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Enhancing the Compressive Strength and Density of Cement Mortar by the Addition of Different Alignments of Glass Fibers and Styrene Butadiene Rubber

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Abstract

In the field of construction materials the glass reinforced mortar and Styrene Butadiene mortar are modern composite materials. This study experimentally investigated the effect of addition of randomly dispersed glass fibers and layered glass fibers on density and compressive strength of mortar with and without the presence of Styrene Butadiene Rubber (SBR). Mixtures of 1:2 cement/sand ratio and 0.5 water/cement ratio were prepared for making mortar. The glass fibers were added by two manners, layers and random with weight percentages of (0.54, 0.76, 1.1 and 1.42). The specimens were divided into two series: glass-fiber reinforced mortar without SBR and glass-fiber reinforced mortar with 7% SBR of mixture water. All specimens were tested after curing for 7 and 28 days, glass-fiber reinforced mortar exhibited better properties than control mortar in improvement of compressive strength and lowering the density after curing for 28 days due to the completion of cement hydration reaction.. For compressive strength the best results were achieved with 1.42 wt.% layers glass-fiber reinforced mortar with 7% SBR which gave 41.56 MPa. On the other hand, the addition of 1.42 wt.% random glass-fiber without SBR addition caused the beast reduction in density by 10.6% and produced lighter structure than control sample.

Keywords**:** *Random glass fibers, Glass fibers layers, SBR, compressive strength, density.*

1. Introduction

Cement mortar that is free from any fibers addition develops cracks due to the plastic and dry shrinkage as well as changing in volume, consequently these cracks lead to elastic deformation of cement mortar.[1,2] The addition of polymers to cement mortar provides a noticeable improvement in workability, extensibility, adhesion, and water tightness over conventional cement mortar.[3]

The Addition of glass fibers to cement mortar is one of adopted methods to improve the properties, performance and durability of mortar. This addition constructs a cohesive structure which overcomes the property of dimensional instability due to the influence of external conditions because of the fragility of the mortar. [5]

Glass fibers reinforced mortar is considered a new building material which has superior properties than ordinary mortar. Among these properties are improved compressive strength and lower density which produce a light weight structure. [4]

The possibility of using a glass fiber reinforced concrete system was recognized by Russians in the 1940s these were unsuccessful due to the alkaline nature of the cement attacking and breaking down the fibers. The problem was solved in the mid-1960s with the development of alkaline resistant glass fibers containing a high level of zirconium dioxide. Academic studies have continued to develop this addition and recently has become widely used for many construction applications such as facades, balconies, fountains, ceilings, rail applications and architectural units.[6]

The first emulsion polymerized SBR was known in the 1930's as Buna S. It was prepared by I. G. Farbenindustrie in Germany. In 1940 the U.S. Government established the Rubber Reserve Company to start a stockpile of natural rubber and a synthetic rubber program. These programs were expanded when the United States entered World War II. The synthetic rubber efforts were initially focused on a hot polymerized (41°C) emulsion polymerized Styrene Butadiene rubber. Utilization of SBR was limited to the production of car and light truck tires and truck tire retread compounds, it was entered in the field of building materials recently. [7]

Bridges failure as a result of earthquakes, such as 1989 Loma Prieta earthquake in California, USA, attracted the attention of the engineering community to innovate a new solutions to avoid these situations. H. Saadatmanesh, M. R. Ehsani, and M. W. Li, in 1994,[7] presented a new technique for seismic strengthening of concrete columns, this technique used wrapping thin, flexible high strength fibers straps around the column to improve the ductility and strength. The stress-strain models for concrete surrounded with composite straps indicated significant increasing in compressive strength and strain at failure when compared with the stress-strain behavior of non-surrounded concrete.[8]

Mahdi S. Essa and Nada F.Hassan, in 2008,[9] conducted a study involving the effect of adding Styrene Butadiene Rubber emulsion on compressive strength of cement mortar with various percentages (10%, 25%, 35%) by volume of water after curing for (7, 28, 60) days. They also studied the effect of this addition on Compressive strength, absorption, slump loss with time and flexural strength of concrete of mix 1:2:4 with 0.45 water to cement ratio by weight. The results showed that the addition of Styrene Butadiene Rubber negatively affects the compressive strength at all ages. Initial and final setting time decrease with increasing the percentage of Styrene Butadiene rubber. Addition of Styrene Butadiene rubber to concrete decreased the compressive strength at early ages (7 days) and increased it at later ages. It also reduced the absorption of concrete and slump loss with time and increased the flexural strength.[9]

Manjunath V Melkundi and Vaijanath Halhalli, in 2013,[10] investigated the behavior of conventional concrete, Styrene Butadiene Rubber latex-modified convectional concrete, steel fiber reinforced concrete and Styrene Butadiene Rubber latex modified steel fiber reinforced concrete in compressive strength, split tensile strength and flexural strength. The results showed that the concrete added with fiber and latex behaved much better with regards to higher first crack load and ultimate load and also lesser deflection.[10]

