مقاومة الانضغاط ومعاير الكسر بحـدود 45و60٪ على التوالي في حين كان الانخفاض في معاملي المرونة الستاتيكي والديناميكي بحـدود 66و86٪ على التوالي بعد التعرض الى درجة حرارة 600 م°

1. Introduction

In mortar, the cement paste matrix is the most important constituent, and the most expensive of all the ingredients. If low cost construction is to be achieved, then it is essential to save as much as cement as possible and reduce the overall cost whether it is for housing, buildings or other infrastructure construction. So in this investigation it is vital to consider the use of local cement replacement materials, such as feldspar powder to produce high

https://doi.org/10.30684/ etj.26.8.14

University of Technology-Iraq, Baghdad, Iraq/2412-0758

performance mortar. High performance mortar can be used in ferrocement constructions and as facings in sandwich constructions, since the long term durability of the sandwich constructions depends on facings which are normally exposed to weather and aggressive agents.

2. Experimental Work

2-1 Materials

2-1-1 Cement

Ordinary Portland cement was used. It conforms to the provisions of Iraqi specification No.5-1985.

2-1-2 Fine Aggregate

Natural sand of maximum size 4.76mm was used. It was brought from Al-Ukhaider region and its gradation lies in zone 4. The grading test results conform to Iraqi specification No.45-1984.

2-1-3 Feldspar

Feldspar taken from Bahar Al-Najaf was used throughout this work, it was grounded by pulverizing by air plast, and then it was grounded using "Porcelain Ball Mill" for 20 hours. The specific surface area of feldspar powder (FP) was 12200cm^2/gm which was found by Blain method according to ASTM C-204. The specific gravity of feldspar powder was 2.733 determined according to ASTM C-188 and the pozzolanic activity index was 98.9% determined according to ASTM C-311.

The chemical and mineralogical analysis by using X-ray diffraction showed that feldspar is mainly consists of high percentage of potassium feldspar ($KALSiO_3O_8$) and silica (SiO_2) as shown in Table (1) and Fig.(1).

2-1-4 Superplasticizer

A high range water reducing (HRW) admixture (superplasticizer) was used in preparing all the specimens in this investigation. Chemically it is Naphthalene formaldehyde sulphonate, and it is known commercially as Sikament N-N. It was used in its liquid state as a percentage of cement content (by weight).

2-2 Mixing and Curing

Several mixes were carried out in this investigation with 10 and 20% FP as a partial replacement of sand by weight and 11.5, 17 and 23% FP as a partial replacement by weight of cement, different dosage of superplasticizer (1, 2, 3, 4, 5 and 6%) were also used inorder to produce mortar mix with high compressive strength and low porosity.

Mixing of cement and cement – feldspar mortars was carried out according to ASTM C-305. In case of cement – feldspar mortars, before mixing, the required amount of feldspar powder was added to the quantity of cement, and then the materials were mixed dry by using porcelain ball mill for a period of 15 minutes. This is necessary so that lumps of feldspar powder particles will be broken up and thoroughly dispersed within the cement particles. All materials were proportioned by weight, after casting the specimens were demoulded after 24 hours, some specimens cured in water for 3, 7, 14, 28, 60, 90 and 180 days , then they were tested at room temperature(25°C). Other specimens were cured in water for 60 days, then they were dried in oven at temperature of 60°C for at least 48 hours before exposure to high temperatures to avoid explosive spalling[1].

2-3 Details of the Tests

The following tests were carried out to evaluate the properties of the mortar at room temperature**:**

Six cubes of 50mm to determine the compressive strength.

Three prisms of 40×40×160mm to evaluate the modulus of rupture.

Three cylinders of 150×300mm to evaluate the static and dynamic modulus of elasticity.

Three prisms of 25×25×285mm to evaluate the shrinkage.

Three cubes of 100mm to determine the initial surface absorption.

An electric furnace was used for heating other mortar specimens; the maximum furnace temperature was 1000°C. The temperature was controlled by an electronic controller. The specimens were exposed to different temperatures of 150, 250, 350, 450, 600, 750 and 900°C. They were heated

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

to the test temperature, allowed to remain at that temperature for one hour then allowed to cool gradually in air at room temperature for a period of 24 hours before being tested. The following tests at each temperature level were carried out:

1-Six 50mm cubes were heated to evaluate the residual compressive strength.

2-Three cylinders of 150×300mm were heated and their residual static and dynamic modulus of elasticity was evaluated.

3- Three prisms of 40×40×160mm were heated to determine the residual modulus of rupture.

3- Results and Discussion

3-1 Effect of Feldspar Powder and Superplasticizer Content on Workability and Compressive Strength of Mortar Mixes

Table (2) shows the details of mixes that contain FP (10 and 20%) as a partial replacement by weight of sand with different dosage of superplasticizer (1, 2, 3, 4, 5 and 6% by weight of cement). Also the results of mortar mixes of different mix proportions containing different percentages of FP (11.5, 17 and 23%) as a partial replacement by weight of cement and different dosages of superplasticizer are shown in Table(3). The water – cement ratio were adjusted to obtain the same standard consistency of reference mix. Results indicate that a superplasticizer leads to a considerable improvement in early and later compressive strength and allows a reduction in water – cement ratio relative to the reference mix. This may be attributed to the mode of action of the superplasticizer whose long molecules wrap themselves around the cement particles giving them a negative charge, so they repel each other resulting in deflocculation and dispersion of cement particles, thereby greatly enhancing the fluidity of the system and consequently lowering the amount of water required to attain a certain consistency and thus increasing the compressive strength[2,3]. This high early compressive strength is significant for early stripping of forms and application of loads. Also generally it can be noted from Table(3) that the compressive strength at 28 days for mortar mix of 1:1 is more than the compressive strength of mortar mixes of 1:1.5 and 1:2; this is probably due to the fact that the increase in cement content improves the strength.

The effect of FP content upon the compressive strength of 1:1 cement – FP mortars without superplasticizer is indicated in Figures (2) and (3). Figure (2) shows that the higher the percentage of FP content, the lower is the compressive strength at early ages (7 days), while at age of 28, 60 and 90 days the mortar mix with 17% cement replacement exhibits higher compressive strength than other FP content. Each point in Fig.(3)represents the ratio in percent of the compressive strength of cement – FP mortar to the compressive strength of plain mortar (without FP). It can be seen that at age of 28 days, the compressive strength ratio of cement – FP mortar containing 17% feldspar powder is 96%, while at age 90 and 180 days the compressive strength reaches nearly the same value as those of the corresponding plain mortar. This may be due to the slow reaction between FP and calcium hydroxide (pozzolanic reaction), therefore the strength development will be slow accordingly, besides, the pore size and grain size refinement processes associated with pozzolanic reaction can effectively reduce the microcracking and strengthen the transition zone[4]. From the results indicated, it can be noted that the optimum percentage of FP that can replace cement by weight without later compressive strength (90 and 180 days) being less than that of the corresponding plain mortar is 17%.

The results for most trial mixes shown in Table (3) indicate that the compressive strength at 28 days reaches its maximum value when the dosage of superplasticizer is between 3 and 4%, and it decreases when the dosage is increased to 5 and 6%, this may be because the hydration of cement was delayed at high concentration of superplasticizer which was responsible for

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

the lower strength observed[5]. Fig.(4)shows the relationship between superplasticizer dosage and compressive strength at different ages of 1:1 cement – FP mortar mix with 17% cement replacement by FP. It can be seen that the optimum dosage of this admixture (superplasticizer) is 4%.

3-2Correlation between the Compressive Strength and Ultrasonic Pulse Velocity Results

The experimental results of UPV test and compressive strength for different mix proportion with different percentage of FP as partial replacement of cement and different dosages of superplasticizer has been used to develop such a correlation between the compressive strength (f'_c) and ultrasonic pulse velocity (UPV) results at 7 and 28 days as shown in Figures (5) and (6) respectively. The correlation analysis has lead to the following empirical equations:

For 7 days

$f'_c = 117\ UPV - 494.7$ ……………… (1)

For 28 days

$f'_c = 130\ UPV - 556$ …………………….. (2)

The coefficients of correlation for Equations (1) and (2) are 0.94 and 0.86 respectively.

