Mechanical Properties of High Strength Concrete Containing Different Cementitious Materials

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ABSTRACT

High strength concrete has strength significantly beyond what is used in normal practice. According to American Concrete Institute (ACI), high strength concrete revised the definition to cover mixtures with specified design strength of 55 MPa or more.

The main objective of this investigation is to study the effect of using different supplementary cementitious materials in binary blends on mechanical properties of high strength concrete.

The experimental work includes three stages: firstly, preparation of cementitious materials (metakaolin and pumice) from local materials, second involves conducting several trial mixes to choose the best of superplasticizer that satisfies the required properties and to specify the optimum water content which is designed in laboratory by 0.3 W/Cm ratio, to achieve workability with (60-80mm) slump and the best compressive strength which was 64.6 at 28 days.

Thirdly carrying out tests to find out the compressive strength, splitting tensile strength, modulus of rupture, on binary concretes including mixes containing silica fume as cement replacement at percentages of 8%, 10% and 15%, mixes containing metakaolin as cement replacement levels of 10%, 15%, and 20% and mixes containing pumice at cement replacement of 10%, 15%, and 20%.These properies were measured at ages ranging from7 days to 180 days.

The results indicate that the silica fume performs better than other supplementary cementitious materials (metakaolin or pumice) in terms of the compressive strength, splitting tensile strength and modulus of rupture development at ages of 7,28,60,90and180 days where the average percentage of increase when using 8%,10% and 15% of silica fume was about (19%,23% and 18.7%) ,respectively, while when using 10%,15% and 20% metakaolin the average percentage of increase was (10%,12.6% and 4%) respectively, also when using 10%,15% and 20% of pumice the average percentage of increase was (2.6%, 6% and 1.5%), respectively.

Keywords: High strength concrete, compressive strength, splitting tensile strength, modulus of rupture, modulus of elasticity, silica fume**,** metakaolin and pumice**.**

الخواص الميكانيكية للخرسانة عالية المقاومة والحاوية على أنواع مختلفة من المواد الأسمنتية

الخلاصة

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تعريف الخرسانة عالية المقاومة تغير على مر السنين، حيث ان الخرسانة عالية المقاومة تملك مقاومة تتجاوز بشكل كبير ما نحصل عليه من الممارسة العادية لإنتاج الخرسانة. وفقا لمعهد الخرسانة الأمريكي (ACI)الخرسانة عالية المقاومة هي الخلطات المصممة على (55MPa) أو أكثر.

الهدف الرئيسي من هذا البحث هو دراسة أثر استخدام مختلف المواد الأسمنتية في المزيج الثنائي على الخواص الميكانيكية للخرسانة عالية المقاومة.

ويشمل العمل ثلاث مراحل: أولاً، إعداد المواد الأسمنتية (الميتا كأولين و حجر الخفاف) من المواد المحلية، والمرحلة الثانية تشمل إجراء عدة خلطات تجريبية لاختيار افضل نسبة من الملدن المتفوق التي تلبي الخصائص المطلوبة وتحديد المحتوى المائي الأمثل الذي تم تصميمه في مختبر بنسبة (٠.٣ W/cm) لتحقيق قابلية تشغيل بين (٦٠-٨٠ mm) وأفضل مقاومة الضغط.

ثالثا تم دراسة الخواص الميكانيكية المتضمنة مقاومة الانضغاط ، مقاومة شد الانشطار ، مقاومة التصدع ومعامل المرونة الستاتيكي حيث أجريت على الخرسانة ذات مخالط ثنائية (السيليكا عند نسبة استبدال ٨٪، ١٠٪ و ١٥٪ ،ميتا كأولين بنسبة ١٠٪، ١٥٪، و ٢٠٪ وحجر الخفاف بنسبة ١٠٪، ١٥٪، و ٢٠٪ بديلاً جزيئاً عن الاسمنت.

وتشير النتائج إلى أن غبار السيليكا أفضل من المواد الأسمنتية الاخرى (الميتاكأولين أو حجر الخفاف) من خلال قياس مقاومة الانضغاط ، مقاومة شد الانشطار ومقاومة التصدع عند عمر ٧,٢٨,٦٠,٩٠,١٨٠ حيث كان متوسط النسبة المئوية للزيادة عند استخدام ٨٪، ١٠٪ و ١٥٪ من غبار السيليكا حوالي (١٩٪، ٢٣٪ و ١٨.٧٪) على التوالي، وعند استخدام ١٠٪ ، ١٥٪ و ٢٠٪ من الميتاكأولين كان متوسط نسبة الزيادة (١٠٪، ١٢.٦٪ و٤٪) على التوالي، وأيضا عندما نستخدم ١٠٪ ، ١٥٪ و ٢٠٪ من حجر الخفاف كان متوسط نسبة الزيادة (٢.٦٪، ٦٪ و ١.٥٪) على التوالي.

INTRODUCTION

High strength concrete has been widely used in civil engineering in recent years. This is because most of the rheological, mechanical, and durability properties of these materials are better than those of conventional concretes. High strength is made possible by reducing porosity, inhomogeneity and microcracks in concrete and the transition zone. This can be achieved by using superplasticizers and supplementary cementing materials such as metakaolin, silica fume, fly ash, granulated blast furnace slag, pumice, and natural pozzolan. Fortunately, most of these materials are industrial by-products and help in reducing the amount of cement required to make concrete less costly, more environmentally friendly, and less energy intensive**[1].**

The use of high strength concrete results in many advantages, such as reduction in beam and column sizes and increase in the building with much stories. In pre-stressed concrete construction, a greater span-depth ratio for beams may be achieved with the use of high strength concrete. In addition, high strength concrete can perform much better in extreme and adverse climatic conditions, and can reduce maintenance and repair costs **[2].**

The effect of silica fume on compressive strength of high strength concrete (HSC) was studied by **Koksal et al. [3]** Four concrete mixtures with cement, 400 kg/m^3 were used. The amounts of the replacement of silica fume by weight of cement were 0%, 5%, 10% and 15%. The results showed that the percentages of increases in the compressive strength of concrete were 12%, 73.4% and 85.5%, respectively.

