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Improving Compressive strength of Lightweight Aggregate Concrete

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ABSTRACT

This work aims to improve the strength of Lightweight Aggregate Concrete (LWAC) developed in Egypt using available local materials. The Crushed Sand Brick (CSB) was used with (50, 60, and 70 percent) replacement ratios of crushed dolomite by volume in two options, once without surface coating another time after coating its surface with cement mortar before mixing. It is recommended to use uncoated CSB with a replacement ratio of 60 percent which provided optimum compressive strength/density ratio. Expanded Polystyrene (EP) was cut manually and used with of 60 % replacement ratio of crushed dolomite by volume by study the effect of type of Lightweight Aggregate (LWA) on properties and strength of LWAC, finally Expanded Polystyrene Granules (EPG) with particle size less than 4.75 mm was used as 60% replacement of sand by volume. Cement content was increased from 350 Kg/m^3 to 450 Kg/m^3, Silica Fume (SF) was added with different doses (10, 20, and 30) % of cement by weight, and High Range Water Reducer (HRWR) was used with different doses (2, 3, and 4) % of binder materials by weight to improve compressive strength and properties of LWAC. The type of LWA was found to be the most effective factor on the strength of LWAC.

1. Introduction

LWAC is a type of concrete that depends on partial or total replacement of the normal weight aggregate with LWA causing extreme reduction in mechanical properties than normal weight concrete, unit weight of LWAC varies from 1500 to 2000 kg/m^3, and compressive strengths also varies from 10 to 21 MPa [1], variation of LWAC properties is related to properties of materials used in its production [2], smaller sections can be obtained for structural elements. LWA may be also used as insulating fill[3], LWAC has a degree of durability[4], the elasticity modulus of LWA and matrix is approximately equivalent resulting in extreme reduction in stress concentration at the aggregate matrix interface compared to normal weight concrete [5].Several factors affect properties of LWAC such as type and properties of used LWA and its content in the mix, water to cement ratio, cement content, and used additives, water absorption of LWA isn't the only factor affecting mixing water absorption but also its moisture content [6],using LWA instead of normal weight aggregate causes reduction in strength and stiffness of LWAC [7], the thermal insulation efficiency depends significantly on the thermal conductivity of LWA [8], higher concrete durability can be achieved when LWA is replaced with normal weight sand[9], durability against physical attack is related to LWA type [10],using air-

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entraining agent cause reduction in density of LWAC [11], LWAC using EP has higher strength, less unit weight, and lower thermal conductivity than that produced with vermiculite[12],initial curing and its duration hasa greater effect on durability comparing with its effect on compressive strength [13],the compressive strength of EP concretes with fly ash can gradually increase over 90 [14], strength and durability of LWAC can be increased by using silica fume[15],compressive strength and elasticity modulus are improved by 57% and 14% respectively when introducing 5–15% silica fume of cement content by weight in case of LWAC [16], structural applications of LWAC could be enhanced as it met the requirements of code of practice [17].

2. Methods and Experimental Program

2.1. Materials

Properties of Concrete Raw Materials are shown in Table 1 all results were obtained experimentally, CSB was weighed without coating, another time it was immersed in cement mortar then it was extracted to dry for one day and then it was weighed.

Table 1. Properties of Concrete Raw Materials

Property / Material	Specific Gravity	Unit Weight (Kg/m^3)	Absorption Ratio (%)
Crushed Dolomite	2.67	1770	1.5
Sand	2.53	1774	1.5
CSB	.898	396	69.8
CSB after surface coating with cement mortar	1.81	1043	4.8
EP	.011	17.33	1
Cement	3.15	___	___
Silica Fume	2.15	___	___
HRWR	1.15	___	___

2.2. EXPERIMENTAL METHOD

The experimental program was planned to improve the compressive strength of LWAC, firstly normal weight concrete mix (A)was cast without additives, secondly LWAC mixes were cast using CSB as a partial replacement of crushed dolomite by volume with differentratios (50, 60, and 70 percent) in two options firstly without surface coating for Mixes (B, C, and D) respectively as shown in Table 2, another time for coated surface CSB with cement mortar before mixing with the same volumetric replacement ratios for Mixes (E, F, and G) respectively as shown in Table 3. According to the results of unit weight and compressive strength of LWAC mixes it's recommended to use uncoated CSB with 60% replacement ratio of crushed dolomite by volume as it gave the optimum compressive strength to density ratio comparing with 50 and 70 % replacement ratios.