Rasha Salah Mahdi, in 2014,[4] studied the effect of glass fibers on compressive strength and flexural strength of cement mortar using three mixes of glass fibers reinforced mortar with glass fibers content of (1, 1.5 and 2)% by weight of cement. The results showed that the mortar mixed with 1% fiber content gave a higher compressive and flexural strength than the mortar mixed with 2% fiber content. [4]

2. Aims

This work aims to study the effect of glass fibers addition in layers and random manner with and without addition of SBR on density and compressive strength of cement mortar compared with control specimens, as well as studying the effect of curing for 7 and 28 days on these specimens.

3. Experimental Procedure

3.1. Materials

3.1.1. Cement

Sulfate-resistant Portland cement (Type V) was used, it was of (Tasluja) Al-Jissir trade mark from Lafarge cement factory. In order to avoid the humidity effect on cement properties it was stored in a dry place. Several chemical and physical tests were carried out in NCCLR (National Center for Construction Labs. & Researches) to verify its specification, the cement was identical to the Iraqi standard specification No.5/1984. Table (1) and Table (2) show the chemical composition and physical properties of the cement, respectively, according to the Iraqi standard specification No.5/1984.

Table 1,
Chemical composition and properties of cement.

Chemical composition & properties		
Tests	**Results%**	**Limits**
SiO_2	19.74	———
Al_2O_3	4.28	———
Fe_2O_3	5.04	———
CaO	64.13	———
MgO	2.92	≤ 5%
SO_3	2.36	≤ 2.5%
C_3A	2.82	≤ 3.5%
Lime Saturation Factor (L.S.F)	0.98	≤ (1.022-0.66)%
Insoluble residue (I.R)	0.96	≤ 1.5%
Loss on ignition(L.O.I)	3.92	≤ 4%

Table 2,
Physical properties of the cement.

Physical properties	**Results**	**limits**
Fineness (m/kg) (blain's method)	358	≥ 250
Setting time (hr : min) (Vicat's method)		
-Initial setting	2 : 15	≥ 45 min.
-Final setting	4 : 15	———
Soundness (Autoclave)	-0.1	≤ 0.8
Compressive strength (MPa)		
-3 days	19.5	15
-7days	25.5	23

3.1.2. Sand

Sand from Al-Ukhaidhir region was used as fine aggregate with specific gravity of (2.58) and fineness modulus of (2.17). A sieve analysis was carried out in the National Center for Construction Labs. & Researches (NCCLR) of the Iraqi ministry of construction and housing, in order to know the grading of the fine aggregate according to the Iraqi standard specification No.45/1984. Table (3) shows the results of sieve analysis process and the Fig (1) shows the upper and lower limits of Iraqi specification and the used sand.

Table 3,
The results of sieve analysis process.

Sieve size	**Weight in gram**	**Retained %**	**Passed %**	**Limits of third area %**
10 mm	0	0	100	100
4.75 mm	1	0.133	99.9	90-100
2.36 mm	57	7.6	92.4	85-100
1.18 mm	132.5	17.66	82.3	75-100
600 μ	277.5	37	63	60-79
300 μ	506.5	67.53	32.5	12-40
150 μ	655.5	87.4	12.6	0-10
salts%	714	95.2	4.8	5

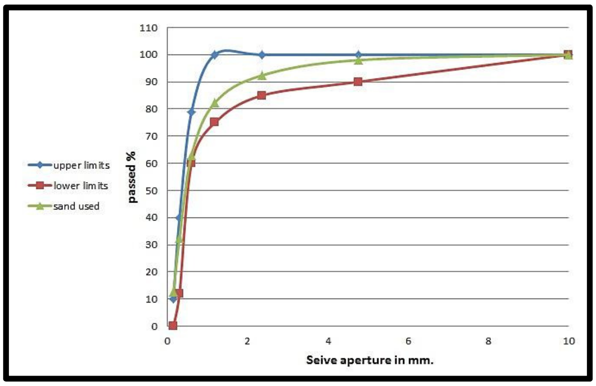

Fig. 1. The upper and lower limits of Iraqi specification and the used sand.

2.1.3. Glass Fibers

A chopped strand mats glass fibers of CHINA BEIHAI trade mark was used. Table (4) shows some properties of glass fibers. Layers of glass fibers were of thickness (2mm) and fiber length (3cm). It was cut into two shapes layers and random fibers as shown in Plate (1).

Table 4,
Some of glass fibers properties

Property	**Value**
Modulus of elasticity (E)	72 GPa
Density	2.58 g/cm^3
Tensile strength	1.9 GPa
Compression strength	150 MPa
Poisson's coefficient	0.22

Plate. 1. A: Random glass fibers, B: Glass fibers layers.