4-3Initial Surface Absorption of the Mortar

It is necessary to reduce the absorption of the mortar as much as possible to decrease the ingress of aggressive agents and thus to enhance its durability. Table (4), Figures (7) and (8) show the effect of feldspar powder content on the initial surface absorption (ISA) of 1:1 cement – FP mortar mix with 4% superplasticizer. Generally it can be seen that the ISA is reduced as the period of time is increased, up to a period of 120 minutes; this was found to hold for all mixes. This may be attributed to the fact that, when the liquid comes in contact with dry mortar it is initially absorbed at a relatively high rate, but this rate decreases with time as the capillary length filled with liquid increases. In fact the rate of flow of water into mortar is inversely proportional to the length of capillary filled with water[6].

It can be observed also that the ISA for mortar mixes containing FP decreases as the FP content increases relative to the reference mortar mix (without FP). The reduction for mortar mix with 17% cement replaced by FP was about 67, 73, 73 and 95% for time periods 10, 30, 60 and 120 minutes respectively relative to the reference mortar mix. The increase in FP content to 23% very slightly reduces the value of ISA as compared with that of mortar mix with 17% FP as shown in Figures (7) and (8). It is clear that the ISA values measured at 120 minutes was very small for mortar mixes containing 17 and 23% FP. The reduction in ISA is possibly because the feldspar powder works as a filler, blocking or reducing some pores[6].

From the results indicated previously, it can clearly be seen that 1:1 mortar mix with 17% FP replacement of cement by weight with water – cement ratio (0.249) and superplasticizer dosage 4% by weight of cement, gives the highest compressive strength of 79.5 N/mm^2 at 28 days. Therefore this mortar is selected in this work to investigate its properties at room temperature (25°C) and after exposure to high temperatures.

4-4Effect of Age on Mechanical Properties of the Selected Mortar

Tables (5) and (6) show some of the mechanical properties at different ages for the selected mortar mix used in this investigation at room temperature. It can be seen from Tables (5) and (6) that this mortar is dense and has high compressive strength and modulus of rupture, this is because of the reduction in water – cement ratio due to incorporation of superplasticizer and the activity of feldspar powder as a result of its high fineness, resulting in reducing porosity, in producing

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

homogeneity and reducing microcracks in the system leading to an extremely dense matrix[7]. Also the pozzolanic action of FP can ensure continuous hydration and strength development at 180 days. The results indicate that the compressive strength, modulus of rupture and UPV increase with age, the rate of increase in strength and UPV is rapid at early ages (3 to 14 days) and up to 28 days, thereafter, the rate is slow at 60, 90 and 180 days. This is because of the fact that the hydration process slows down at later ages with the completion of mortar inner structure. These results are in agreement with previous finding[8,9].

The results obtained from measurement of shrinkage with age are also shown in Table (5). Generally, the presented data indicate that initially the rate of shrinkage is high and then it decreases with age. This phenomenon (initial rapid shrinkage) is damped out after a short period (few days). The reason for this initial high rate of shrinkage can be expected from the diffusion theory of drying. The moisture will be evaporated initially from the surface and near the surface at a high rate. This is due to the high diffusion coefficient of the moisture from the surface as a vapour. In general, high cement content used in this mix and the incorporation of superplasticizer increases the shrinkage values[10].

Table (6) shows the results of static and dynamic modulus of el

determine the dynamic modulus of elasticity (E_d) by using the following equation:

$$E_d = \rho V_c^2 \ \dots\dots\dots\dots\dots \ (3)$$

It can be observed that the static and dynamic moduli increase with age and the dynamic modulus is considerably higher than the static modulus. These results are in agreement with those obtained for concrete[11].

4-5 Effect of High Temperatures on Properties of the Selected Mortar

4-5-1 Weight Changes

Table (7) shows the effect of elevated temperature on the weight loss of high performance mortar. It can be noticed that with the increase of exposed temperature, the mortar showed increased weight loss. The loss of weight is attributed to the fact that when hardened mortar is heated gradually, the loss of weight appears to take place in three stages. In the drying stage, evaporation of water from large capillaries and voids will take place. At the dehydration stage, which occurs between 100 and 600°C, loss of nonevaporable water from gel pores and small capillary pores will take place. In the decomposition stage, several changes will occur in the mortar system. At the temperature above 1000°C, the combined water from hardened paste will be released. This will cause the hardened paste to loss its cementing property and thus significantly reducing the hardened mortar properties. This process will be accompanied with significant shrinkage of cement paste as well as loss in strength[12].

4-5-2 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity measurements may help to assess the damage of concrete (mortar) caused by fire. Reduction in mortar strength as a result of fire is usually accompanied by a corresponding, but not proportional, reduction in pulse velocity[13]. It can be seen from Table (7) that the UPV test results after exposure to different elevated temperatures decrease as the temperature increases. This may be because the water in the pores will expand on heating and exert significant internal pressure within the system and thus result in the formation of internal micro – cracks. These micro – cracks have caused the UPV to decrease noticeably compared to the mortar at temperature 25°C, so the loss in pulse velocity is due to the combination of the effects of drying, internal cracking as

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

well as to the changes in the microstructure of the paste on heating.

4-5-3 Compressive Strength

Table (8) shows the percentage loss in compressive strength relative to the original strength (at 25°C) for the mortar after exposure to different temperatures. Generally, it can be seen that the compressive strength of high performance mortar dropped significantly as the maximum temperature was increased. The loss in compressive strength was about 24, 32, 28 and 33% of the corresponding initial strength when the mortar was heated to temperatures 150, 250, 350 and 450°C respectively. Beyond 450°C the strength continued to drop significantly, and at temperature 900°C, there was a very considerable drop in the compressive strength by about 71% relative to the original strength. The experimental results of compressive strength and UPV of high performance mortar after exposure to high temperature can be used to develop a correlation between the percentage loss in UPV (V) and the percentage loss in compressive strength (F_c) due to heating as shown in Fig. (9), several trials were carried out in order to obtain a good correlation coefficient, the correlation analysis has led to the following empirical equation with correlation coefficient of 0.99:

$$F_c=0.00001V^5 - 0.0015V^4 + 0.074V^3 - 1.56V^2 + 12.8V + 0.57 \quad \text{.......... (4)}$$

This relationship is very useful in site investigations to assess the strength of mortar subjected to fire.

4-5-4 Modulus of Rupture

Table (8) indicates that the modulus of rupture of the selected mortar decreased with the increase in temperature. It can be observed that after heating to 600, 750 and 900°C the loss in the modulus of rupture was about 60, 80 and 90% respectively relative to the initial modulus of rupture.

Also a correlation between the percentage loss in UPV (V) and percentage loss in modulus of rupture (F_r) due to heating can be obtained from the experimental results as shown in Fig. (10), after several trials the following empirical equation with high correlation coefficient (R=0.96) is obtained:

$$F_r=0.0018V^3 - 0.134V^2 + 3.6V + 8.8 \quad \text{......... (5)}$$

4-5-5 Static and Dynamic Modulus of Elasticity

It can be noticed from Table (9) that the static and the dynamic moduli also decreased with the increase in temperature. In general, the decrease in strength and other properties of mortar (concrete) is due to the fact that several mechanisms have been identified for the deterioration of mortar (concrete) at high temperature. These include decomposition of the calcium hydroxide into lime and water, expansion of lime on rehydration, destruction of gel structure, and development of micro – cracks due to water pressure[14].

