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Properties of Foamed Concrete Containing Glass Powder

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الملخص العربى :

هذا البحث يدرس تأثير استخدام الزجاج المطحون بإستبدال جزء من الاسمنت بالوزن في الخرسانة الخفيفةوالتي تم استخدام بودرة الرخام بدلا من الرمل كمادة مالئة وذلك في إطار اعادة تدوير المخلفات البيئية مثل الزجاج المطحون و مخلفات تصنيع الرخام ودراسة الخواص المختلفة للخرسانة بكثافات مختلفة (400-600-800) كجم/م3 ونسب استبدال للزجاج المطحون من وزن الاسمنت (5-10-15) % علي خواص الخرسانة الخفيفة مثل مقاومة الضغط و الامتصاص و التفاعل القلوي للسيليكا النشطة و قد اعطت النتائج لإختبار الضغط انخفاضا في المقاومة عند عمر 28 يوم لنسب الاستبدال المختلفة للزجاج من وزن الاسمنت ولكن بعد عمر 90 يوم اظهرت النتائج ارتفاعا في نتائج مقاومة الضغط تتراوح بين 2% الي 8%(لنسبة الإستبدال 10%) وذلك يوضح التأثير البوزولاني للزجاج المطحون عند الاعمار المتأخرة وكلما زادات درجة نعومتة(كلما يقل المقاس الحبيبي عن 45 ميكرون) كلما كان افضل وتزداد الخاصية البوزلانية كما تم دراستة من قبل (42).

أظهرت نتائج الامتصاص ان زيادة نسبة الزجاج المطحون في الخلطة تؤدي إلي قلة الماء التي تمتصة العينة نتيجة ان الزجاج لة خاصية ملئ الفراغات الدقيقة وكما ان نسبة الاسمنت تقل في الخلطة فتؤدي بدورها إلي تقليل الشروخ الشعرية و التي تكون شرهه لإمتصاص الماء كذلك يقل الإحتياج للماء كلما قلت نسبة الاسمنت و كما اكدتة النتائج ان نتائج الامتصاص في الكثافة 800كجم/م3 كانت تحظي بكمية ماء ممتص اعلي من الكثافات الاخري وداخل الكثافة الواحدة نجد ان الخلطة بنسبة الإستبدال 15% تظهر اقل كمية للماء الممتص .

أظهرت النتائج للتفاعل القلوي للسيليكا النشطة ان تاثيره غير ضار علي الخرسانةالرغوية الخفيفة وذلك لان الزيادة الحجمية الناتجة من التفاعل يمكن للفراغات الداخليةان تحتوي تلك الزيادة الحجمية كما اظهرت النتائج ان الانكماش الذي يحدث للخرسانة تقابلة زيادة حجمية تلاشية تقريبا لذا كان التاثير غير ضار علي الخرسانة الرغوية الخفيفة.

الكلمات المفتاحية : زجاج مطحون، خرسانة رغوية ، بودرة الرخام.

ABSTRACT :

This paper studies the influence of using recycled glass powder as a sustainable solution, low cost material for future construction as glass powder is used as cement replacement. This study shows that glass powder characterized by pozzolanic activity at later ages and as its finesse increases it gives better results for this important property.

Foamed concrete mixes is prepared by using glass powder as cement replacement by (5%, 10%&15%) of cement by mass, compressive strength test shows that a reduction of compressive strength values in the early ages but contradictory observation were recorded as compressive strength was increases with different ranges depending on the replacement percentage of glass powder from cement.

Foamed concrete containing glass powder is observed to absorb a reduced amount of water due to the micro-filling effect of glass powder and replacing amount of cement leads to reduction of capillary pores glutton to absorption of water and decreasing the water demand for cement to complete its process for hydration.

One of the most important factors which has a great vulnerable effect of concrete is alkali-silica reaction (ASR) which has a great effect on the concrete durability, SEM and results Foamed concrete containing glass powder showed that ASR takes place but it has negligible effect on foamed concrete as the cellular and porous structure of foamed concrete can sustain the expansion of the ASR gel with considerably less expansion and no cracking.

Keywords: Foamed Concrete (FC); Glass Powder (GP); Marble powder (MP).