3.1.4. Styrene Butadiene Rubber (SBR)

The polymer which is used in this study was a liquid resin of Styrene Butadiene rubber (SBR). SBR is an aqueous dispersion of (25%) Styrene and (75%) Butadiene copolymer when mixed with Cementitious products giving high performance water resistance properties, it is especially suitable for primers, renders, mortars and floors with high abrasion resistance and for patching and bonding onto substrates of low suction. The SBR used in this research was of SBI trade mark in UAE. Table (5) shows the typical properties of the used SBR and all of the information from the manufacturer data sheet.

Table 5,
Typical properties of used SBR

Appearance	**Fluid liquid**
Color	Milky white change to transparent when dry
Density	1050 Kg/in^3
Solid content	36 - 38 %
pH	8-9
Temperature resistance	-20 up to +90 C

3.1.5. Water

Tap water was used for mixing process and distilled water for curing process at (NCCLR) National Center for Construction Labs. & Researches.

3.2. Experimental Work

Mixtures of 1:2 cement/sand ratio and 0.5 water/cement ratio were prepared for making mortar. The glass fibers were added by two manners, layers and random with weight percentages of (0.54, 0.76, 1.1 and 1.42). The specimens were divided into two series: glass-fiber reinforced mortar free from SBR and glass-fiber reinforced mortar with 7% SBR of mixture water. Table (6) shows the mix design proportions.

Table 6,
Mix design proportions.

Specimens	**Cement Kg/m^3**	**Sand (Kg/m^3)**	**W/C ratio**	**Water (L/m^3)**	**SBR (L/m^3)**	**Glass fibers Wt.%**
control mortar	627.9	1255.7	0.5	313.93	0	0
Glass fibers reinforced mortar without SBR	627.9	1255.7	0.5	313.93	0	0.54
	627.9	1255.7	0.5	313.93	0	0.76
	627.9	1255.7	0.5	313.93	0	1.1
	627.9	1255.7	0.5	313.93	0	1.42
Glass fibers reinforced mortar with 7% SBR	627.9	1255.7	0.5	291.96	21.96	0.54
	627.9	1255.7	0.5	291.96	21.96	0.76
	627.9	1255.7	0.5	291.96	21.96	1.1
	627.9	1255.7	0.5	291.96	21.96	1.42

The glass fibers were weighed before mixing as shown in Plate (2:A). For achieving a homogenous mixing of the materials, sand, cement, and glass fibers were mixed together by hand for about two minutes in dry state, the water was added to the mixture and mixed for four minutes according to ASTM C305.[11] Plate(2:B) shows the preparation of random glass-fiber reinforced mortar. After the mixing process the resulting mortar was poured in cast iron molds of (15×15×15) cm. dimensions. In glass-fiber layers reinforcing a glass-fiber mat was cut into square layers of (15×15) cm. dimensions. The mortar and glass fiber layers were sequentially fed into molds in order to produce a cohesive structure. Plate (3:A) shows the molding of glass fibers layers reinforced mortar. The layers were well compacted by hand until the mixture water penetrate through it which made better bonding between the cementitious matrix and glass-fiber layers reinforcement as shown in Plate(3:B). After the solidification of specimens they were demolded and cured at temperature of (20∓5)°C for 7 and 28 days at controllable room of (50∓5)% humidity as it is shown in Plate (4).

Plate. 2. A: Glass fibers weighing, B: Preparation of GF mortar.

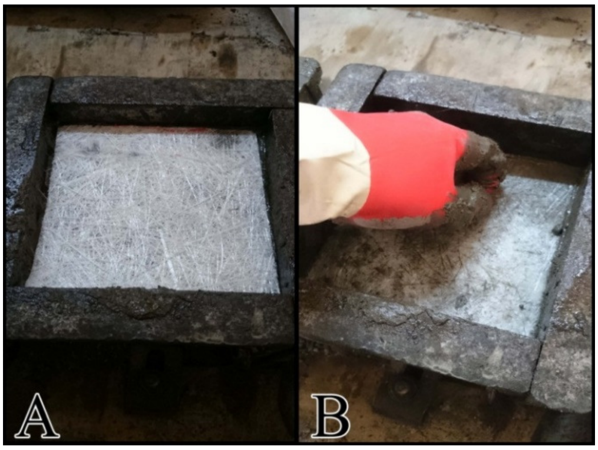

Plate. 3.A: Molding of glass fibers layers reinforced mortar, B: Glass fibers layer compacting.