4-5-6 Stress – Strain Relationship

Fig. (11) shows the effect of elevated temperature upon the relationship between the stress and the strain of the mortar under compression. It can be seen that the increase in temperature higher than 150°C significantly affect the stress – strain relationship. Also it can be observed that the increase in temperature flattens the ascending branch of the stress – strain diagram. The mortar is very brittle below 250°C, however the higher the temperature, the softer the material becomes. It can be also observed that the strain at maximum stress of mortar increases as the temperature is increased.

4- Conclusions

1. The incorporation of 17% of feldspar powder as a partial replacement of cement and 4% of superplasticizer by weight of cement to 1:1 cement to sand mortar mix enabled the production of high performance mortar with compressive strength of about 80 N/mm^2 at 28 days**.** This mix was selected to study its properties at room temperature and after exposure to high temperatures.

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

2. Empirical relationships were found between the pulse velocity (*UPV*) and the compressive strength (f'_c) of the different mortar mixes at 7 and 28 days.

At 7 days $f'_c = 117\ UPV - 494.7$

At 28 days $f'_c = 130\ UPV - 556$

3. The initial surface absorption for mortar mixes containing feldspar powder was very low and it decreases as the feldspar powder content increases.

4. The selected high performance mortar shows a loss in weight of about 1 to 12% after exposure to temperature in the range from 150 to 900°C respectively.

5. When the selected high performance mortar is exposed to temperature in the range 150 to 450°C it showed about 24 to 33% loss in compressive strength, 28 to 46% loss in modulus of rupture, 19 to 55% loss in static modulus of elasticity and 7 to 59% loss in dynamic modulus of elasticity.

6. At temperature higher than 600°C, the selected high performance mortar progressively lost its strength. The drop in compressive strength and modulus of rupture was 71 and 90% respectively after exposure to 900°C.

7. Ultrasonic pulse velocity measurement after exposure to high temperature can be used to estimate the temperature related damage in high performance mortar. An empirical relationship is derived between the percentage loss in compressive strength (F_c) and the percentage loss in pulse velocity (V):

$$F_c = 0.00001V^5 - 0.0015V^4 + 0.074V^3 - 1.56V^2 + 12.8V + 0.57$$

Also another empirical relationship is derived between the percentage loss in pulse velocity (V) and the percentage loss in modulus of rupture (F_r) after exposure to different elevated temperatures:

$$F_r = 0.0018V^3 - 0.134V^2 + 3.6V + 8.8$$

8. The stress – strain curve of the selected high performance mortar is significantly affected when the exposure temperature increases higher than 150°C, the increase in temperature flattened the ascending branch of the stress – strain diagram. The strain at maximum stress of mortar increases as the temperature is increased.

References

1- Suhaendi, S.L., "*Residual Strength and Permeability of Hybrid Fibre Reinforced High Strength Concrete Exposed to High Temperature*", Proceedings of the Japan Concrete Institute, **Vol.26**, **No.1**, **July 2004**, Kochi, Japan, PP.315-320.

2- Yamamoto, Y. and Kobayashi, M., "*Use of Mineral Fines in High Strength Concrete: Water Requirement and Strength*", Concrete International: Design and Construction, **Vol.4**, **No.7, 1982**, PP.33-40.

3- Hover, K.C., "*Concrete Mixture Proportioning with Water – Reducing Admixtures to Enhance Durability: A Quantitative Model*", Cement and Concrete Composites, **Vol.20**, **No. 213**, **1998**, PP.113-119.

4- Mehta, P.K., "*Concrete: Structure, Properties and Materials*", Prentice-Hall, Inc., New Jersey, **1986**, PP.200-203.

5- Moeed, S., "*Countering Shrinkage Cracking in Renders*", report, University of Warwick, U.K., **April 2002**.

6- Levitt, M., "*The ISAT – A Non – destructive Test for the Durability on*

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

Concrete”, British Journal of Non-destructive Test, **July 1971**, PP.106-112.

7- F
rancois de Larrard, “*Ultrafine Particles for the Making of Very High Strength Concretes*”, Cement and Concrete Research, **Vol.19**, **No.2**, **1989**, PP.161-172.

8- “
High – Strength Concrete: Mechanical Properties”, The Indian Concrete Journal, **Vol.56**, **No.9**, **1982**, PP.225-227.

9- A
li, F.A., Abu-Tair, A., O' Connor, D., Benmarce, A., and Nadjai, A., “*Useful and Practical Hints on the Process of Producing High – Strength Concrete*”, ASCE, Practice Periodical on Structural Design and Construction, **Vol.6, No.4**, **2001**, PP.150-153.

10-
Soroka – I., “*Portland Cement Paste and Concrete*”, 1st Edition, Chemical Publishing Co. Inc., **1980**, PP.39.

11-
Illston, J.M., “*Construction Materials – Their Nature and Behaviour*”, 2nd Edition, Published by E & FN Spon, **1994**, PP.146.

12- R
Ravindrarajah, R.S., Lopez, R., and Reslan, H., “*Effect of Elevated Temperature on the Properties of High – Strength Concrete Containing Cement Supplementary Materials*”, 9th International Conference on Durability of Building Materials and Components, Brisbane, Australia, **17-20th March 2002**.

13-
Wan Chung, H., and Sang Law, K., “*Assessing Fire Damage of Concrete by the Ultrasonic Pulse Technique*”, Cement, Concrete, and Aggregates, **Vol.7**, **No.2**, **1985**, PP.84-88.

14- H
Horiguchi, T., and Suhaendi, S.L., “*Residual Strength and Permeability of Hybrid Fibre Reinforced High Strength Concrete Exposed to High Temperature*”, Proceedings of the Japan Concrete Institute, **Vol.26**, **No.1**, **July 2004**, Kochi, Japan, PP.315-330.

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

Table (1) Chemical analysis of feldspar powder

Substance	Percentage
SiO_2	86.34
Al_2O_3	8.49
Na_2O	1.4
K_2O	2.2
Fe_2O_3	0.7
CaO	0.4
MgO	0.11
SO_3	0.1
L.O.I	0.26

Table (2) Trial mixes for mortar with feldspar as partial replacement of sand

Mix symbol	Mix proportion by weigh	Feldspar/ % by weight of sand	Super – plasticizer/ % by weight of cement	water/cement ratio w/c	Flow %	Compressive strength N/mm^2 7 days	Compressive strength N/mm^2 28 days
S10	1:1.5	10	0	0.473	105	40.3	49.7
			2	0.387	106	47	50.3
			3	0.327	105	53.6	60.4
			4	0.307	106	47.7	52.3
			5	0.3	105	44.7	50.6
			6	0.293	113	42.5	49.9
S20	1:1.5	20	0	0.52	105	37	42.7
			2	0.42	114	45.4	48.8
			3	0.347	110	47.6	50.2
			4	0.32	115	50.5	52.9
			5	0.313	112	48.5	51.5
			6	0.3	115	48.4	50.9

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

Table (3) Trial mixes for mortar with feldspar as partial replacement of cement

Mix symbol	Mix proportion by weight	Feldspar/ % by weight of cement	Super – plasticizer/ % by weight of cement	water/cement ratio w/c	Flow %	Compressive strength N/mm^2 7 days	Compressive strength N/mm^2 28 days
P	1:2	0	0	0.533	104	33.1	47.5
		11.5	0	0.563	112	26.2	32.8
			1	0.485	108	30.9	37.9
			2	0.44	110	36.3	47.2
			3	0.38	114	37.1	50.8
			4	0.373	108	41.1	52.4
			5	0.365	105	41.6	46.3
			6	0.345	115	37.5	45.8
		17	0	0.544	106	25.3	39.4
			2	0.43	105	29.5	42.2
			3	0.38	111	32.5	44.4
			4	0.36	106	41.2	47.8
			5	0.353	105	40.1	52.7
			6	0.337	115	42.9	49.5
		23	0	0.55	109	28.9	32.7
			2	0.41	111	36.6	45.4
			3	0.36	107	44.2	56.9
			4	0.36	105	35.8	54.1
			5	0.34	111	37.8	53.9
			6	0.327	107	38.4	43.3
N	1:1.5	0	0	0.473	107	36.1	48.1
		8	0	0.47	110	28.4	43.4
			2	0.373	115	37.2	45.6
			3	0.317	115	40.3	47.3
			4	0.293	114	38	45.2
			5	0.293	111	36	44.9
			6	0.287	105	33.9	43.7
		11.5	0	0.468	108	34.8	46.3
			2	0.38	106	36.2	48.7
			3	0.33	115	39.3	49.2
			4	0.293	114	46.2	52.7
			5	0.293	108	47.9	54.2
			6	0.267	110	40.8	47.5