1. LITERATURE REVIEW:

Recently, sustainability attracts the attention along with functionality aspects in construction field. Assessment of sustainable materials or building approaches mainly relies on increasing energy efficiency, reduction of CO_2 emissions and pollutions and saving natural resources during construction process and service life of building [1-4]. Despite the society attention to energy efficiency of buildings, the current buildings consume about 40% of world's energy consumption [5,6]. In addition, cement industry contributes approximately 5-7% of global CO_2 emissions [7,8]. Extensive production of conventional concrete containing cement and natural aggregates leads to more energy consumption and pollutions as well as over-exploitation of natural aggregates [9].

To impart sustainability to the building process, some approaches can be considered. Reducing weight of buildings leads to reduction of required resources. In addition, increasing thermal insulation leads to energy saving hence, reduction in pollutions and operational cost [10,11]. Consequently, foamed concretes are gaining popularity as reliable materials to attain the concept of sustainability owing to their superior characteristics [12].

Foamed concrete is obtained by introducing air bubbles (0.10 to 1.0 mm size) into cement paste or mortar by diverse techniques. Controlling quantity of introduced air bubbles attain wide range of densities (400 – 1600 kg/m^3). It possesses low density, high specific strength, high flowability, superior thermal and acoustic properties, high fire resistance and minimal aggregate consumption [13-18]. Above all aforementioned features, foamed concrete can address the growing need to dispose waste materials. Either binder or filler materials can be fully or partially replaced by other waste materials like fly ash, silica fume, gypsum, blast furnace slag, marble powder and glass powder [19]. Many researchers have focused on utilizing fly ash and blast furnace slag in foamed concrete. Nambiar [20] prepared foamed concrete with densities 1000, 1250 and 1500 kg/m^3 to investigate influence of replacing 50%

and 100% of sand filler by fly ash on density and compressive strength. Tian et al. [21] prepared foamed concrete with densities of 400–1000 kg/m^3 and compressive strengths of 0.8–7.4 MPa by blending 25% Portland cement, 25% granulated blast-furnace slag and 50% phosphogypsum. Zhang et al. [22] utilized fly ash and granulated blast-furnace slag in the proportions of 70% and 30%, respectively to prepare geopolymer foamed concrete with density of 1000 kg/m^3 and compressive strength of 4 MPa. Oren et al. [23] used Portland cement, fly ash, granulated blast-furnace slag, gypsum and sand to prepare foamed concrete with densities of 926–1132 kg/m^3 and compressive strengths of 1.0–1.62 MPa. Bayraktar [24] replaced fine aggregate with marble powder at rates of 0, 30 and 60% to prepare foamed concrete and observed improvement in strength and porosity. Jones et al. [25] studied influence of using glass powder in foamed concrete and observed improvement in compressive strength and reduction in workability due to angular particle shapes.

Recently, municipal glass waste generation is fast growing all over the world causing environmental problem of discarding such non-biodegradable material [26]. According to USA Environmental Protection Agency (EPA), about 25% of used glass is recycled while, the rest is sent to landfill sites [27,28]. In Australia, about 1.5 million tons of municipal glass waste is generated annually. Only two-third of this quantity is recycled while, the rest is sent to landfill sites [29]. Incorporating glass waste into concrete industry is creative method to address landfilling problem. Glass waste can be used as replacement material for binder or filler according to its fineness. Particle size lower than 45 μm yields pozzolanic reactivity hence, used for binder replacing. While, particle size above 45 μm is used for filler replacing [30-34]. Growing studies are conducted to attain development in this field by maximization of benefits and elimination of drawbacks. Alkali silica reaction (ASR) is main problem that facing durability leading to restriction of glass waste application into concrete. (ASR) occurs between high content of reactive silica in glass waste and alkaline cement in the presence of moisture causing expanding gel, therefore internal cracks occur [35-37]. To mitigate this influence of (ASR), some procedures could be followed. Increasing the fineness of the used glass yields decrease of (ASR). This phenomenon was detected by many researchers [30-35, 38,39]. In addition, incorporating glass fines into foamed concrete reduces the influence of (ASR) whereas, the porous structure of foamed concrete is able to accommodate the expansion due to (ASR) [35].