Dinakar et al. [4] studied the effect of incorporating metakaolin on the mechanical properties of high strength concrete containing 5, 10, and 15 % MK in a partial replacement by weight of cement . The compressive strength results show that all the concretes made are high in strength. They also found out that the compressive strength, splitting tensile strength and modulus of elasticity exhibited the highest strength at 10% MK .

Dadu et al. [5] carried out a series of tests on compressive strengths of concrete containing pumice of 5, 7.5 % and 10%, of the OPC. The results show that the increases in compressive strength are 11% , 9% and 7.5 % ,respectively above the reference specimens .

The main aim of this investigation is to produce high strength concrete by using local pozzolan such as metakaolin and pumice as well as the use of imported material such as silica fume, and also to study the mechanical properties of this type of concrete.

Experimental Work

Materials:

- **Cement:**

Ordinary Portland cement (Type I) manufactured by United Cement Company commercially known (Mass-Bazian) was used. The chemical composition and physical properties results show that the cement conforms to the provisions of **Iraqi Specification No. 5 (1984) [6]**.

- **Fine Aggregate:**

Al- Ukaider natural sand passing through 4.75 mm sieve, falling under zone II with fineness modulus of 2.86, specific gravity of 2.65 and sulfate content of 0.1% was used as a fine aggregate. Results indicate that the sand are within the requirements of the Iraqi **specification No.45/1984[7].**

- **Coarse Aggregate:**

Crushed gravel of nominal maximum sizes of 14mm with specific gravity of 2.68, bulk density of 1630 kg/m^3, water absorption of 0.58% and sulfate content of 0.072% was used as a coarse aggregate. It was brought from ***(Al- Nebai quary)*** region. The results show that the coarse aggregate used conforms to the requirements of Iraqi specification No.45/1984**[7]**.

- **Supplementary Cementitious Materials:**

Three types of supplementary cementitious materials were used in this work:

a-Metakaolin.

The Iraqi kaolin clay brought from (***Dwekhla region***) was used as partial replacement by weight of cement in this investigation. This material was used in this work after being converted to metakaolin. The calcination temperature and the time of calcinations at that temperature used in this work were (700C^o, and 1hr.) respectively.

Before calcinations process, big fragments of kaolin clay were crushed with handy hammer into smaller sizes, and ground into fine particles of (600μm) in size, after that they were finely ground to the required fineness (8900 cm^2/gm) with a laboratory ball mill. Chemical and physical properties of metakaolin conform to the requirements of pozzolan **ASTM C618-03[8] ,** which are presented in Tables (1) and (2), respectively.

b- Pumice.

Pumice is a textural stone formed from volcanic eruptions. The quarry of this stone occurs in north of Iraq in AL- Sulaymania Governorate .Pumice stone has dark color. Pumice was prepared and used in this work after it was converted into a fine powder by crushing into smaller size by using jaw crusher laboratory, after that a laboratory blast grinding was used to make finely ground pumice into the required fineness (4180 cm^2/gm). Chemical and physical properties of pumice conform to the requirements of pozzolan **ASTM C618-03[8]** , which are presented in Tables (1) and (2), respectively.

c-Silica fume.

Silica fume was bought from Sika Company and used as a mineral admixture added to the mixtures of research. The physical properties of silica fume used in this investigation are shown in Table (2). The results show that the silica fume used satisfied the requirements of **ASTM C 1240-06 -03[9]**.

Materials Proportional, Mixing and Preparation of Specimens:

Mix design was made in accordance with guide for selecting proportion for high strength Concrete **ACI 211.4R-08[10]** . Many trial mixes were carried out to select suitable mix, the final mix had the following constituents:

Cement content of 525kg/m^3 , water content of 158 kg/m^3,fine aggregate of 750 kg/m^3, coarse aggregate of 1050 kg/m^3 and 1.5% by weight of cement of superplasticizer.

The percentages of silica fume in mixtures were(8, 10, and 15%) of silica fume in partial replacement of cement, also the proportions of metakaolin in partial replacement of cement in mixtures were (10, 15, and 20%), and the percentages of pumice were 10%, 15%, and 20% in partial replacement of cement .

Dry materials (sand and coarse aggregate) were first mixed for 1 minutes, and earlier cement and cementitious materials were mixed together by hand together until obtaining a homogeneous mixture which was added into the mix. Then, water and superplasticizer were added to mix which was stirred. Generally mixing time was about (4-5) minutes.

The specimens of HSC were prepared and compacted by using moulds ,100mm cubes and prisms of 100×100×400 mm were made according to **BS EN 12390-part1:2000[11]** for testing in terms of compressive strength and modulus of rupture. Moreover, cylindrical specimens' molds of 100×200 mm were made for splitting tensile strength and 150×300mm for modulus of elasticity according to **ASTM C-192[12]**. After compaction, the specimens were leveled by hand troweling, and covered with polyethylene sheet and sealed with tape in the laboratory for about (24) hours at laboratory temperature to prevent evaporation of moisture from the fresh concrete.

Curing:

After demolding, all the specimens were cured in the same method which involved placing them in tap water; the specimens were cured until the beginning of test at 7,28,60,90,180 day age.

Results and Discussion

Workability:

Table (3) show the effect of using different percentages of pozzolanic materials on the workability. The results also show that the silica fume and pumice have slight effect on workability. On the other hand, MK has a slight effect on the workability at the percentages of (10% and 15%), while at 20% replacement, the percentages of decrease in the workability was 13.3%. This may be due to the fact that used pozzolanic materials with high fineness increase water demand. This results are in agreement with that reported by **Ramachandran[13]**

Compressive Strength:

The effect of using different percentages of SF(8%,10%, 15%) in a partial replacement by weight of cement upon compressive strength at various ages is shown in Fig. (1) and Fig. (2). From these figures it can be seen that the average percentage increases in compressive strength at 7,28,60,90 and 180days were 16.5%,22.3%,18.4%,18.3 and 16.8%, respectively compared with their reference specimen.

The results also show that the high rate of increase in compressive strength is at 28 days, then after that the rate become approximately constant. The improvements in compressive strength may be due to the chemical and physical effects of silica fume. Chemical effect is mainly due to the pozzolanic reactions between the amorphous silica in SF and calcium hydroxide (CH) produced by the hydration of cement to form secondary calcium-silicate-hydrates (C–S–H). The physical effect, includes reduced bleeding, provision of nucleation sites, and more efficient packing of the solid particles which can also be considered as having filler effect by filling the spaces between the cement grains in much the same way as cement fills the spaces between fine aggregates and fine aggregates fill the spaces between coarse aggregates in concrete **[14,15,16].**

Metakaolin second material will be used as a partial replacement by weight of cement**.** Fig.(3) shows the relationship between compressive strength and the percentages of MK 10%, 15% and 20% used. On the other hand Fig.(4) shows the relationship between the relative compressive strength and age of curing of HSC specimens.