Mix symbol	Mix proportion by weight	Feldspar/ % by weight of	Super – plasticizer/ % by weight	water/cement ratio w/c	Flow %	Compressive strength N/mm^2

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

		cement	of cement			7 days	28 days
N	1:1.5	17	0	0.48	110	26.4	37
			2	0.373	112	37.8	50.1
			3	0.323	107	50.7	54.5
			4	0.3	114	48.8	55.6
			5	0.293	114	42.8	55.6
			6	0.28	107	45.7	48.2
		23	0	0.48	113	28.6	38.2
			2	0.36	107	38.3	50.5
			3	0.306	106	48.1	67.1
			4	0.29	115	48.4	53.9
			5	0.287	107	54.2	60.4
			6	0.27	109	53.8	58.4
C	1:1	0	0	0.397	105	47.3	56.4
			2	0.32	107	50.9	61.3
			3	0.271	111	59.2	68.4
			4	0.254	105	61	70.1
			5	0.253	105	59.4	69.8
			6	0.24	115	54.4	62.3
		11.5	0	0.406	111	40.4	48.1
			2	0.294	106	47	59.5
			3	0.254	105	67.2	76.9
			4	0.249	113	53.1	68.5
			5	0.243	113	53.7	55.1
			6	0.237	107	49.3	52.7
		17	0	0.411	115	36.6	54.2
			2	0.32	114	46.8	59.7
			3	0.26	105	52.7	73.3
			4	0.249	113	64.6	79.5
			5	0.243	109	53.5	75
			6	0.234	105	53.1	74.4
		23	0	0.413	115	34.7	52.7
			2	0.29	108	38.3	55.8
			3	0.249	115	43.6	63.4
			4	0.246	108	51	70.6
			5	0.24	111	45.7	60.7
			6	0.234	109	36	57.8

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

Table (4) Initial surface absorption results for mortar mixes

Feldspar content %	Initial surface absorption at 60 days ml / m / sec			
	10 mins.	30 mins.	60 mins.	120 mins.
0	0.413	0.352	0.298	0.213
11.5	0.275	0.231	0.177	0.092
17	0.135	0.094	0.081	0.011
23	0.127	0.089	0.078	0.008

Table (5) Mechanical properties for the selected mortar

Age days	Compressive strength N/mm^2	Modulus of rupture N/mm^2	Shrinkage$\times 10^{-6}$
3	38.2	5.3	530
7	64.6	7.2	777.4
14	67.4	8.6	918.7
28	79.5	9.2	982.3
60	84.4	9.8	1014
90	90.5	10.8	1021
180	95.4	11.3	1030

Table (6) Static and dynamic modulus of elasticity for the selected mortar

Age days	Pulse velocity Vc km/sec	Density (ρ) kg/m^3	Dynamic modulus (Ed) GPa	Static modulus (Es) GPa
7	4.1	2300	38.7	16.5
14	4.2	2317	40.9	18.2
28	4.3	2340	43.3	20.3
60	4.36	2360	44.9	22.4
90	4.42	2382	46.5	24.7
180	4.55	2397	49.6	26.1

Table (7) Effect of high temperature on the weight and pulse velocity of the selected mortar

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept./ Baghdad University
***Building and Construction Engineering Department/University of Technology

Temp. °C	**Weight before heating gm**	**Weight after heating gm**	**Loss in weight %**	**UPV before heating km/sec**	**UPV after heating km/sec**	**Loss in UPV %**
150	321.3	317.6	1.15	4.98	4.86	2.41
250	326.6	303.97	6.93	5.07	4.56	10.1
350	329.03	299.5	8.97	4.92	3.78	23.17
450	331.47	299.24	9.72	4.815	3.426	28.85
600	325.5	291.4	10.5	4.82	2.69	44.2
750	323.5	287.8	11	4.824	2.31	52.1
900	326	286.2	12.2	5.13	2.35	54.2

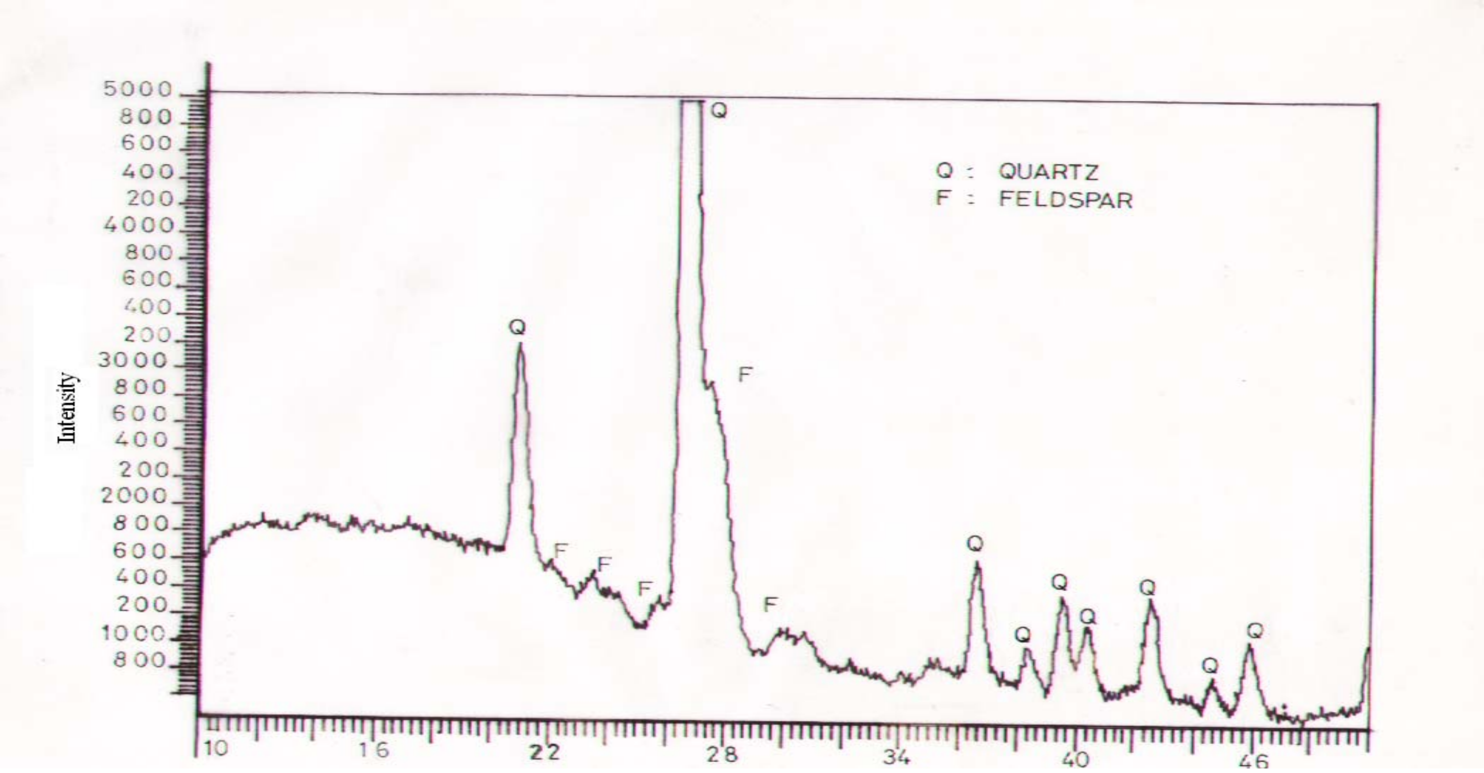
Table (8) Effect of high temperature on the strength of the selected mortar