In the current study, influence of partially replacing of Portland cement by fine glass powder on properties of foamed concrete containing marble powder as filler is investigated.

2. EXPERIMENTAL PROGRAM

2.1. Materials.

The used materials to prepare foamed concrete comprise Portland cement type I (CEMI 42.5-N) conforming ASTM C150, Marble powder (SG = 2.58- chemical composition is displayed in Table 1.and its particle size in microns displayed in Fig 2), Glass powder with particles size of microns (See Fig. 1 - SG = 2.55 - chemical composition is displayed in Table 2.), tap water and protein based foaming agent (80 kg/m^3-Ultra-core 150A).

Table 1: Chemical Composition of Marble Powder.

Element	SiO_2	TiO_2	AL_2O_3	Fe_2O_3	MNO	MgO	CaO	Na_2O	K_2O	P_2O_5	CL	SO_3	L.O.I
Percentage%	0.14	<0.01	<0.01	0.06	0.01	0.07	55.70	<0.01	0.08	<0.01	<0.01	<0.01	43.50

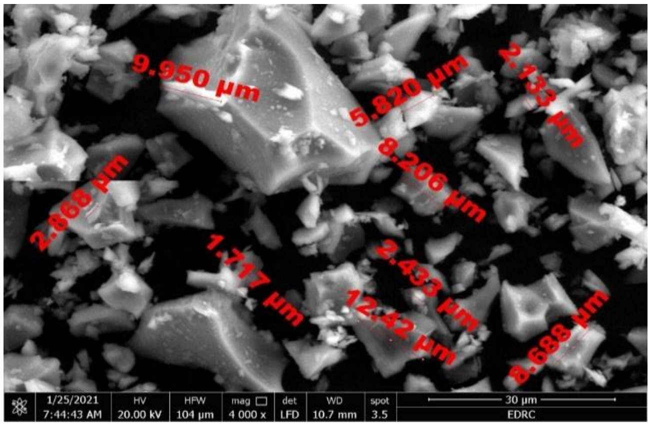

Fig 1. Particle Size of Glass Powder.

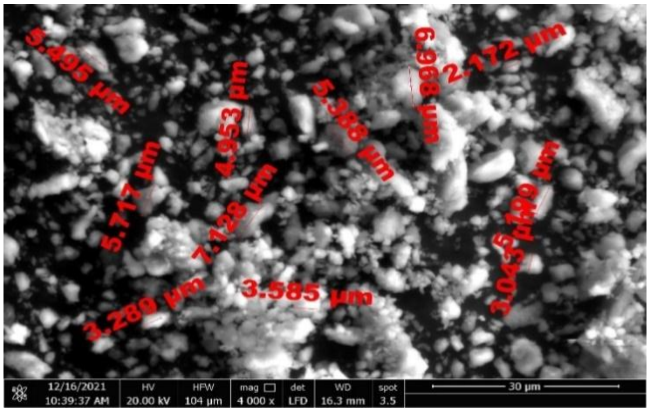

Fig 2. Particle Size of Marble Powder

Table 2: Chemical Composition of Glass Powder

Element	SiO_2	TiO_2	AL_2O_3	Fe_2O_3	MNO	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I
Percentage%	71.50	0.17	1.73	0.56	0.02	1.22	13.80	9.55	0.15	0.2	0.54

2.2. Procedures

2.2.1. Mix design

Mix proportions were designed to achieve three diverse hardened densities of 400, 600, and 800 kg/m^3. Cement was replaced by glass powder at percentages of 0%, 5%, 10% and 15% as shown in Table 3.