In order to improve the compressive strength of LWAC, cement content was increased, chemical and mineral admixtures were also introduced.

Table 2. Mix Design for normal weight concrete and lightweight aggregate concrete using uncoated crushed sand brick

Mix Id / Material	A	B	C	D
Weight of Cement(Kg)	350	350	350	350
Weight of Sand (Kg)	740	645	645	645
Weight of Dolomite (Kg)	1163	506	405	304
Weight of Crushed Sand Brick (Kg)	0	172	206	240
Weight of Water (Kg)	175	252	252	252

Table 3. Mix design for lightweight aggregate concrete using crushed sand brick coated with cement mortar.

Mix Id / Material	E	F	G
Weight of Cement (Kg)	350	350	350
Weight of Sand (Kg)	715	715	715
Weight of Dolomite (Kg)	562	450	337
Weight of Crushed Sand Brick (Kg)	384	461	537
Water Content (Kg)	182	182	182

Cement content was increased as following 350, 400, and 450 Kg/m^3 for mixes (C, H, andI) respectively as shown in Table 4.

Table 4. Mix design for lightweight aggregate concrete using uncoated crushed sand brick by increasing cement content

Mix Id / Material	H	I
Weight of Cement(Kg)	400	450
Weight of Sand(Kg)	592	540
Weight of Crushed Dolomite (Kg)	372	339
Weight of Crushed Sand Brick (Kg)	189	172
Water Content (Kg)	288	324

HRWR was used with different doses (2, 3, and 4) % of binder materials by weight for mixes (J, K, and L) respectively, finally silica fume was added with different doses (10, 20, and 30) % of cement by weight for mixes (M, N, and T) respectively, as shown in Table 5.

Table 5. Mix design for lightweight aggregate concrete using uncoated crushed sand brick with additives

Material \ Mix Id	J	K	L	M	N	T
Cement Content (Kg)	450	450	450	405	360	315
Wt of Sand (Kg)	600	646	683	654	624	595
Wt of Crushed Dolomite (Kg)	377	508	429	410	393	374
Wt of Crushed sand Brick (Kg)	191	173	218	210	200	190
Water Content (Kg)	257	207	167	189	212	234
Silica Fume Content (Kg)	0	0	0	45	90	135
High range water reducer Content (Kg)	9	14	18	18	18	18

EP was also used in two options once it was cut manually with size greater than 4.75 mm and used with 60% replacement ratio of crushed dolomite by volume with cement contents 350, and 450 Kg/m^3 for mixes P and Q respectively another time with size smaller than 4.75 mm and used as 60% replacement of sand by volume for mixes W and X respectively as shown in Table6.

Table 6. Mix design for lightweight aggregate concrete using Expanded Polystyrene with increasing cement content

Material \ Mix Id	P	Q	W	X
Weight of Cement(Kg)	350	450	350	450
Weight of Sand(Kg)	740	662	296	265
Weight of Crushed Dolomite (Kg)	465	416	1162	1041
Weight ofExpanded Polystyrene (Kg)	3	3	2	2
Water Content (Kg)	158	203	158	203

According to EP as coarse LWA (2%) HRWR of binder materials by weight was used as in mix (R), and 20% silica fume of cement by weight was also used as in mix(S).In case of EP as fine LWA (2%) HRWR of binder materials by weight was used as in mix (Y), and 20% silica fume of cement by weight was also used as in mix (Z) as shown in Table 7.

All concrete mixes were designed according to absolute volume method.

Table 7. Mix design for lightweight aggregate concrete using expanded polystyrene with additives

Material \ Mix Id	R	S	Y	Z
Weight of Cement(Kg)	450	360	450	360
Weight of Sand(Kg)	700	695	282	267
Weight of Crushed Dolomite (Kg)	440	437	1106	1049
Weight of Expanded Polystyrene (Kg)	3	3	2	2
Weight of Water(Kg)	158	144	158	180
Wt of Silica Fume (Kg)	0	90	0	90
High Range Water Reducer Content (Kg)	9	9	9	9

3. Results and Discussion

Tables and figures of the experimental data which exhibits the effect of the various parameters on (W/C) ratio, unit weight, and compressive strength will be discussed as following.