From this figure it can be noticed that the compressive strength of MK-HSC specimens at 7 days is higher than that of their reference HSC specimens (without pozzolana) for 10 and 15 percent cement replacement by MK and the percentage of increase was (7.5%and 6%) ,respectively, while at replacement of 20%MK the compressive strength is approximately the same when compared with reference HSC specimens. On the other hand the average percentage increases in compressive strength of HSC specimens at 28,60,90 and 180 days age were 4.5%, 14.2%, 11.1%,10.9%and 8.7%, respectively compared with their reference.

It can be seen also that the increase in (MK) content beyond the 10% of MK causes reduction in the compressive strength of specimens compared the result obtained from value of 10% of MK**[4,17]**.

The increase in compressive strength of HSC specimens containing MK may be due to the pozzolanic reaction between MK and $Ca(OH)_2$ that leads to the reduction in the concentration of the $Ca(OH)_2$ crystals in transition zone and results in improving the bond between the cement paste and the aggregate surface**[18,19]**.

Pumice third material will be as blended cement to investigate its effect on the compressive strength of HSC specimens at various ages.

The effect of pumice as a partial replacement by weight of cement on the compressive strength is also shown in Fig.(5). While Fig.(6) shows the relationship between the relative compressive strength and age of curing of HSC specimens.

It is clearly seen that the use of pumice as replacement materials with cement develops the strength with progress of age. At early ages of 7days, different percentages of pumice content cause a slight decrease by 9% compared with the reference specimen. While the compressive strength of specimens containing 10%,15%and 20% of pumice indicates that the percentage increase after 28 days age up to 180 days is slight when compared with that of the reference specimen because the average percentage of increase in compressive strength at 28 days age is (4.7%) compared with the reference specimen.

Generally ,it can be seen Figures (1) to(6) confirm that silica fume has higher compressive strength than other supplementary cementitious materials (MK and pumice), because the average percentage of increase in compressive strength when using SF is 19%,and when using MK and pumice it is 12% and 4.7%, respectively .

Splitting Tensile Strength:

Figure (7) shows the effect of different percentage of silica fume on splitting tensile strength. While Fig(8)shows the relationship between the relative splitting tensile strength and age of HSC specimens containing (10%,15%and 20%) of MK.

The results indicate that the splitting tensile strength at 7 days with the silica fume replacement causes an average increase by 12 % compared with their reference, and at age of 28 and 60 days it is (26.4 %) and (27.2%) ,respectively compared with reference , while percentage increase at 90 and 180 days is approximately the same with respect to age of 60 days when compared to the reference specimens.

Relationship between the splitting tensile strength and percentage of MK (10%, 15% and 20%) is shown in Fig.(9).While Fig.(10) illustrates the splitting tensile strength of specimen containing MK as a percentage of reference specimens with age .

From the figures it can be seen also that the average percentage increase in splitting tensile at 7 days is 3.2% compared with reference. While the average percentage increases in splitting tensile strength, at age 28 and 60 days it is (15.2%) and (15.6%) ,respectively compared with reference. On the other hand, at age 90 and 180 days it slightly increases compared with 60 days specimens.

Figure(11) shows the splitting tensile strength with percentage of pumice of (10%, 15% and 20%).Conversely, Fig. (12) shows the splitting tensile strength of HSC that contained pumice as a percentage of reference specimens with age .

The figures show that the splitting tensile strength of specimens at 7 days compared with reference specimens and the average of decrease is 11.1%. The figures also show that the average percentage of increase in splitting tensile strength at age 28,60,90 and 180 days is 7.6%,8.1%, 8.6% and 6.3% ,respectively compared with reference specimens.

Flexural Strength (Modulus of Rupture):

Figure (13) shows the variation in modulus of rupture at(8%,10% and15%) of silica fume used in a partial replacement by weight of cement. while Fig(14)shows the relationship between the relative modulus of rupture and age of HSC specimens.

The average percentage increase in the modulus of rupture with respect to reference specimen of SF (8%,10% and 15%) at 7,28,60,90 and 180 days is 17.5%,17.3%,18.9%, 18.8% and 20.4%, respectively.

Figure(15) indicates the relationship between modulus of rupture of HSC specimens containing (10%, 15%and 20%) of MK and age . While Fig.(16)shows the relationship between the relative compressive strength and age, the percentage of increase in modulus of rupture at 7day age of is 3.1% relative to the reference specimens. The results also show that the modulus of rupture of specimens containing 10 % of MK at 28 days shows a slight increase of 1.3% , while HSC specimens containing 15% and 20% of MK shows a slight reduction compared with their reference. The results also indicate the average percentage of increase in the modulus of rupture at 60,90 and 180 days is 3%, 6% and 7.1%, respectively compared with their reference specimens.

Figure (17) shows the modulus of rupture at different percentages of replacement of pumice of(10%,15%and20%). Fig.(18) shows also the modulus of rupture of HSC specimens containing pumice as a percentage of reference specimens at age 7,28,60,90 and180 days.

The results show that the decrease in modulus of rupture at 7and 28 days measured relative to the reference specimens is 8.9% and 10.2 ,respectively. On the other hand, the percentage of increase in the modulus of rupture at 60 ,90and 180 days is very slight compared with reference specimens.

Static Modulus of Elasticity

Table (4) shows the results of static modulus of elasticity, obtained from stress–strain relationship carried out after 28 days curing on reference specimen and HSC specimens containing(8%,10%,15%) of silica fume, (10%,15%,20%)of metakaolin and (10%,15%,20%) of pumice in a partial replacement by weight of cement .

It can be observed from these results there is a slight increase in static modulus of elasticity in the HSC specimens with all percentages of replacement in comparison with reference specimen. The average percentages of increase in static modulus of elasticity of specimen containing silica fume, MK and pumice is 7.1%, 4.8% and 1.4 %, respectively compared with their reference specimen.