Table 3: Mix Proportions

Mix ID	Cement(kg)	Water (kg)	Marble Powder(kg)	AdditiveUltacore20ST(kg)	Glass Powder(kg)	Foam (liters)
Fc-400-R0	250	125	120	0.625	0	420
Fc-400-R5	237.5	126	120	0.59	12.5	420
Fc-400-R10	225	126.67	120	0.56	25	420
Fc-400-R15	212.5	126.67	120	0.53	37.5	420
Fc-600-R0	320	160.9	275	0.8	0	370
Fc-600-R5	304	164	275	0.76	16	370
Fc-600-R0	288	162.6	275	0.72	32	370
Fc-600-R0	272	162.6	275	0.68	48	370
Fc-800-R0	375	210	440	0.9375	0	305
Fc-800-R5	356.25	214.30	440	0.8906	18.75	305
Fc-800-R10	337.5	210	440	0.8437	37.5	305
Fc-800-R15	318.75	210	440	0.7968	56.25	305

Table 4: Abbreviations

FC	Foamed Concrete
400-600-800	Density of mix in kg\m3
R0	Zero-Replacement.
R5	5% Replacement
R10	10% Replacement
R15	15% Replacement

2.2.2. Mixing process

Portland cement, marble powder and glass powder were blended in dry condition, afterwards tap water was added and mixed until reaching homogeneous paste. Finally, foaming agent was added according to mix design.

2.2.3. Compressive strength

Compressive strength was determined at ages of 28&90 days through six 50 mm cubes for both of cement paste and foamed concrete according to ASTM C109.

2.2.4. Hardened density and water absorption

Hardened density and water absorption were determined through five 100 mm cubes according to ASTM C642.

2.2.5. Alkali silica reaction

An accelerated test with respect to ASTM C1567 was made with samples dim25x25x285 mm.

3. RESULTS & DISCUSSION

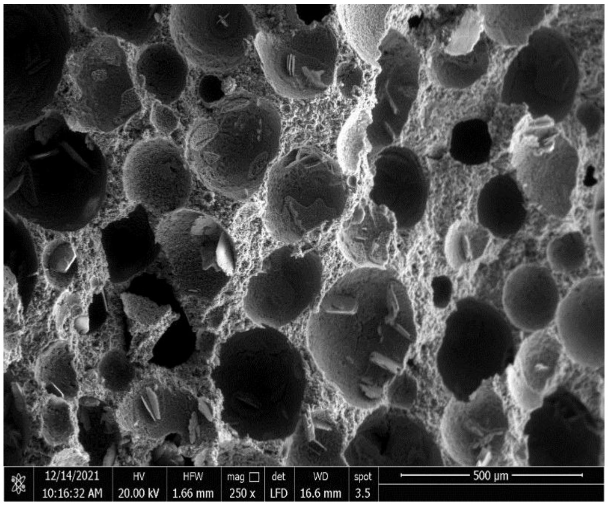

Fig 3. Foamed concrete by SEM.

3.1. Compressive strength

Compressive strength has been determined for cement paste and foamed concrete as shown in Table 4.

Mix ID		Compressive strength (MPa)				
	28 days	COV.	$R_{5,10,15}/R_0$	90 days	COV.	$R_{5,10,15}/R_0$
FC400-R0	1.20	5.44	1.00	1.28	5.52	1.00
FC400-R5	1.16	5.09	0.97	1.33	5.52	1.04
FC400-R10	1.13	4.51	0.94	1.38	3.13	1.08
FC400-R15	1.03	4.86	0.86	1.31	4.98	1.02
FC600-R0	2.88	3.40	1.00	3.18	4.37	1.00
FC600-R5	2.59	4.72	0.90	3.25	3.22	1.02
FC600-R10	2.56	7.76	0.88	3.31	7.47	1.04
FC600-R15	2.29	5.00	0.79	2.93	6.330	0.92
FC800-R0	4.08	5.25	1.00	4.33	6.20	1.00
FC800-R5	3.92	6.82	0.96	4.51	5.30	1.04
FC800-R10	3.81	7.50	0.93	4.60	7.01	1.06
FC800-R15	3.64	4.72	0.89	4.40	4.61	1.02

Table 5

As a result of replacing cement by glass powder, compressive strength of foamed concrete with different percentages of glass powder has been altered. It can be noticed easily that the increase of glass powder percentage leads to decrease in 28 days compressive strength by 3% to 21%. Contradictory observations were recorded for 90 days compressive strength which are increased by 2% to 8% for replacement percentage of 10%. It is attributed to the pozzolanic effect of glass powder. Similar explanation was mentioned by **[41-42-43].** Foamed concrete with different densities yielded similar behavior.