3.1. Effect of Different Parameters on Water to Cement Ratio

3.1.1 Effect of Aggregate Type on (W/C) Ratio

That effect is shown in Table 8 and figure 1. Normal weight concrete made with crushed dolomite and sand possessed a water to cement ratio of 0.50, while using LWA caused extreme increase in (W/C) ratio, whereas LWAC using uncoated CSB presented in mix (C) indicates (W/C) ratio of 0.72, and 0.52 when using CSB coated with cement mortar as in mix (F).

0.50 (W/C) ratio was used for LWAC using EP as coarse LWA presented in mix (P) and for LWAC using EPG as fine LWA presented in mix (W).

Table 8. Effect of aggregate type on (W/C) ratio

Mix Id	(W/C) Ratio %	(W/C) Ratio of the Mix Relative to Mix (A) %
A	0.50	100
C	0.72	144
F	0.52	104
P	0.50	100
W	0.50	100

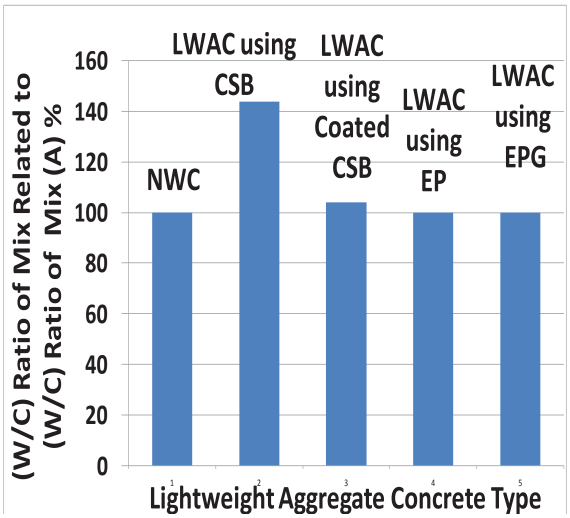

Fig 1 Effect of aggregate type on (W/C) Ratio

3.1.2 Effect of HRWR on (W/C) Ratio

That effect is shown in Table 9 and figure 2. The (W/C) ratio of LWAC using uncoated CSB changes according to the dose of HRWR, whereas 57, 46 and 37% (W/C) ratios have been indicated for 2, 3 and 4% HRWR of binder materials by weight as presented in mixes J, K, and L respectively, 2% HRWR of binder by weight reduces (W/C) ratio from 0.50 to 0.35 for both LWAC using EP as coarse LWA and for LWAC using EPG as fine LWA presented in mixes R and Y respectively.

Table 9. Effect of HRWR on (W/C) Ratio

Mix ID	% of HRWR	(W/C) Ratio %	(W/C) Ratio of the Mix Relative to Mix (C) %
C	0	0.72	100
J	2	0.57	79.166
K	3	0.46	63.88
L	4	0.37	51.39
P	0	0.50	69.44
R	2	0.35	48.61
W	0	0.50	69.44
Y	2	0.35	48.61

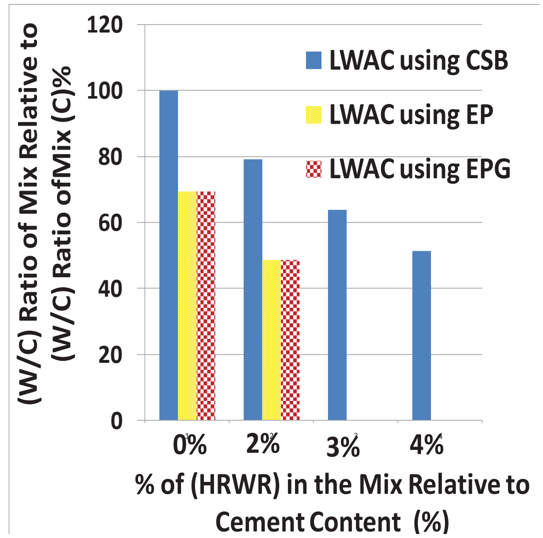

Fig 2 Effect of HRWR on (W/C) Ratio

3.1.3 Effect of Silica Fume on (W/C) Ratio

That effect is shown in Table 10 and figure3. The (W/C) ratio of LWAC using uncoated CSB changes according to the dose of silica fume in the mix, whereas 42, 47, and 52% (W/C) ratios have been indicated for 10, 20, and 30% silica fume doses of cement by weight as presented in mixes M, N, and T respectively, 20% silica fume of cement by weight increases (W/C) ratio from 0.37 to 0.40 for both LWAC using EP as coarse LWA and for LWAC using EPG as fine LWA as presented in mixes S, and Z respectively.