Despite the differences between the elastic modulus of the HSC and reference specimens, it is evident that at high replacement levels, the elastic modulus is less sensitive to increased cement replacement when compared to compressive strength. This finding could result from the reduction in porosity due to C–S–H formation of the pozzolanic reaction, particularly at later ages. The elastic modulus is significantly affected by porosity, with lower porosity resulting in a higher elastic modulus**[20].**

From the table it can be seen that the experimental measured results are in close agreement with those theoretically predicted by **ACI 363R-92[21]** for the high strength concrete.

CONCLUSIONS

From the experimental results, the following conclusions can be made.

1. Using different percentages of cementitious materials (silica fume, metakaolin and pumice) have slightly effect on the workability of HSC.

2. The use of silica fume in a partial replacement of cement shows improvement in compressive strength, the average percentage of increase from age 7 days to 180 days of 19% when compared with the reference. On the other hand, the specimens containing MK and pumice have showed little and slight effect on compressive strength, respectively.

3. With respect to reference specimens, the average percentage of splitting tensile strength at age 7 to 180 days is 23%, while for those containing MK and pumice is 13%and 6% , respectively.

4. The results show that the behavior of SF, MK and pumice in modulus rupture of HSC is nearly the same as that of the splitting tensile strength.

5. Static modulus of elasticity of HSC specimen is slightly affected by using different percentages of silica fume, MK and pumice , the average percentage increase in static modulus of elasticity at age 28 days is 7.5%,4.8%and1.4%,respectively compared with their reference specimen.

6. It was shown that the specimens with 10% cement replacement by cementitious materials (SF,MK and pumice) exhibit better improvement in all mechanical properties than other percentage.

Table (1). Chemical analysis of MK and pumice.

Oxide Composition	Oxide content %	
	MK	pumice
SiO_2	55.22	70.1
Al_2O_3	32.38	8.26
Fe_2O_3	1.54	3.24
CaO	2.24	4.45
MgO	0.41	1.45
SO_3	2.55	0.08
K_2O	0.3	3.51
L.O.I	2.39	2.18

Table (2).Physical properties of MK, pumice and silica fume .

Physical properties	MK	pumice	Silica fume
Strength activity index with cement at 7 days ,min. % of control	112	106	126
Flow, max. %	110	112	111
Specific gravity	2.63	2.38	-----
Surface area (Blaine Method). cm^2/gm	8900	4180	-----

Table (3).Effect of using cementitious materials on the workability of HSC.

Mix symbol	Cementitious material		Percentage of Superplasticizer(%)	W/Cm	Slump	Slump %
	Type	%				
Mix without super	-----	0	0	٠.٤	٧٥	0
M_0	------	0	1.5	0.3	80	+6.7
Ms_{f8}	Silica fume	8	1.5	٠.٣	٧٥	0
Ms_{f10}	=	10	1.5	٠.٣	٧٥	0
Ms_{f15}	=	15	1.5	٠.٣	٧٠	-6.7
Mm_{10}	Metakaolin	10	1.5	٠.٣	٧٣	-2.7
Mm_{15}	=	15	1.5	٠.٣	٧٠	-6.7
Mm_{20}	=	20	1.5	٠.٣	٦٥	-13.3
Mp_{10}	Pumice	10	1.5	٠.٣	٧٠	-6.7
Mp_{15}	=	15	1.5	0.3	72	-4
Mp_{20}	=	20	1.5	0.3	75	0

Table (2): Effect of cementitious materials (silica fume , metakaolin and pumice) on static modulus of elasticity of HSC at 28 days.

Symbol Mixes	M_0	Ms_{f8}	Ms_{f10}	Ms_{f15}	Mm_{10}	Mm_{15}	Mm_{20}	Mp_{10}	Mp_{15}	Mp_{20}
Modulus of Elasticity (GPa)	٣٣.٦	٣٦.٢	٣٦.٨	٣٦.٢	٣٦	٣٥.٣	٣٥	٣٤.٣	٣٤.٢	٣٤.١
Modulus of Elasticity(GPa)by Equation	٣٧.٨	٤١.٤	٤٢.٣	٤١.٥	٤١.٢	٤٠.٣	٣٩.٦	٣٨.٨	٣٨.٦	٣٨.٥
Difference between two method(%)	١٢.٥	١٤.٤	١٤.٩	١٤.٦	١٤.٤	١٤.٢	١٣.١	١٣.١	١٢.٩	١٢.٩

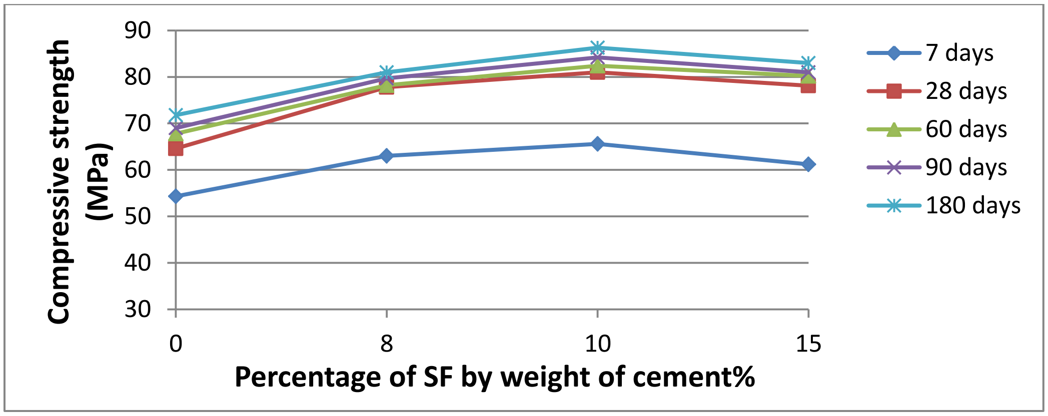


Figure (1): Effect of silica fume content(%) on compressive strength.