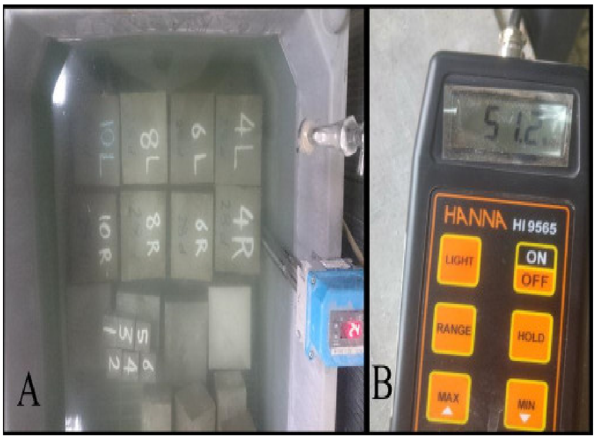

Plate. 4. Curing at A: Controlled temperature, and B: Controlled humidity.

4. Tests

4.1. Density

According to ASTM C642-97[12], After the curing process the regular shape specimens were dried in oven at temperature of (100-110)°C for 24 hours then removed and its weight was recorded. After that the specimens were immersed in water of temperature (20 ∓5 °C) for 7 and 28 days, then removed and its weight was recorded. The density was computed according to Equation (1)

$$\text{Density}\ (\text{Kg/m}^3) = \frac{{}_{Weight}^{Dry}(\text{Kg})}{{}_{Weight}^{Dry}(\text{Kg}) - {}_{Weight}^{Wet}(\text{Kg})} \times {}_{density}^{Water}(\text{Kg/m}^3) \quad \ldots (1)$$

4.2. Compression Test

According to BS 1881-108:1983,[13] the compressive strength of (15× 15× 15)cm. dimensions cubic specimens of glass fibers reinforced mortar with Styrene Butadiene rubber compared with control specimens were tested by the universal compressive machine of (CONTROLS) trade mark which was manufactured in Milan, Italy, it is shown in Plate.5.

Plate. 5. Universal compressive machine.

5. Results and Discussion
5.1. Density
5.1.1. Glass fibers reinforced mortar without SBR

The specimens were tested after curing for (7 and 28) days and the results are shown at Table (6). The specimens with the addition of glass fibers (random and layers) revealed decreasing in density as shown in Fig.(2) & Fig.(3), this decreasing resulted from the light weight glass fibers which made the specimens lighter than the control specimens resulting in decreasing of density due to the direct proportionality between the weight and density.[14]

Table 6,
Results of density testing for glass fibers reinforced mortar without SBR.

Mortar Type	Glass fibers wt.%	Curing days	Density g/cm^3	Reduction %
Control mortar	———	7	2.3	———
		28	2.316	———
Reinforced by layers glass fibers	0.54	7	2.162	5.86
		28	2.193	3.9
	0.76	7	2.160	6.3
		28	2.190	5.22
	1.1	7	2.132	7.3
		28	2.144	6.1
	1.42	7	2.110	8.56
		28	2.161	6.6
Reinforced by random glass fibers	0.54	7	2.141	6.9
		28	2.310	5.3
	0.76	7	2.114	8.0
		28	2.248	5.6
	1.1	7	2.100	8.7
		28	2.278	7.4
	1.42	7	2.054	10.6
		28	2.140	6.7

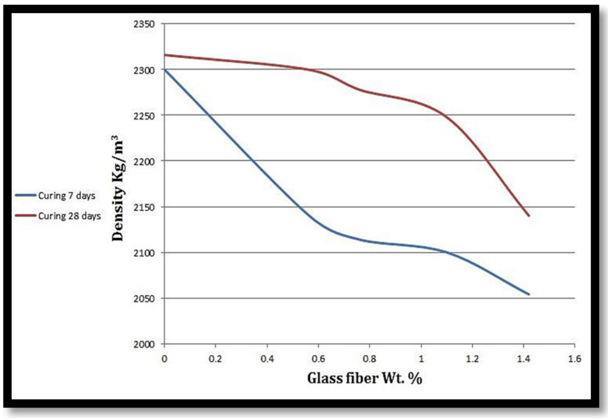

Fig. 2. Effect of random glass fibers addition on the density of mortar without SBR.