Regarding cement pastes, compressive strength was determined for them to be used for obtaining models to predict properties of foamed concrete. Linear regression analysis has been performed to obtain the following model.

Compressive strength results can be explained as following in bar charts:

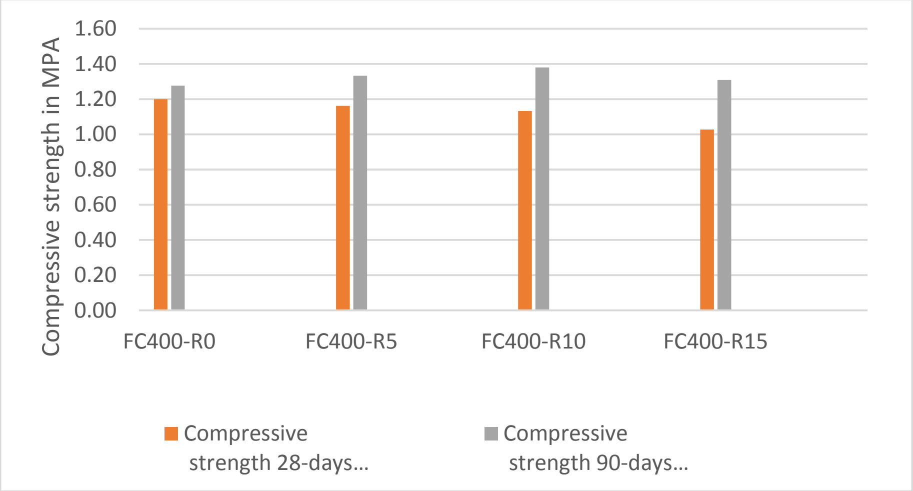

Fig 4-a. Compressive strength results for FC-400 in 28 &90 days.

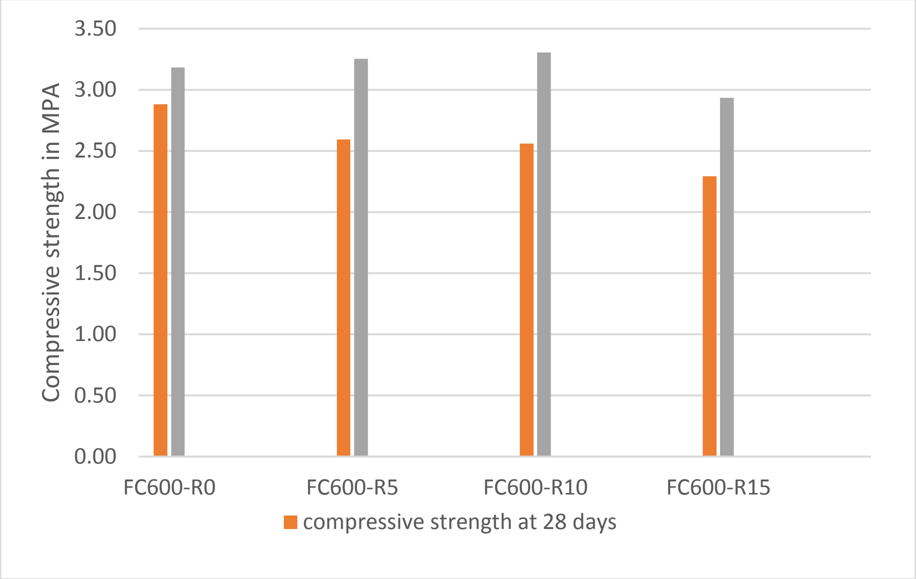

Fig 4-b. Compressive strength results for FC-600 in 28 &90 days.