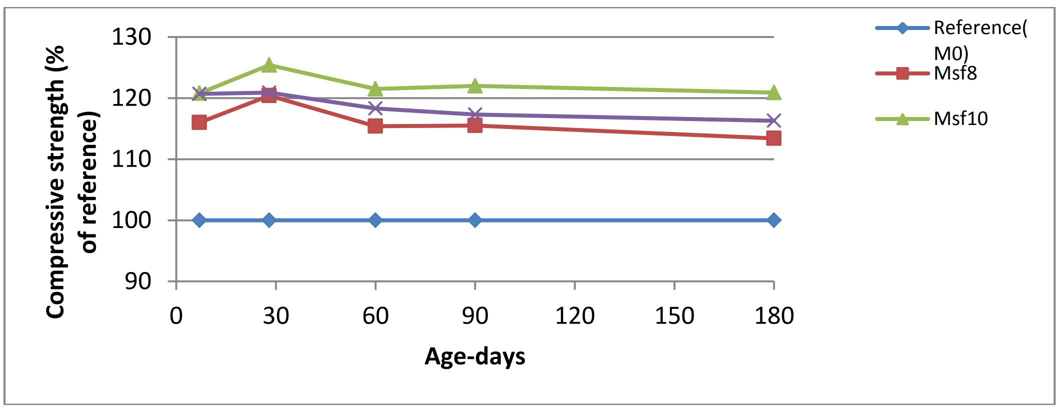


Figure (2): Compressive strength of HSC containing SF as a percentage of reference specimens.

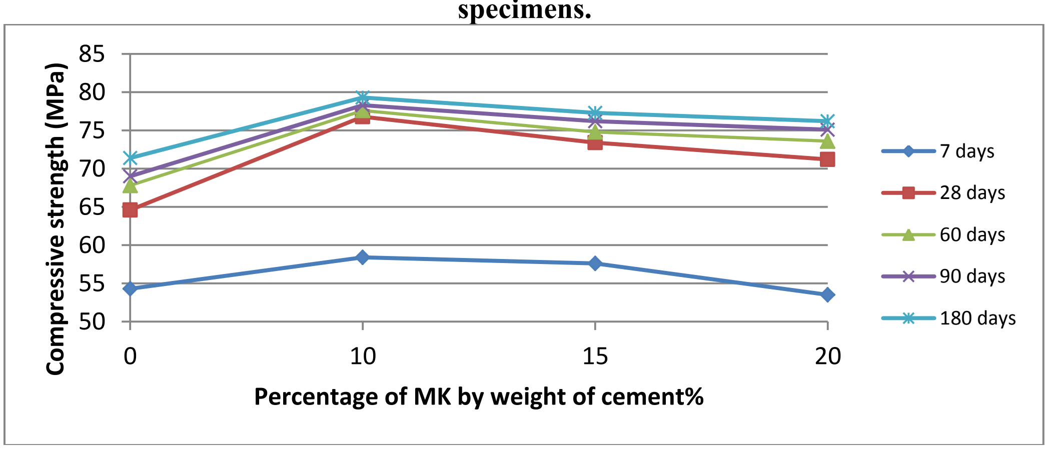


Figure (3): Effect of metakaolin content(%) on compressive strength.

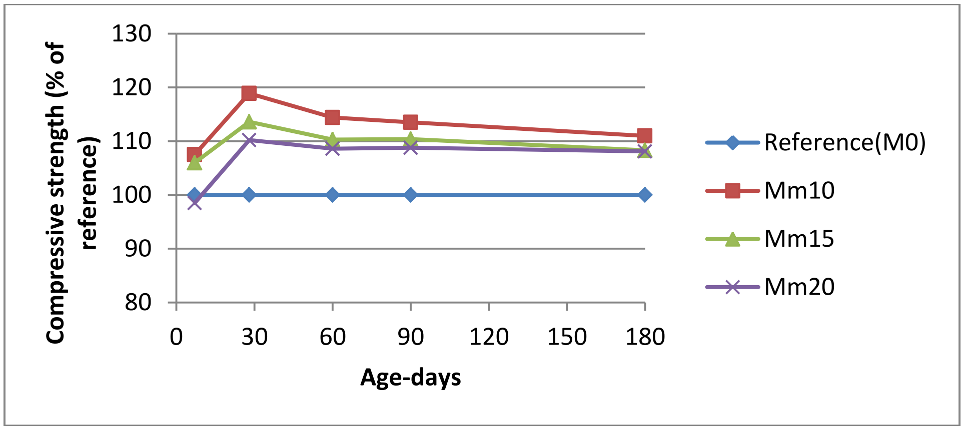


Figure (4): Compressive strength of HSC containing MK as a percentage of reference specimens.

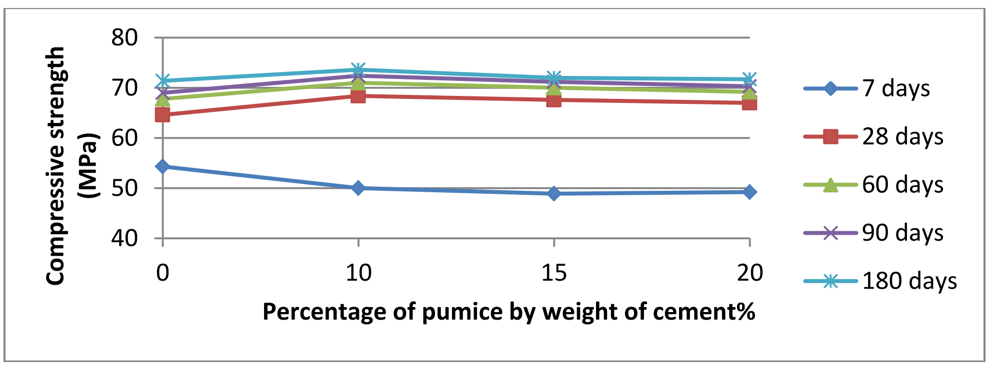


Figure (5): Effect of pumice content(%) on compressive strength.