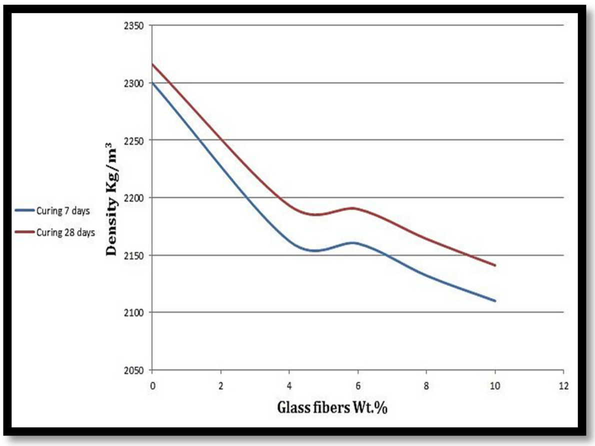

Fig. 3. Effect of glass fibers layers addition on the density of mortar without SBR

5.1.2. Glass fibers reinforced mortar with SBR

All results are shown in Table (7), Fig. (4) and Fig. (5) show the decreasing in density of mortar after the addition of random and layers of glass fibers with 7% SBR, respectively. The increasing in density in this case is lower than glass fibers reinforced mortar without SBR because the SBR fill the pores in the specimen which increase the density. The random glass fibers addition showed higher reduction in density than layers.

Table 7,
Results of density testing for glass fibers reinforced mortar with SBR.

Mortar Type	Glass fibers wt.%	Curing days	Density g/cm^3	Reduction %
Control mortar	———	7	2.3	———
		28	2.316	———
Reinforced by layers glass fibers	0.54	7	2.226	3.22
		28	2.256	1.42
	0.76	7	2.162	5.13
		28	2.195	1.64
	1.1	7	2.143	6.83
		28	2.163	2.42
	1.42	7	2.125	7.6
		28	2.175	4.4
Reinforced by random glass fibers	0.54	7	2.216	3.65
		28	2.311	1.51
	0.76	7	2.161	5.35
		28	2.252	2.12
	1.1	7	2.135	6
		28	2.280	2.5
	1.42	7	2.078	8.35
		28	2.156	5.53

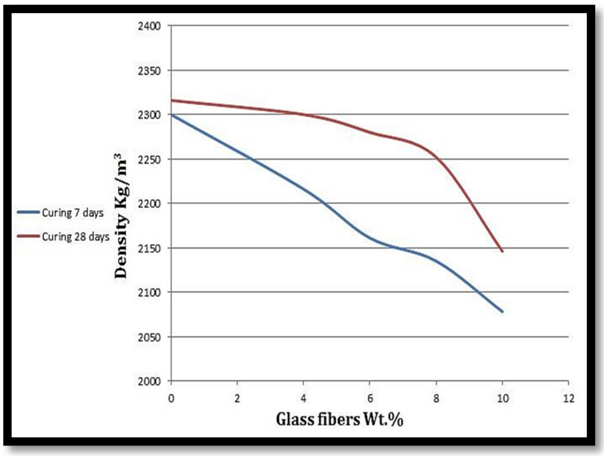

Fig. 4. Effect of random glass fibers addition with SBR after curing for 7 and 28 days.

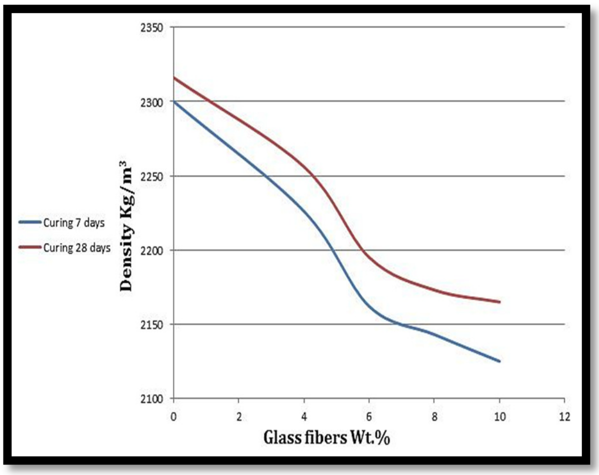

Fig. 5. Effect of layers glass fibers addition with SBR after curing for 7 and 28 days.

A comparison between random glass fibers mortar and layers glass fibers mortar with SBR and their effect on density of mortar specimens at 7 & 28 days of curing relative to control specimens is shown in Fig. (6) and Fig. (7), respectively.

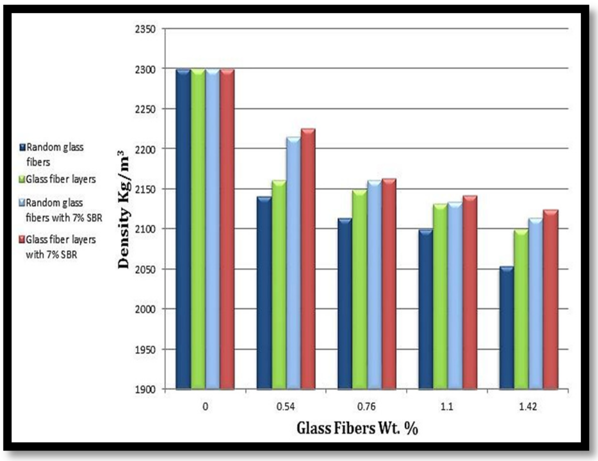

Fig. 6. Comparison between glass fibers reinforced mortar without SBR and glass fibers reinforced mortar with SBR after curing for 7 days.