Table 10. Effect of Silica Fume on (W/C) Ratio

Mix ID	% of SF	(W/C) Ratio %	(W/C) Ratio of the Mix Relative to Mix (L) %
L	0	0.37	100
M	10	0.42	113.5
N	20	0.47	127
T	30	0.52	140.54
R	0	0.35	94.59
S	20	0.40	108.11
Y	0	0.35	94.59
Z	20	0.40	108.11

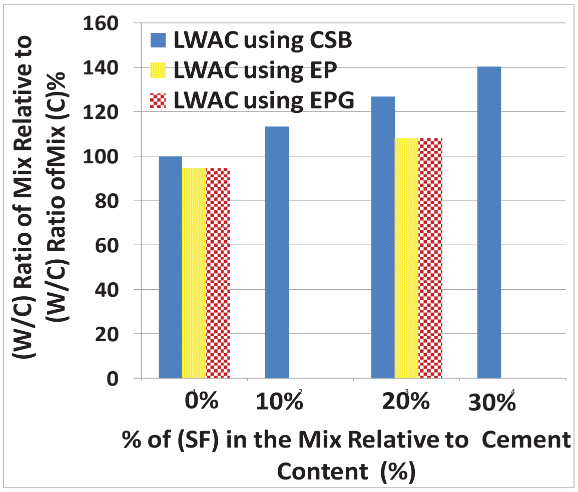

Fig 3 Effect of Silica Fume on (W/C) Ratio

3.2Effect of Different Parameters on Unit Weight

3.2.1 Effect of Aggregate Type on Unit Weight

That effect is shown in Table11 and figure 4.Normal weight concrete made with crushed dolomite and sand possessed a unit weight of 2310 Kg/m^3, while using LWA causes extreme reduction in the unit weight, whereas LWAC using uncoated CSB presented in mix (C) indicates unit weight of 1702 Kg/m^3, Unit weight of 2029 Kg/m^3 for LWAC using coated CSB presented in mix (F), unit weight of 1610 Kg/m^3 for LWAC using EP as coarse LWA presented in mix (P) and unit weight of 1868 Kg/m^3, for LWAC using EPG as fine LWA presented in mix (W).

Table 11. Effect of Aggregate Type on Unit Weight

Mix Id	Unit weight (Kg/m3)	Unit Weight of the Mix Relative to Unit Weight of Mix (A) %
A	2310	100
C	1702	73.679
F	2029	87.835
P	1610	69.697
W	1868	80.866

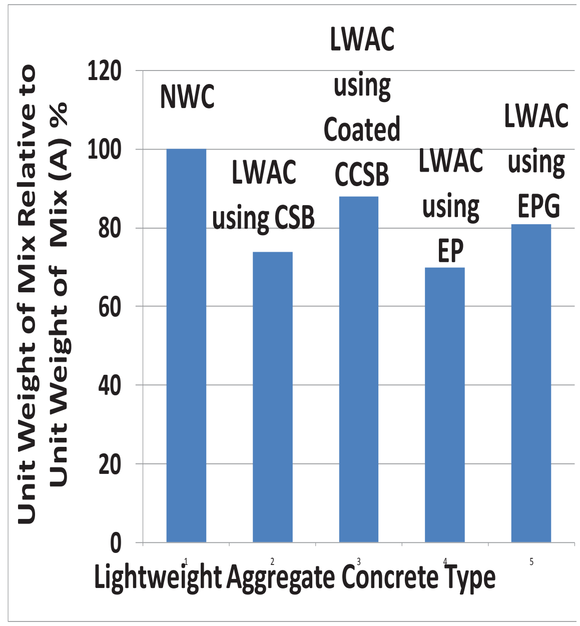

Fig 4Effect of Aggregate Type on Unit Weight

3.2.2 Effect of Cement Content on Unit Weight

That effect is shown in Table12 and figure 5,the unit weight of LWAC using uncoated CSB changes according to the used cement content, whereas unit weights of 1661 and 1617 Kg/m^3, cement contents have been indicated for 400 and 450 Kg/m^3, cement contents as presented in mixes H, and I respectively. Increasing cement content from 350 to 450 Kg/m^3 reduces unit weight from 1610 to 1595 Kg/m^3, for LWAC using EP as coarse LWA shown in mixes P and Q respectively and from 1868 to 1833 Kg/m^3 for LWAC using EPG as fine LWA presented in mixes W and X respectively.