Temp. °C	**Comp. strength N/ mm^2**	**Loss in comp. strength over 25**°C %	**Residual comp. strength %**	**Modulus of rupture N/ mm^2**	**Loss in modulus of rupture over 25**°C %	**Residual modulus of rupture %**
25	79.5	0	100	9.8	0	100
150	60.1	24.4	75.6	7.1	27.6	72.4
250	54.47	31.5	68.5	6.54	33.3	66.7
350	57.1	28.2	71.8	6.28	35.9	64.1
450	53.5	32.7	67.3	5.34	45.5	54.5
600	43.53	45.2	54.8	3.89	60.3	39.7
750	38.91	51.1	48.9	2	79.6	20.4
900	22.85	71.3	28.7	0.94	90.4	9.6

Table (9) Effect of high temperature on static and dynamic modulus of rupture of the selected mortar

Temp. °C	**UPV (Vc) km/sec**	**Densit y (ρ) kg/ m^3**	**Dynami c modulus (Ed) GPa**	**Loss in dynamic modulus at above 25**°C %	**Residual dynamic modulus %**	**Static modulus (Es) GPa**	**Loss in static modulus at above 25°C %**	**Residual static modulus %**
25	4.36	2360	44.9	0	100	22.4	0	100
150	4.23	2332	41.7	7.13	39.3	18.2	18.8	81.2
250	4.15	2292	39.5	12	88	14.5	35.3	64.7
450	2.95	2120	18.4	59	41	10.1	54.9	45.5
600	1.75	2110	6.2	86.2	13.8	7.7	65.6	34.4

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology



Diffraction angle - 2Φ

Fig. (1) X – ray diffraction analysis of feldspar

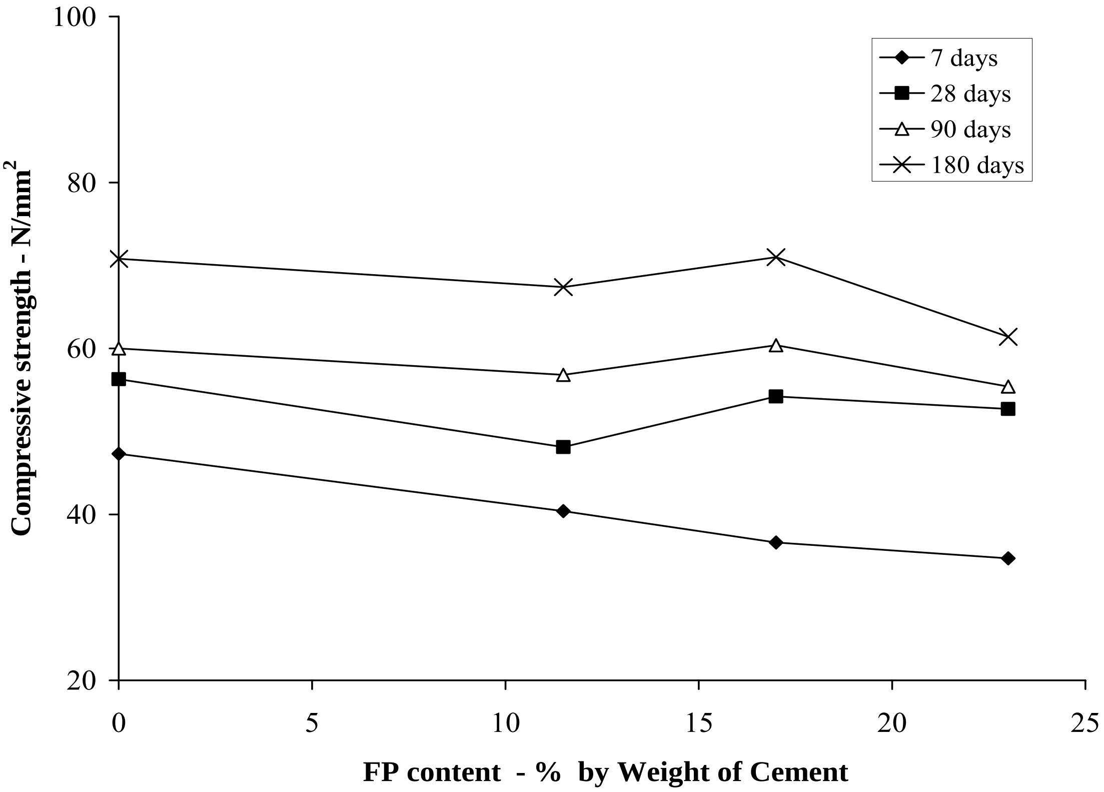


Fig. (2) Relationship between FP content and compressive strength of 1:1 mortar with 0% superplasticizer at different ages

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

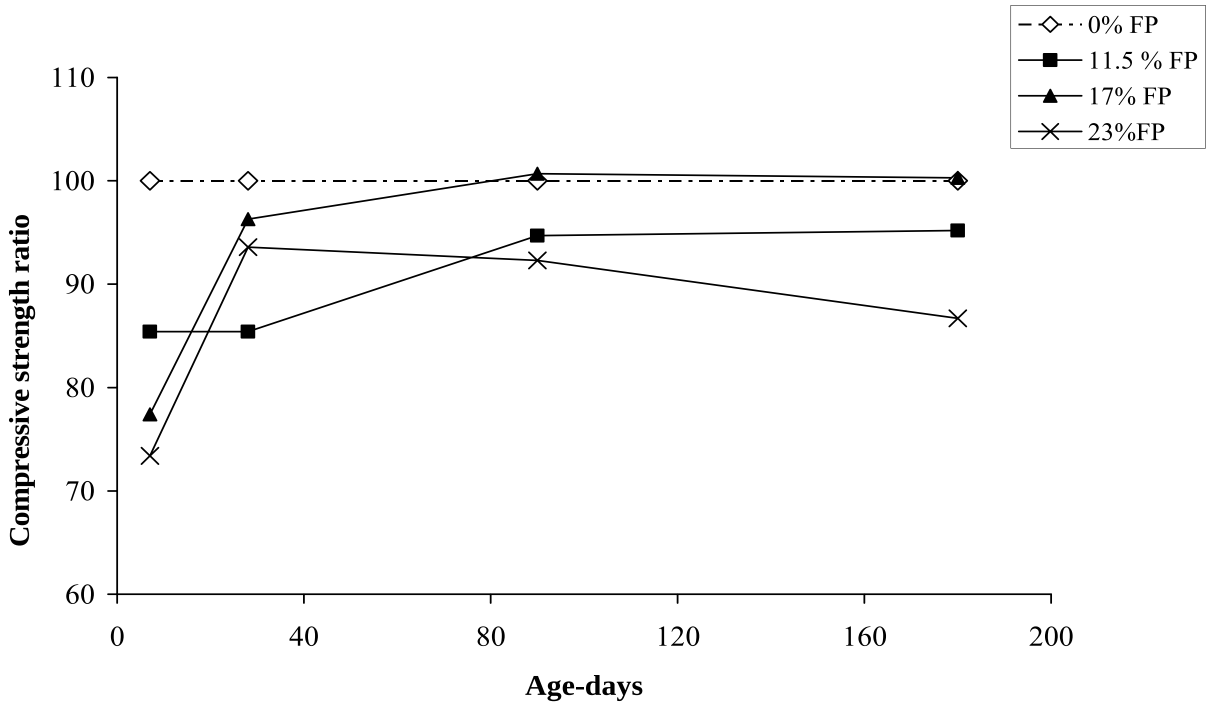


Fig. (3) Compressive strength of 1:1 cement – FP mortar as percentage of plain mortar