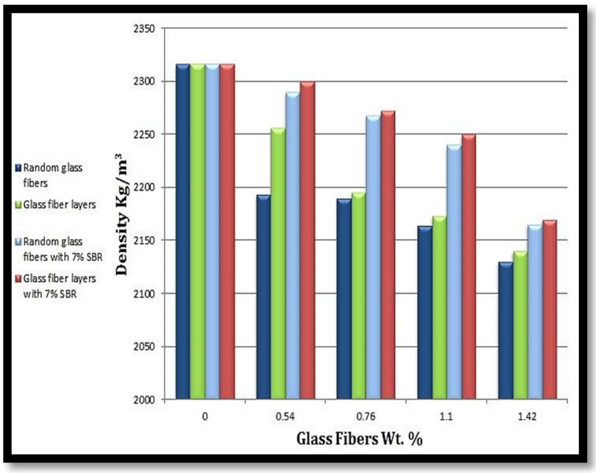

Fig. 7. Comparison between glass fibers reinforced mortar without SBR and glass fibers reinforced mortar with SBR after curing for 28 days.

From the previous figures, the following can be noticed:

- The addition of glass fibers in both random and layers manner decreased the density of mortar. The density was directly proportional to the weight according to the density rule which is the weight divided by the volume, the light weight glass fibers made the specimens lighter than control specimens and consequently reduced the density.[14]
- Random glass fibers addition showed higher reduction in density of mortar (10.6%) than layers glass fibers (8.56%) compared with control specimens.
- Random and layered glass-fiber addition with 7% SBR caused lower reduction in density than glass fibers addition without SBR. The reduction

was (8.35%) and (7.6%) for random and layers, respectively.

- 7 days curing gave higher reduction than 28 days due to the completion of cement hydration reaction which produce a dense structure.

5.2. Compressive Strength

5.2.1 Glass fibers reinforced mortar without SBR

The addition of glass fibers (random and layers) to mortar increased the compressive strength and all results are shown in Table (8). The best addition was with (1.1) % by weight. The further addition caused reduction in compressive strength but still higher than control specimens as shown in Fig. (8) and Fig.(9). The glass fiber enhances the bond strength and This is the explanation of increasing in compressive strength by the addition glass fiber, but the further addition lowers the compressive strength due to the brittleness of glass.[15]

Table 8,
Results of compressive strength testing for glass fibers reinforced mortar without SBR

Mortar Type	Glass fibers wt.%	Curing days	Compressive Strength MPa	Increasing %
Control mortar	——	7	15.404	——
	-	28	20.28	——
Reinforced by layers glass fibers	0.54	7	18.055	17.20
		28	25.271	24.61
	0.76	7	18.842	22.32
		28	27.578	35.99
	1.1	7	19.32	25.42
		28	33.48	65.10
	1.42	7	18.376	19.29
		28	24.341	20.00
Reinforced by random glass fibers	0.54	7	15.644	1.56
		28	21.724	7.12
	0.76	7	16.142	4.79
		28	22.689	11.88
	1.1	7	16.914	9.80
		28	24.663	21.61
	1.42	7	16.464	6.88
		28	23.156	14.18

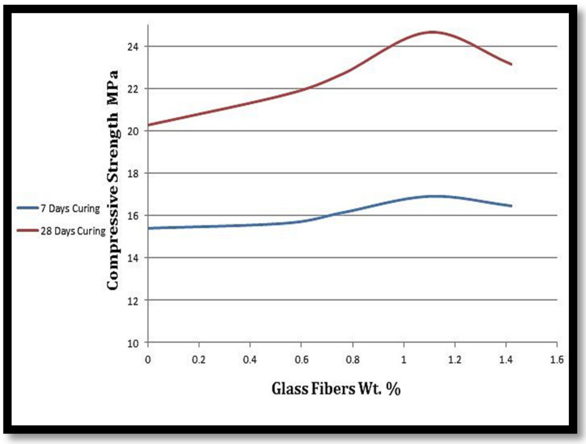

Fig. 8. Effect of random glass fibers addition on mortar after curing for 7 and 28

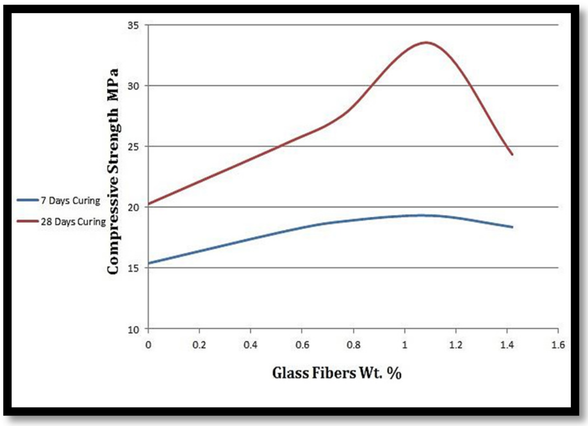

Fig. 9. Effect of glass fibers layers addition on mortar after curing for 7 and 28 days.