Table 12. Effect of Cement Content on Unit Weight

Mix Id	Cement content (Kg/m3)	Unit Weight (Kg/m3)	Unit Weight of the Mix relative to Unit Weight of Mix (C) %
C	350	1702	100
H	400	1661	97.59
I	450	1617	95
P	350	1610	94.594
Q	450	1595	93.713
W	350	1868	109.753
X	450	**1833**	107.697

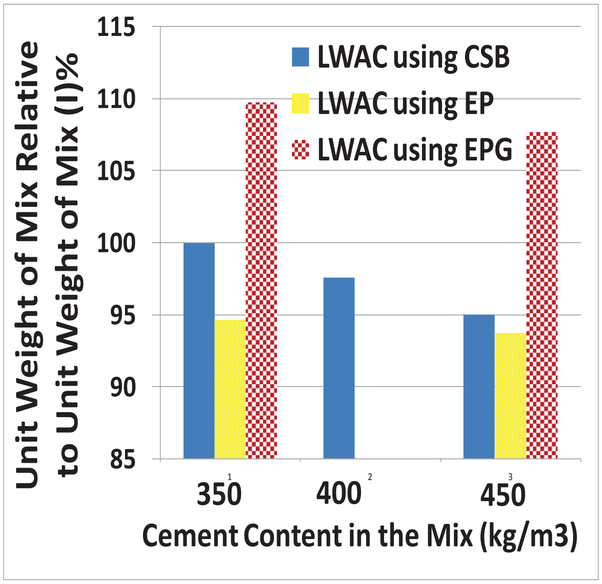

Fig 5 Effect of Cement Content on Unit Weight

3.2.3 Effect of HRWR on Unit Weight

That effect is shown in Table13 and figure 6, the unit weight of LWAC using uncoated CSB changes according to the dose of HRWR, whereas 1723, 1853, and 1825 Kg/m^3 unit weights have been indicated for 2, 3, and 4% HRWR doses of cement by weight as presented in mixes J, K, and L respectively. 2% HRWR of cement by weight reduces unit weight from 1595 to 1650 Kg/m^3 for LWAC using EP as coarse LWA as presented in mixes Q and R respectively, and from 1833 to 1911 Kg/m^3 for LWAC using EPG as fine LWA presented in mixes X and Y respectively.

Table 13. Effect of HRWR on Unit Weight

Mix Id	%of HRWR	Unit Weight (Kg/m3)	Unit Weight of the Mix relative to Unit Weight of Mix (I) %
I	0	1617	100
J	2	1723	106.555
K	3	1853	114.595
L	4	1878	116.141
Q	0	1595	98.639
R	2	1650	102.041
X	0	1833	113.358
Y	2	1911	118.182

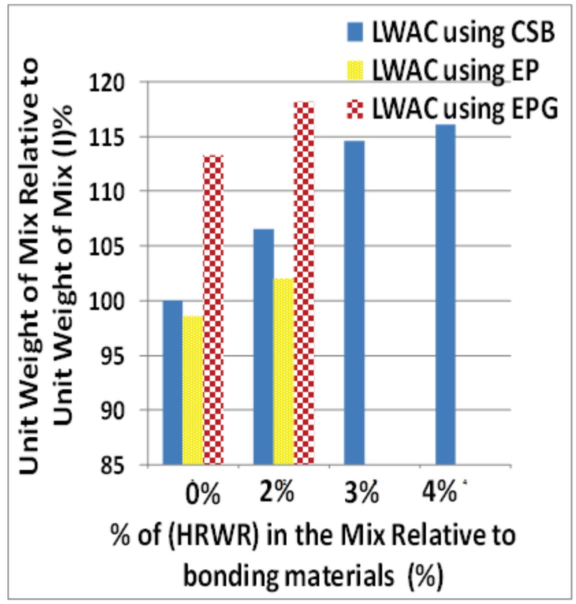

Fig 6 Effect of HRWR on Unit Weight

3.2.3 Effect of Silica Fume on Unit Weight

That effect is shown in Table14 and figure 7,the unit weight of LWAC using uncoated CSB changes according to the dose of silica fume in the mix, whereas 1789, 1741, and 1701 Kg/m^3 unit weights have been indicated for 10, 20, and 30 % silica fume doses of cement by weight as presented in mixes M, N, and T respectively. 20% silica fume dose of cement by weight increases the unit weight from 1650 to 1633 Kg/m^3 for LWAC using EP as coarse LWA presented in mixes R and S respectively and from 1911 to 1877Kg/m^3 for LWAC using EPGas fine LWA as presented in mixes Y and Z respectively.