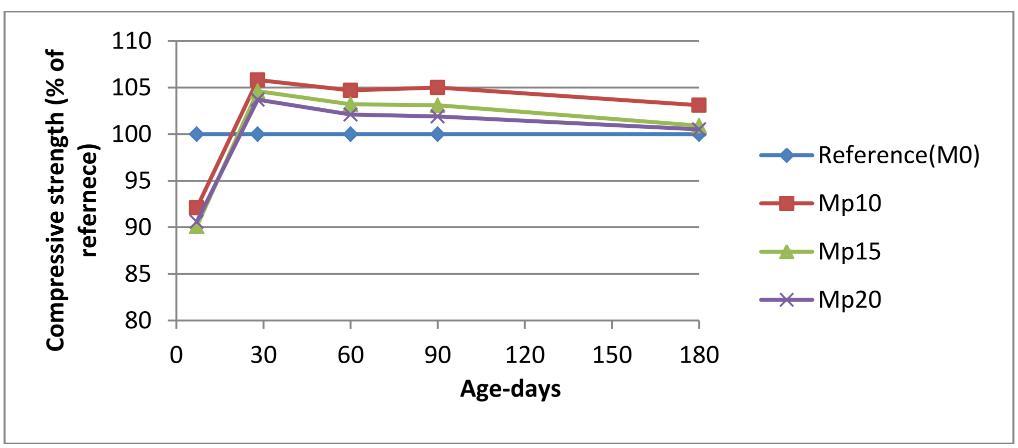
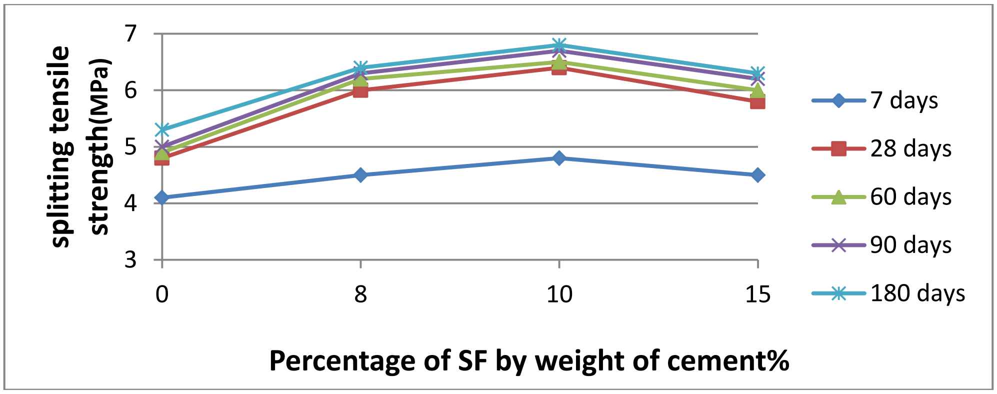


Figure (6): Compressive strength of HSC containing pumice as a percentage of reference specimens.



Figure(7): Effect of silica fume content(%) on splitting tensile strength.

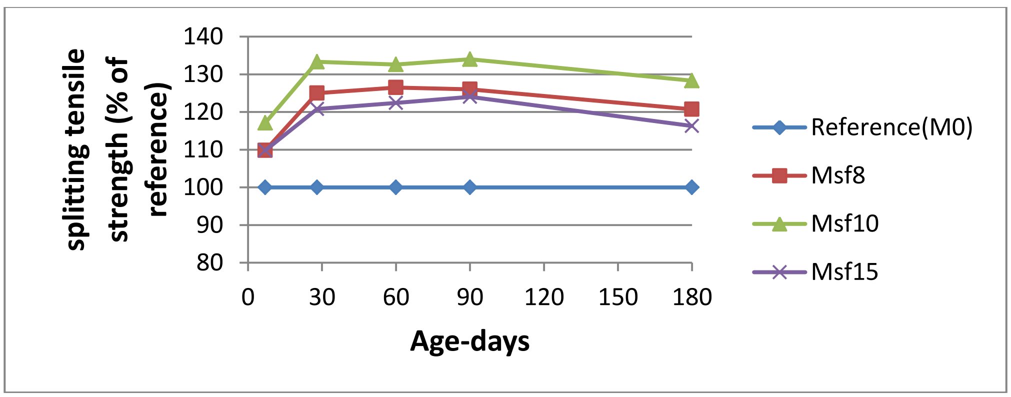
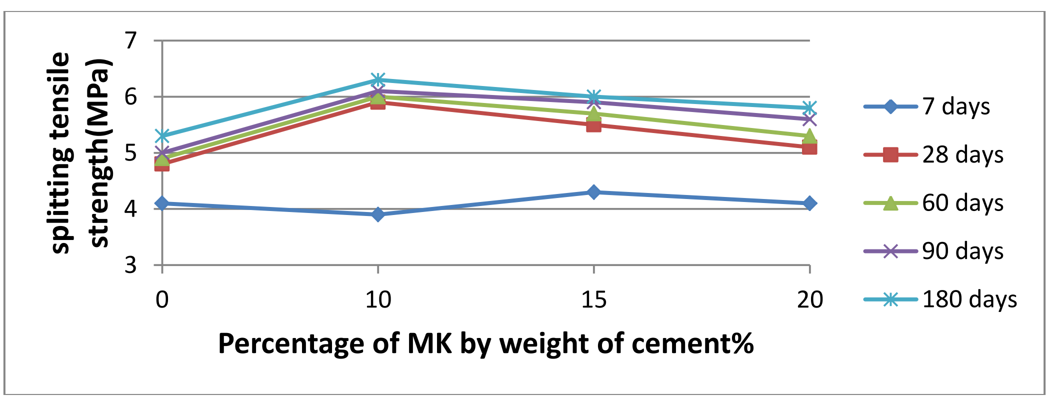


Figure (8): Splitting tensile strength of HSC containing SF as a percentage of reference specimens.



Figure(9): Effect of metakaolin content(%) on splitting tensile strength.

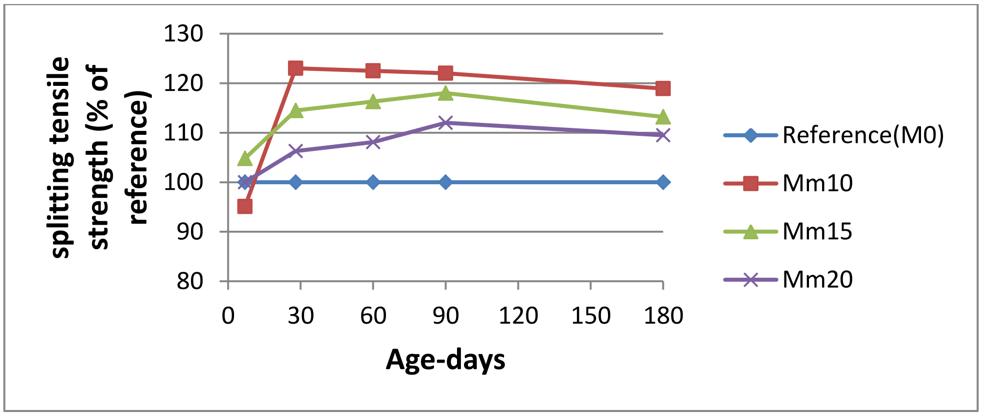


Figure (10): Splitting tensile strength of HSC containing MK as a percentage of reference specimens.