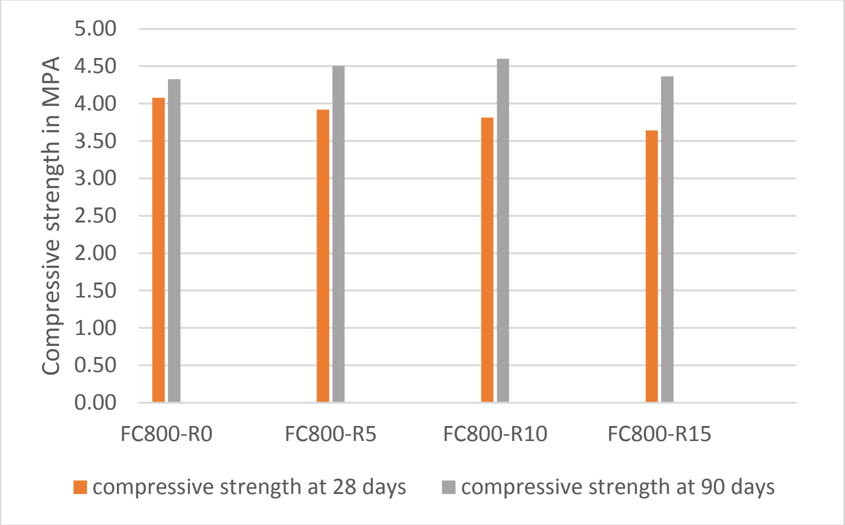

Fig 4-c. Compressive strength results for FC-800 in 28 &90 days.

3.2. Alkali-Silica reaction:

Alkali-siliça reaction occurs when glass powder is used in concrete mixes causing expanding gel. Fig 5. Demonstrates expanding behavior for mix FC-600-R15 in contrast to the shrinkage behavior for mix FC-600-R0. This result is attributed to the alkali-silica reaction due to replacement of cement by glass powder. The expanded gel is enclosed into the voids of foamed concrete as shown in Fig 6. Leading to restriction of its destructive effect on foamed concrete, similar results explained in [44].

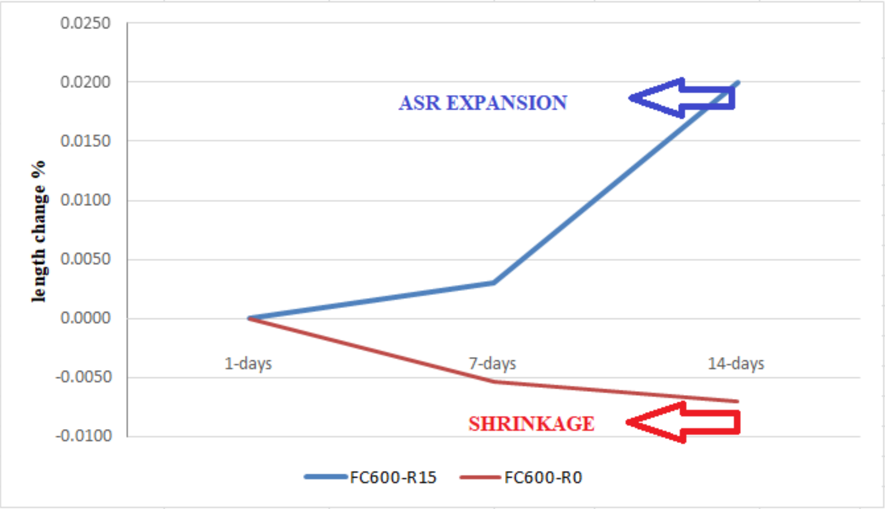

Fig 5. Shows the expansion and shrinkage of foamed concrete.

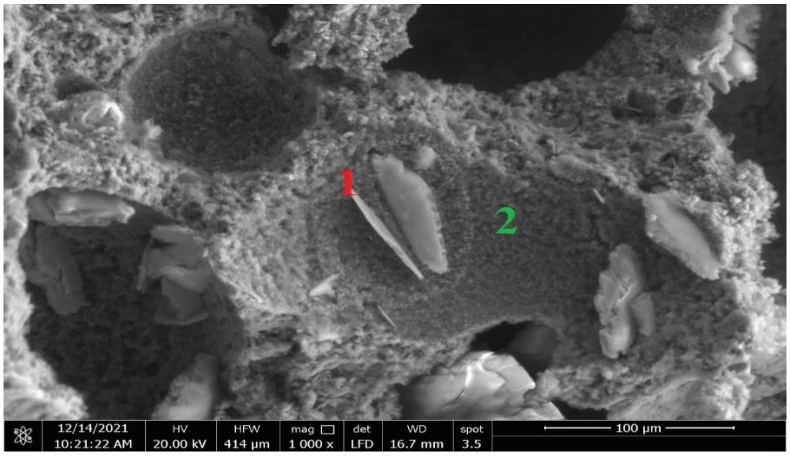

Fig 6-a. Image of the sample with zero replacement of glass (section 1-marble powder particles –section 2 mortar section).