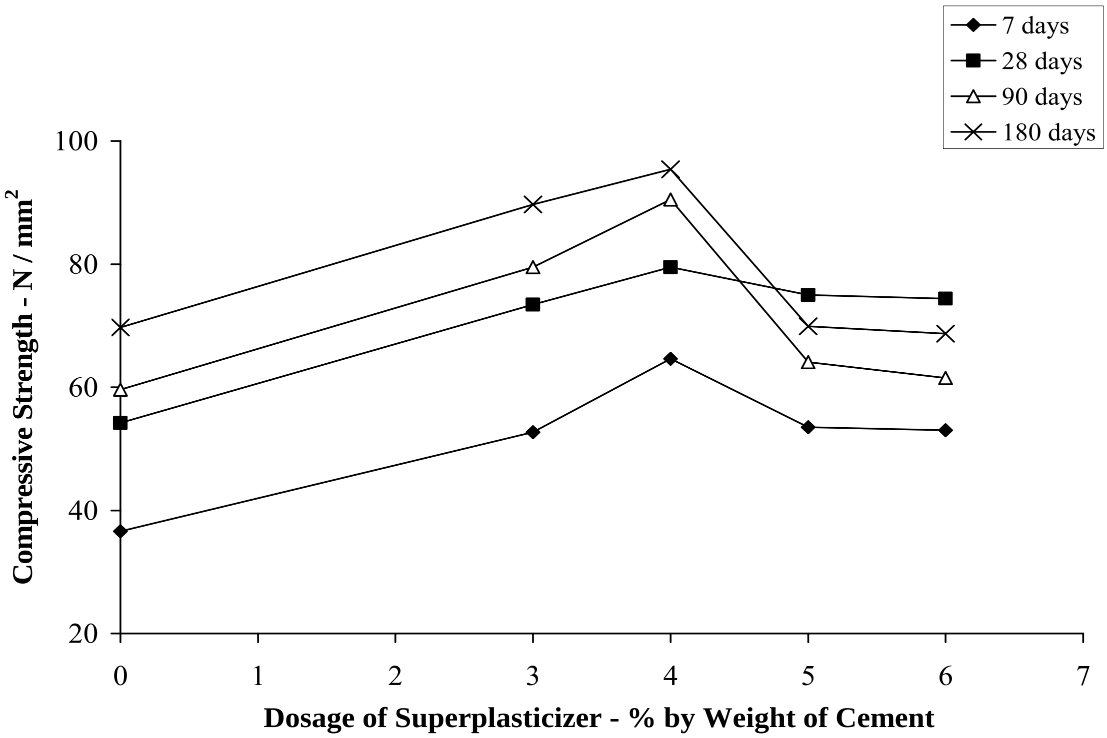


Fig. (4) Effect of superplasticizer dosage on compressive strength of 1:1 cement – FP mortar containing 17% FP