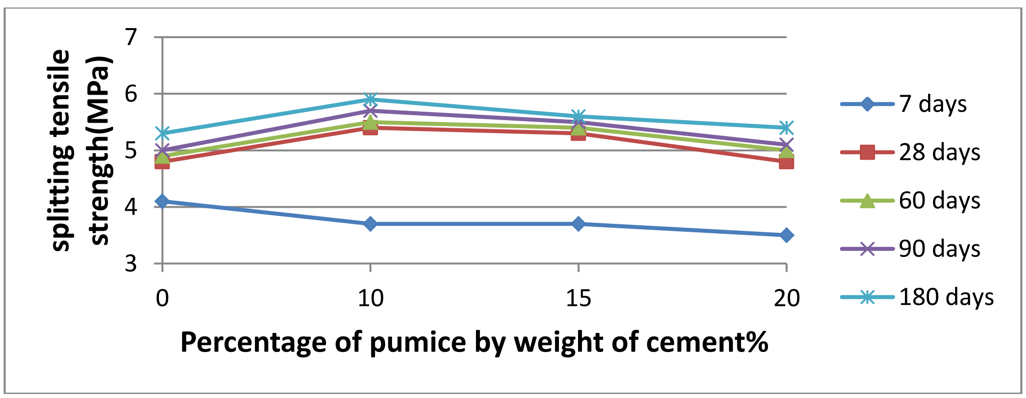


Figure (11): Effect of pumice content(%) on splitting tensile strength.

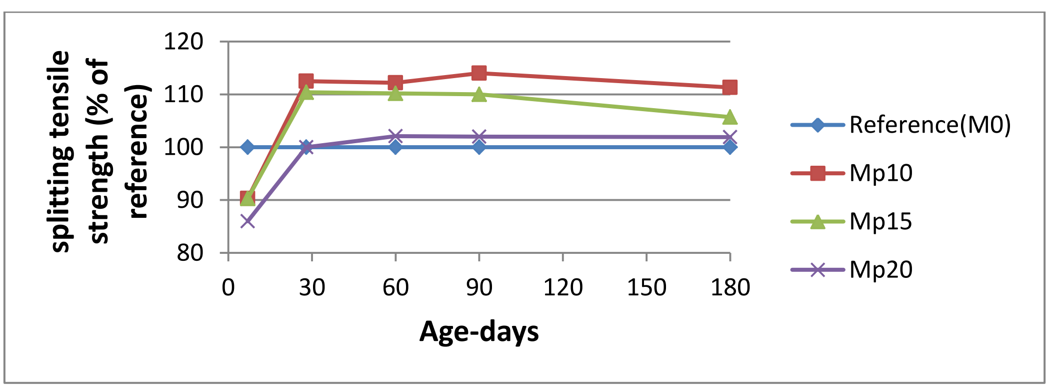


Figure (12): Splitting tensile strength of HSC containing pumice as a percentage of reference

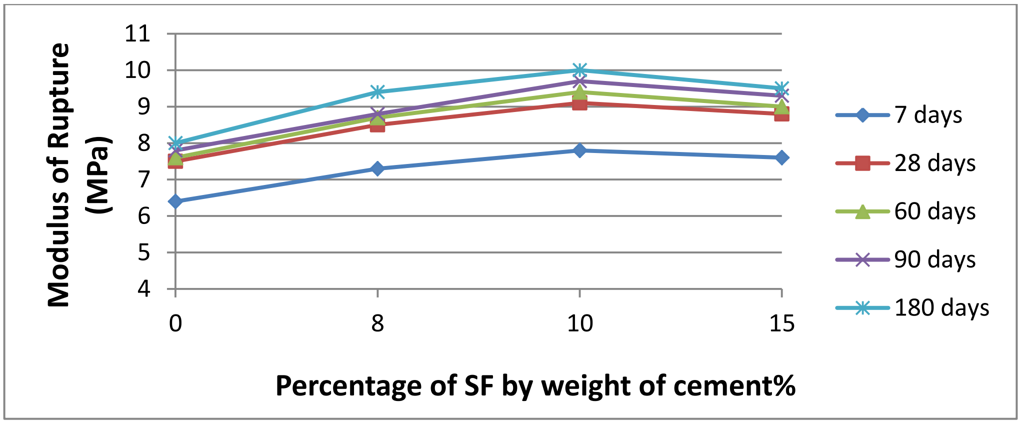
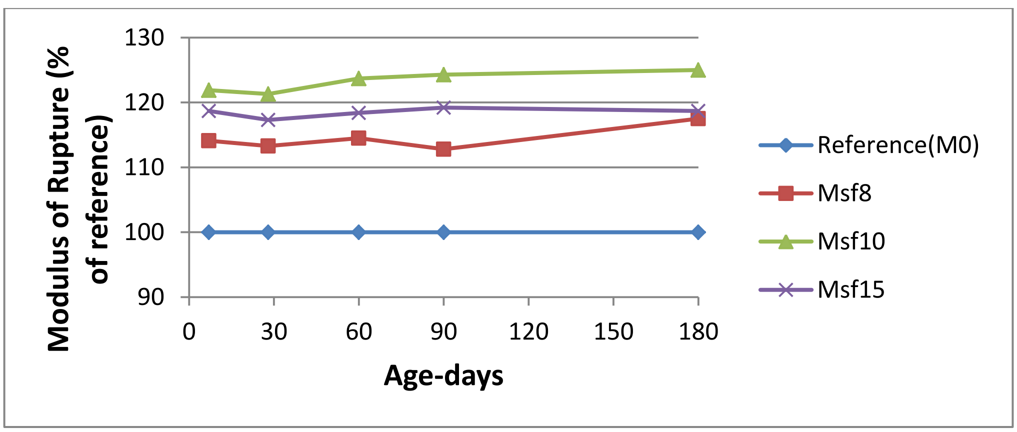


Figure (13): Effect of Silica fume content(%) on modulus of rupture.