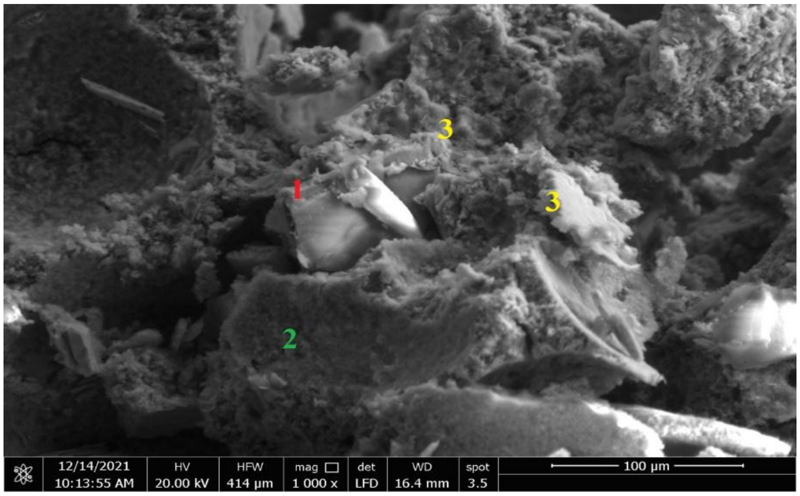

Fig 6-b. Image of the sample with glass powder replacement of glass (section 1-marble powder particles –section 2 mortar- section3 ASR compounds-section).

3.3. Water absorption:

Water absorption is one of the most important factors that have a great effect on the durability of concrete structures.

Results of absorption test for the different specimens demonstrated that the increase of glass powder as a replacement for cement has a slightly positive effect on the reduction of the quantity of the absorbed water of foamed concrete due to the micro filling effect of the glass powder and the reduction of cement content leads to decrease the capillary pores and the water demand this is shown in Fig 7-a, Fig 7-b& Fig 7-c, Mixes

FC-400R0, FC-400R5, FC-400R10 and FC-400R15 demonstrated the quantity of absorbed water (124.54, 113.92, 106.88, 98.02) liters per cubic meter respectively, Mixes FC-600R0, FC-600R5, FC-600R10 and FC-600R15 demonstrated the quantity of absorbed water (125,115.56, 100.01, and 93.00) liters per cubic meter respectively, Mixes FC-800R0, FC-800R5, FC-800R10 and FC-800R15 demonstrated the quantity of absorbed water (141.04,128.80, 112.28, 110.20) liters per cubic meter respectively. As the glass powder content increases quantity of absorbed water is reduced and with the increase of the density of the foamed concrete mix due to the higher cement content the quantity of absorbed water increases, similar explanation is mentioned by [44].

Dry density for FC-400 with replacement (0-5-10-15)% are displayed as the following in kg/m3(392-408-370-397) , Similarly FC-600 (640-626-666-624)& FC-800(880-845-818-824).

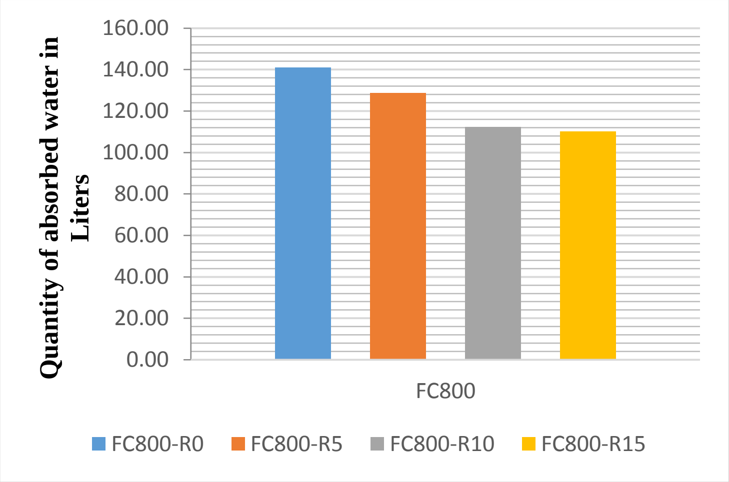

Fig 7-a. quantity of absorbed water in liters for foamed concrete with density 800kg/m3