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

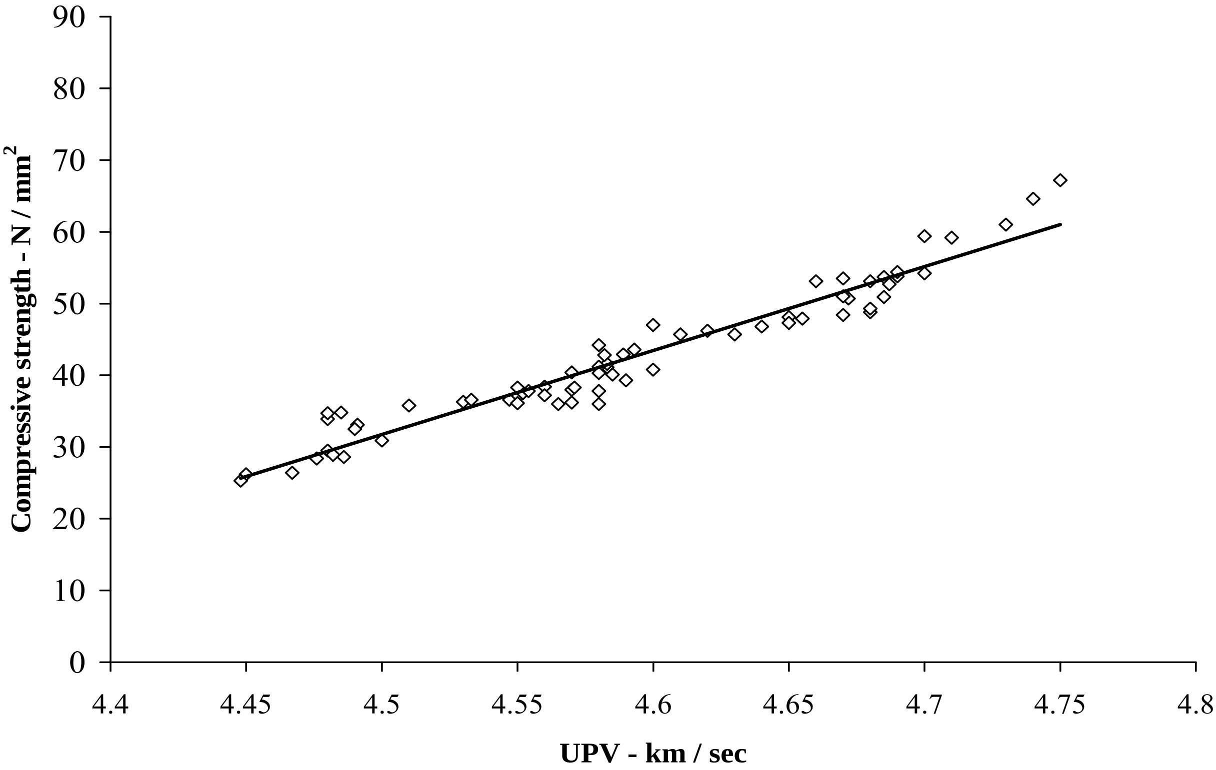


Fig. (5) Relationship between UPV and compressive strength of mortar at 7 days

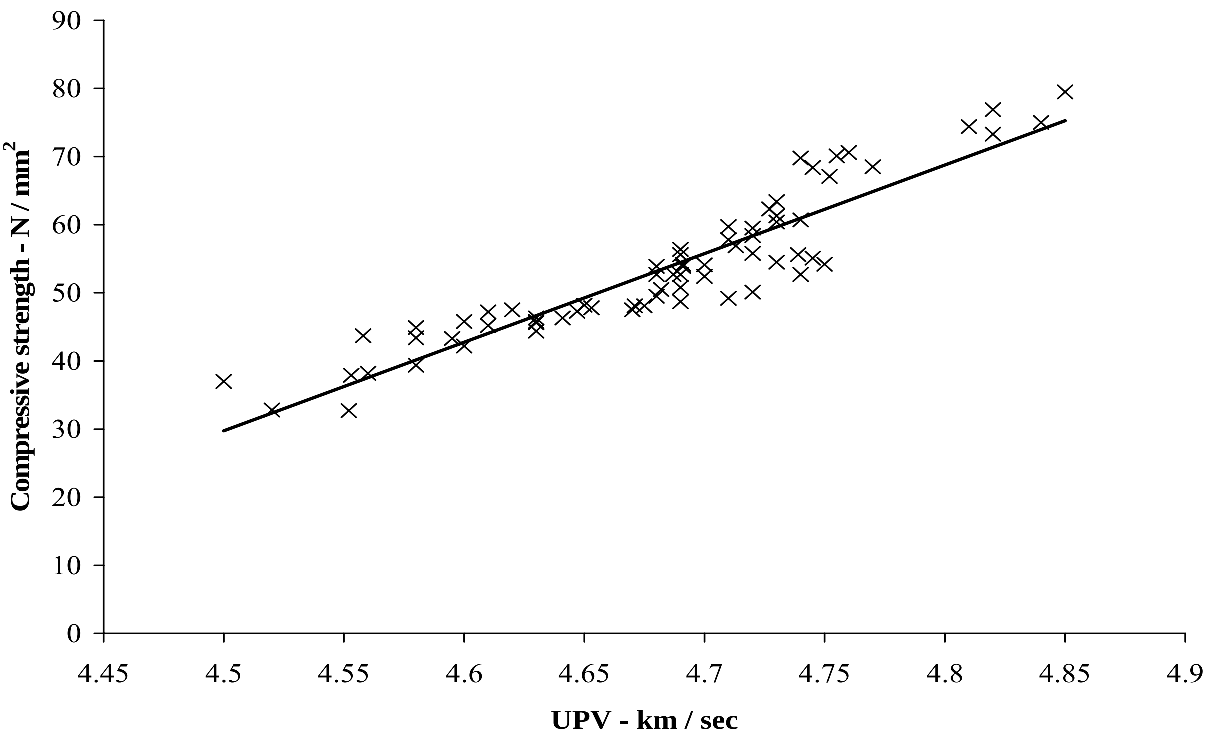


Fig. (6) Relationship between UPV and compressive strength at 28 days

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

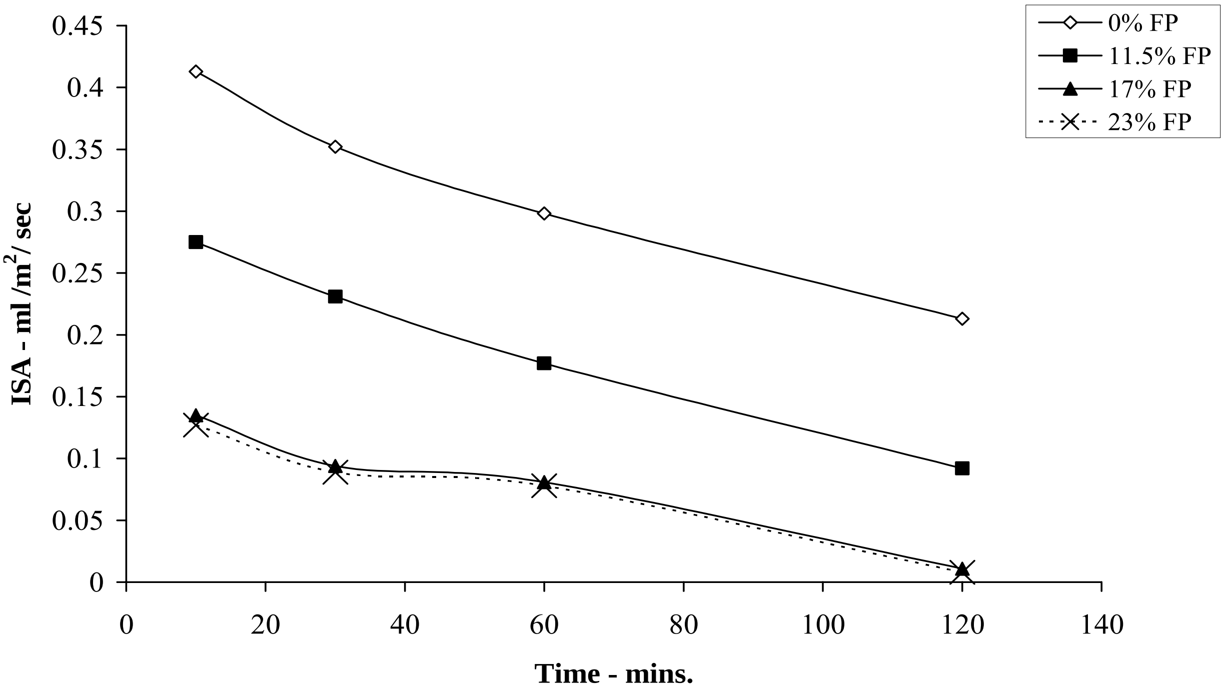


Fig. (7) Initial surface absorption of different mixes versus time

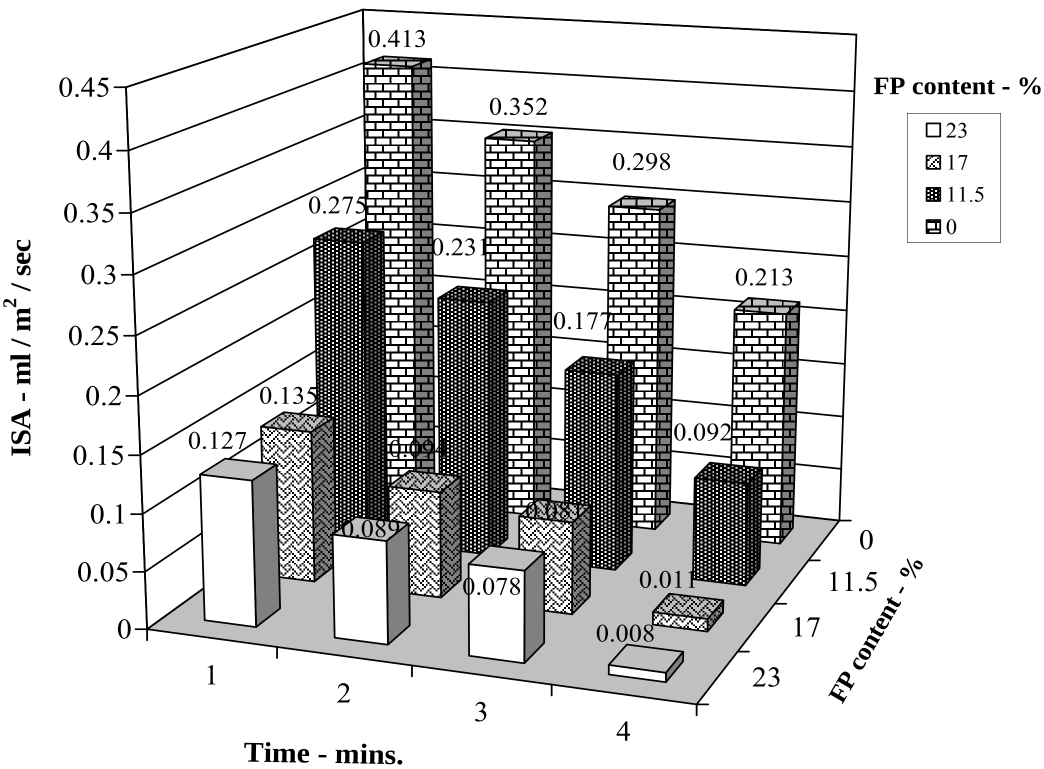


Fig. (8) Comparison of ISA of different mortar mixes containing FP

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology

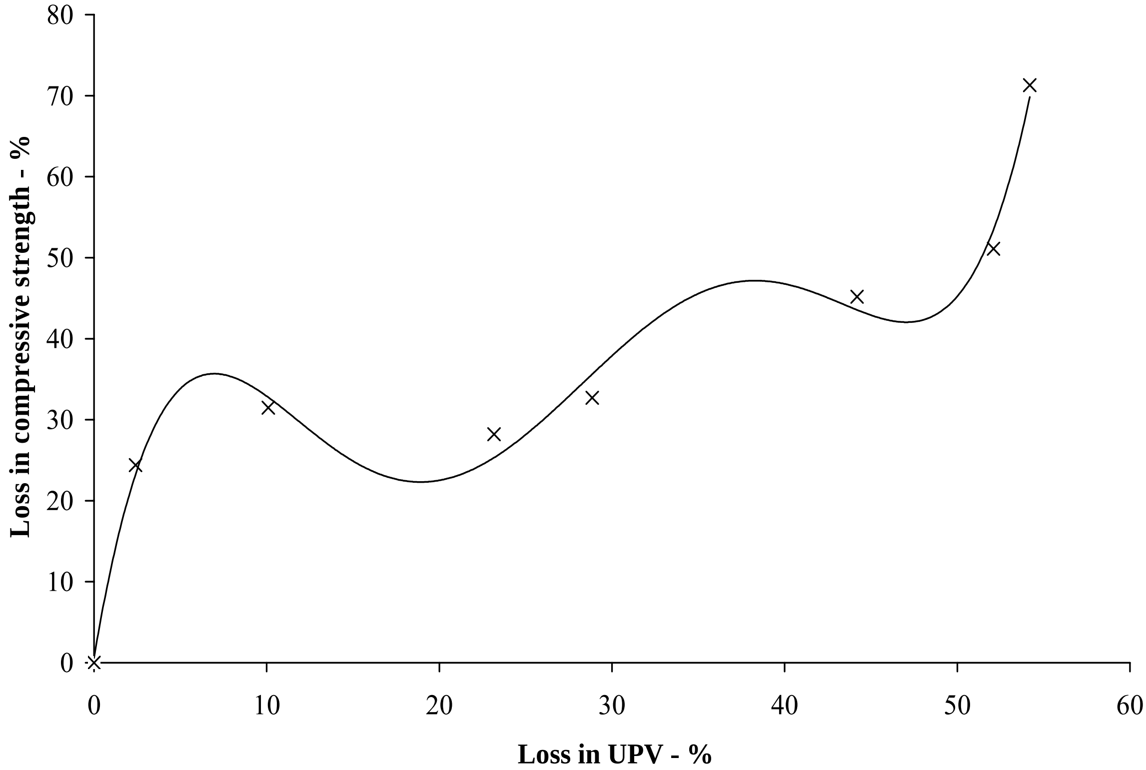