5.2.2. Glass fibers reinforced mortar with SBR

All results are shown in Table (9), Fig. (10) and Fig.(11) show the improving in compressive strength after the addition of random and layered glass-fiber with 7% SBR, respectively. The addition of glass fibers with 7% SBR caused increasing in compressive strength until the glass fibers reached (1.1) % by weight. The more addition caused a reduction in compressive strength but still higher than control specimens. The layered glass fibers addition showed higher increasing in compressive strength than random addition.

Table 9,
Results of compressive strength testing for glass fibers reinforced mortar with SBR

Mortar Type	Glass fibers wt.%	Curing days	Compressive Strength MPa	Increasing %
Control mortar	——-	7	15.404	———
		28	20.28	———
Reinforced by layers glass fibers	0.54	7	26.311	70.80
		28	33.702	66.18
	0.76	7	28.206	83.10
		28	39.87	96.60
	1.1	7	30.71	99.36
		28	41.56	104.93
	1.42	7	28.88	87.48
		28	39.4	94.28
Reinforced by random glass fibers	0.54	7	24.906	61.68
		28	32.643	60.96
	0.76	7	27.43	78.07
		28	35.75	76.30
	1.1	7	28.66	86.10
		28	40.71	100.74
	1.42	7	26.15	69.76
		28	37.22	83.53

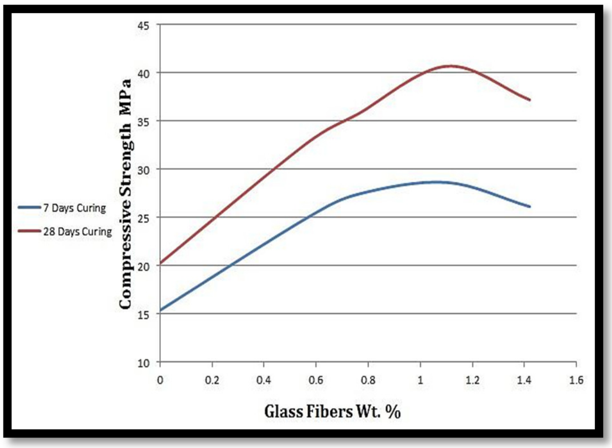

Fig. 10. Effect of random glass fibers addition with SBR to mortar after curing for 7 and 28 days.

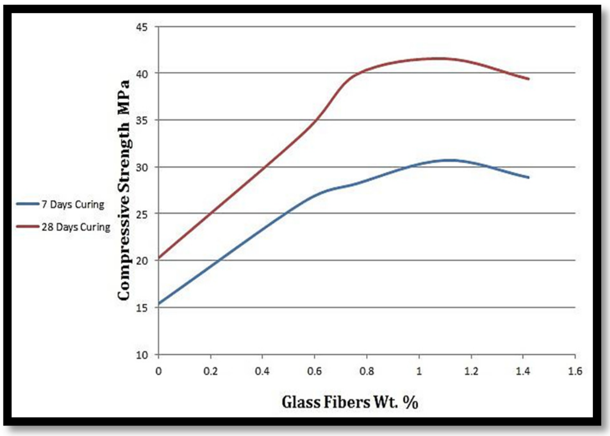

Fig. 11. Effect of layers glass fibers addition with SBR to mortar after curing for 7 and 28 days.

To clarify the effect of adding random and layers glass fibers with and without SBR on compressive strength, a comparison with control specimens is shown in Fig. (12) and Fig.(13) after 7 & 28 days of curing, respectively.

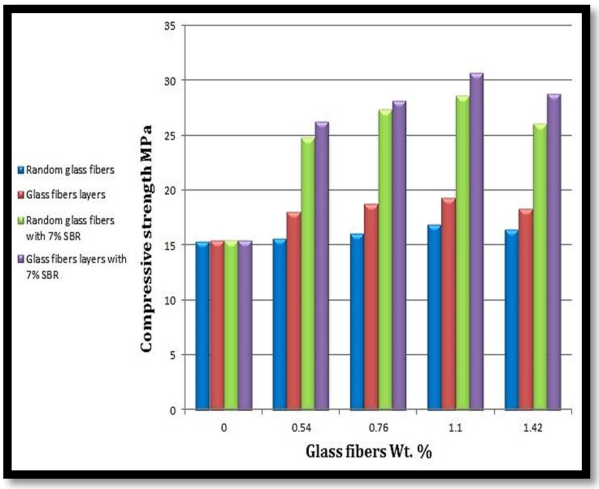

Fig. 12. Comparison between the effect of random and layers glass fibers with and without SBR on compressive strength of mortar after 7 days of curing.