Figure(14):Modulus of rupture of HSC containing SF as a percentage of reference specimens.

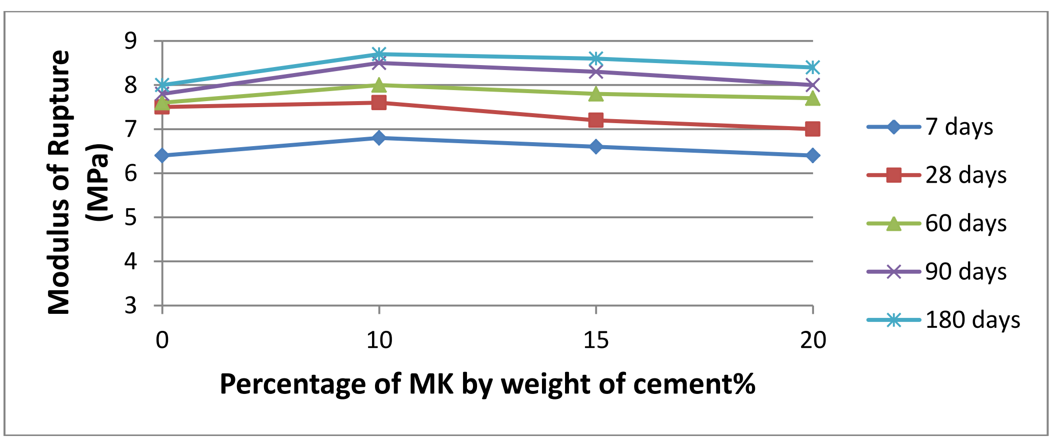


Figure (15): Effect of metakaolin content(%) on modulus of rupture.

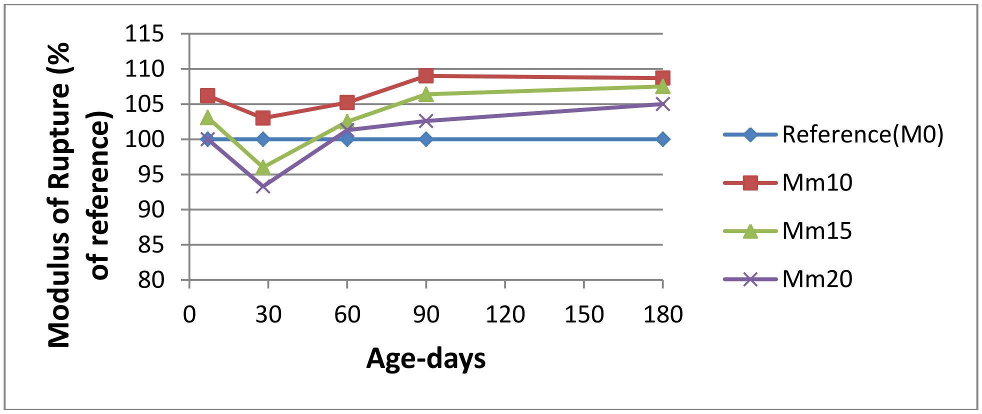


Figure (16): Modulus of rupture of HSC containing MK as a percentage of reference specimens.

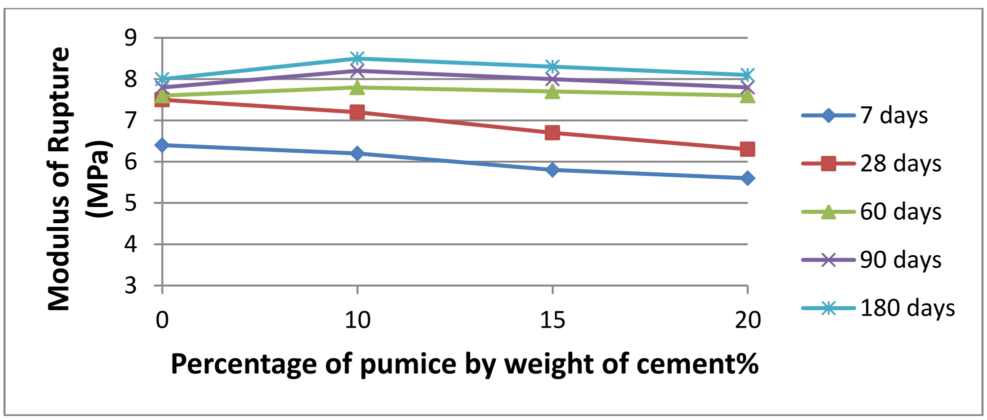


Figure (17): Effect of pumice content(%) on modulus of rupture.

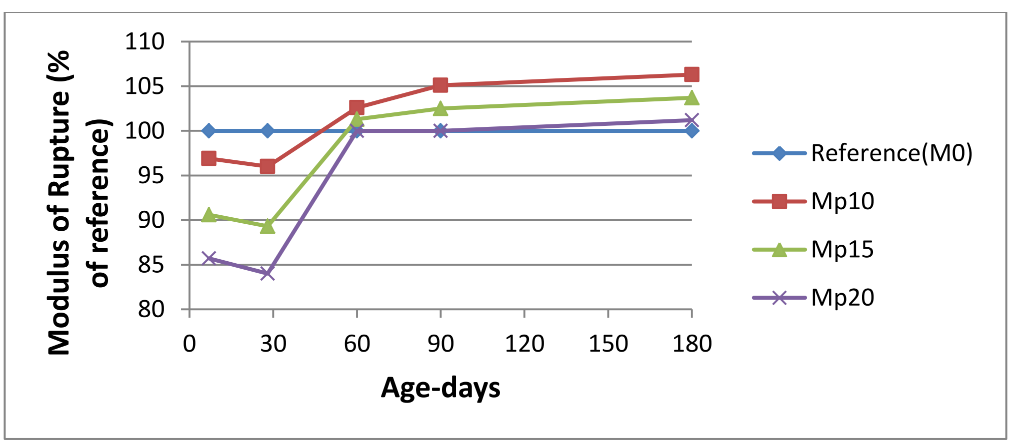


Figure (18): Modulus of rupture of HSC containing pumice as a percentage of reference specimens

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