Fig. (9) Correlation between %loss in compressive strength of the selected mortar and UP*V*

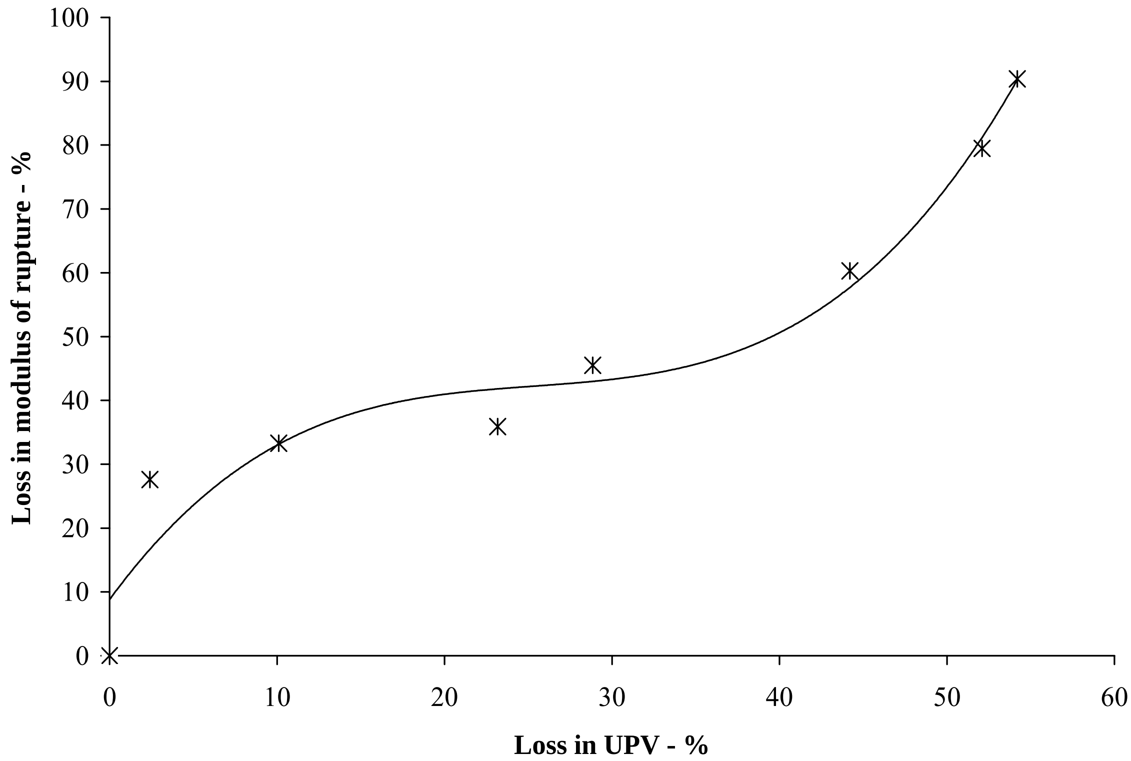


Fig. (10) Correlation between % loss in modulus of rupture of the selected mortar and UPV

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept./ Baghdad University
***Building and Construction Engineering Department/University of Technology

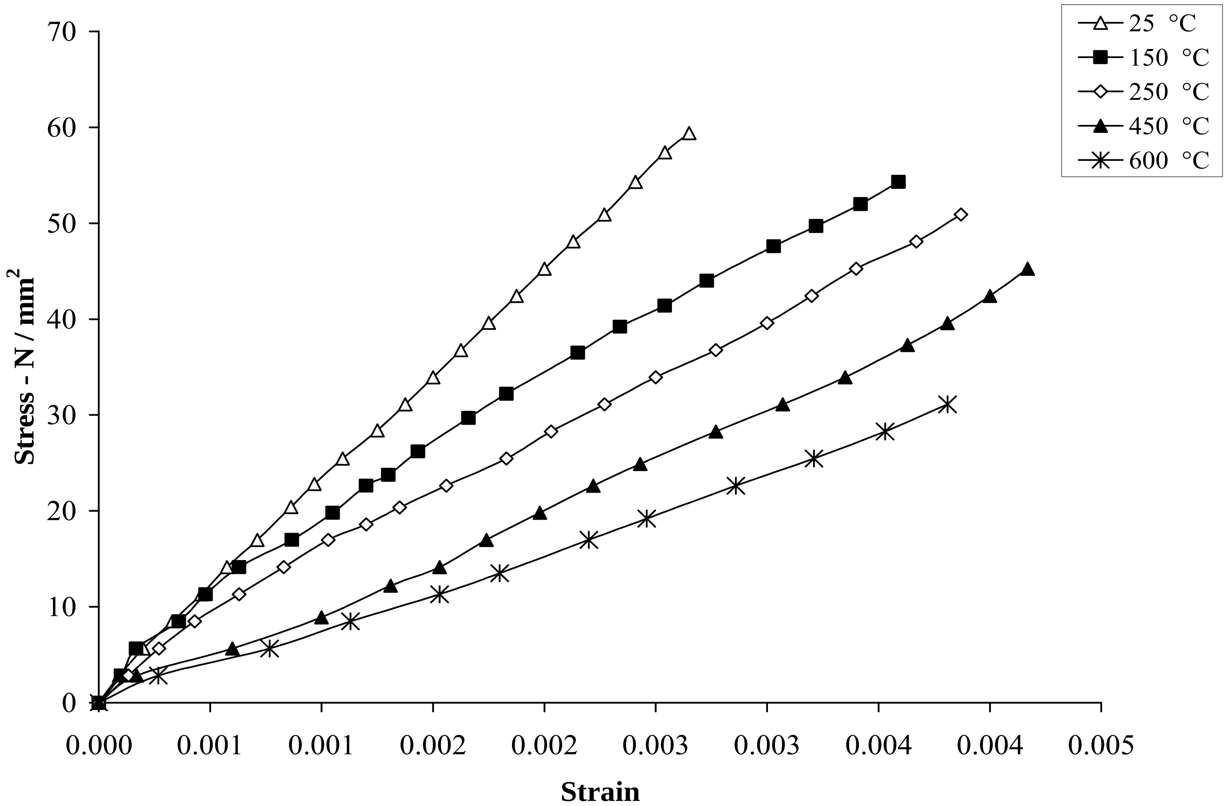


Fig. (11) Effect of high temperature on stress – strain curves of the selected mortar

*Civil Eng. Dept./ Tikrit University **Civil Eng. Dept/ Baghdad University
***Building and Construction Engineering Department/University of Technology