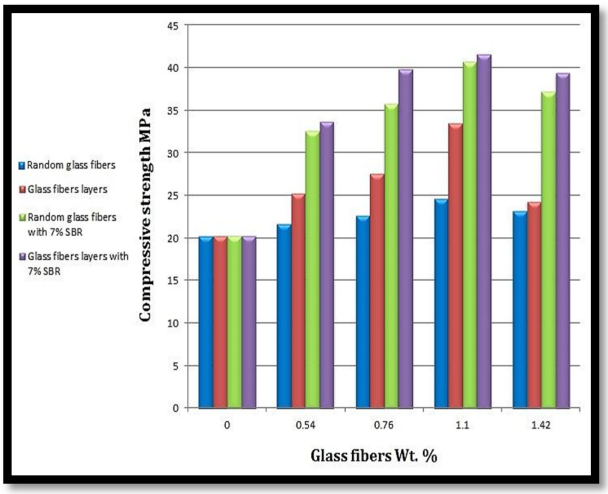

Fig. 13. Comparison between the effect of random and layers glass fibers with and without SBR on compressive strength of mortar after 7 days of curing.

From the previous figures, the following observation can be noticed:

- The addition glass fibers (random and layers) to mortar improved the compressive strength compared with control specimens. The best compressive strength was achieved at (1.1) weight percentage of glass fibers and the further addition caused a reduction in compressive strength but still higher than control specimens. The increasing was (21%) and (65%) for random and layers, respectively. The glass fibers enhanced the bond strength and this is the explanation of increasing in compressive strength by the addition glass fibers but the increasing in the addition of glass fibers lowered the compressive strength due to the brittleness of glass fibers.[15]

- Addition of glass fibers (random and layers) with 7% SBR caused higher increasing in compressive strength and better addition was (1.1) wt.% with 7% SBR. The increasing was (100.4%) and (104.9%) for random and layers, respectively. The further addition negatively affected the compressive strength but still higher than control specimens. The layer addition produced higher results than random addition.
- The curing age had noticeable effect in improving the compressive strength of mortar where 28 days of curing gives better results than 7 days of curing.

6. Conclusions

1. The addition of glass fibers in both random and layers manner to cement mortar caused a reduction in density. The higher reduction was with glass fibers of (1.42 wt. %). The random addition gave more reduction in density than the layered one.
2. The addition of 7% SBR to glass fibers reinforced mortar caused less reduction in density than glass fibers addition without SBR.
3. The curing age for 7 days caused more reduction than 28 days due to the completion of cement hydration reaction which produced more dense structure.
4. Both random and layered glass fibers addition to mortar improved the compressive strength. The layers addition has the better results over the random one and the best weight percentage was (1.1).
5. Addition of 7% SBR to glass-fiber reinforced mortar caused higher improvement in compressive strength than that without SBR.
6. The curing for 28 days has better improvement in compressive strength than 7 days of curing.

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تحسين مقاومة الانضغاط للملاط باستخدام توزيع مختلف من الياف الزجاج ومستحلب الستايرين بيوتادايين

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الخلا□ة

الملاط المدعم بألياف الزجاج والمضاف لها مستحلب □تايرين بيوتادايين (SBR) تعد من المواد الحديثة في مجال المواد الإنشائية. يهدف هذا البحث لدرا□ة تأثير اضافة الياف الزجاج العشوائية وطبقات الياف الزجاج على كثافة و مقاومة انضغاط الملاط مختبرياً في □الة وجود او عد□ وجود مادة (SBR). تم تحضير خلطات من الملاط بنسبة خلط وزنية ١:٢ (□منت- رمل) ونسبة الماء الى الإ□منت (٠,٥). تم اضافة الياف الزجاج بطريقتين عشوائية وطبقات بنسب وزنية (٠,٥٤, ٠,٧٦, ١,١, ١,٤٢). قسمت العينات الى □لسلتين □داهما مدعمة بألياف الزجاج بدون اضافة (SBR) والأخرى مدعمة بألف الزجاج مع اضافة ٧% (SBR) من ماء الخلطة. تم فحص العينات بعد غمرها بالماء لمدة ٧ و ٢٨ يوماً. الملاط المدعم بألياف الزجاج أظهر تحسينا في مقاومة الانضغاط مقارنة مع عينات القياس. اما افضل النتائج كانت مع العينات المدعمة بألياف الزجاج والمضاف لها ٧% (SBR). الإنضاج بعمر ٢٨ يوماً اظهر افضل النتائج بسبب اكتمال تفاعل الماء مع الإ□منت.