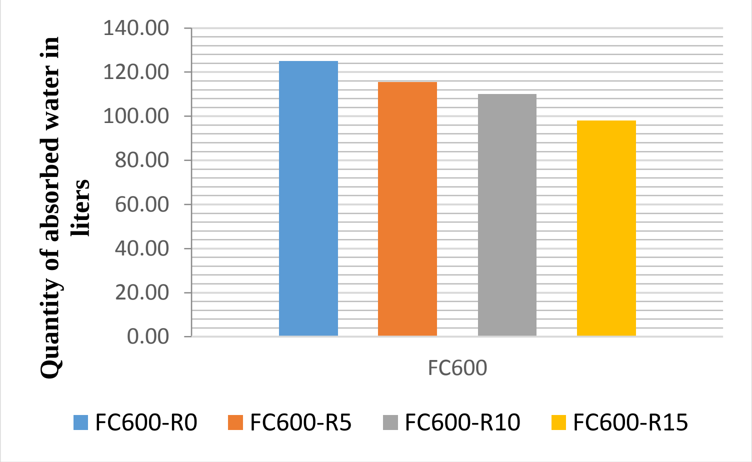

Fig 7-b. quantity of absorbed water in liters for foamed concrete with density 600kg/m3

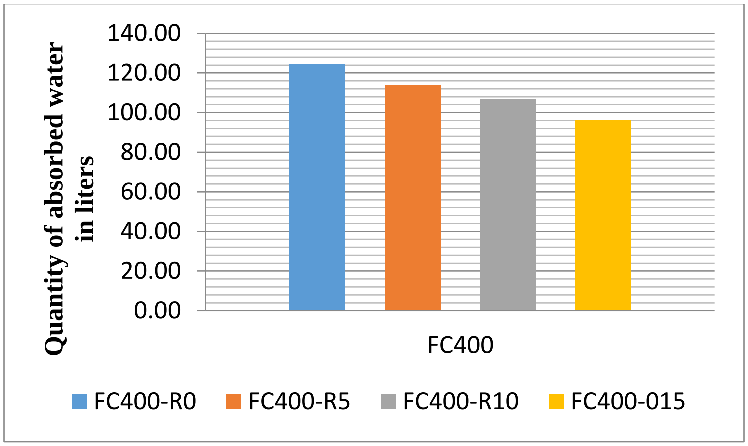

Fig 7-C quantity of absorbed water in liters for foamed concrete with density 400kg/m3

3.4. Conclusion:

This study investigated the effect of using grounded glass powder as a cement replacement by mass on the foamed concrete with different densities (400-600-800) kg/m3.

The study showed that using recycled glass powder as a cement replacement has a positive effect on the different properties if foamed concrete:

A-Glass powder has a pozzolanic effect as its particle size is smaller than 45µm as its being mentioned in [42] , the particle size used in this study ranges from (2-9)µm ,its effects appears after testing compressive samples after 90days it records an increment in the compressive strength results by 2% to 8% for the replacement percentage 10% however it recorded a reduction of compressive strength at 28 days for all samples which gives an evidence that the pozzolanic effect of glass powder appears at later ages .

B- Despite using glass powder as a cement replacement which leads to ASR formation it has a negligible effect on the foamed concrete due to that the formed expanded gel is enclosed into the voids of foamed concrete leading to restriction of its destructive effect on foamed concrete.

C- Using glass powder has a slightly positive effect on the quantity of absorbed water due to its micro filling effect and increasing the replacement percentage of cement leads to decreasing water demand and capillary pores which attracts water.

D- Finally using recycled glass powder is a sustainable solution for our future, it gives us hope to use recycled material for the production of concrete and reduce the usage on cement, as its production has a massive effect on the environment due to the emissions of carbon dioxide gas leading to greenhouse effect, but many studies should be conducted to investigate the feasibility of using it in the production of concrete.

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