Table 14. Effect of Silica Fume on Unit Weight

Mix ID	% of Silica Fume	Unit weight (Kg/m3)	Unit Weight of the Mix relative to Unit Weight of Mix (L) %
L	0	1825	100
M	10	1789	98.027
N	20	1741	95.397
T	30	1701	93.205
R	0	1650	90.411
S	20	1633	89.479
Y	0	1911	104.712
Z	20	1877	102.849

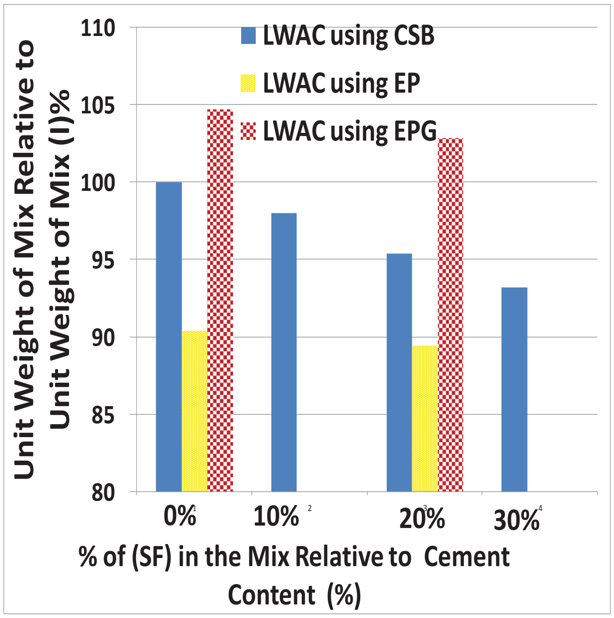

Fig 7 Effect of silica fume on Unit Weight

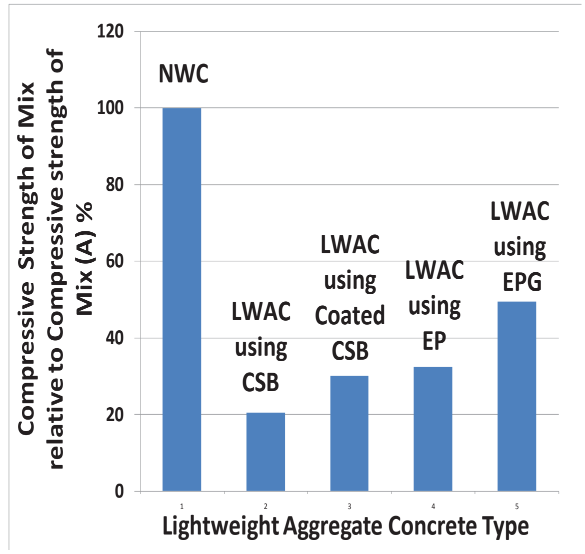

Fig 8. Effect of Aggregate and Concrete Type on Compressive Strength

3.3 Effect of Different Parameters on Compressive Strength

3.3.1 Effect of Aggregate Type on Compressive Strength

That effect is shown in Table15 and figure 8. The normal weight concrete made with crushed dolomite and sand possessed a compressive strength of 253 Kg/cm^2 presented in mix (A), while using LWA causes extreme reduction in the compressive strength, whereas LWAC using uncoated CSB presented in mix (C) indicates compressive strength of 51.5 Kg/cm^2 and compressive strength of 76 Kg/cm^2 for LWAC using coated CSB presented in mix (F).

Compressive strength of 82 Kg/cm^2 for LWAC using EP as coarse LWA presented in mix (P) and compressive strength of 125 Kg/cm^{2}LWAC using EPG as fine LWA presented in mix (W).

Table 15. Effect of Aggregate and Concrete Type on Compressive Strength

Mix Id	compressive strength (Kg/cm^2)	(Compressive Strength of the mix relative to Compressive Strength of mix (A) %
A	253	100
C	51.5	20.356
F	76	30.039
P	82	32.411
W	125	49.407

3.3.2 Effect of Cement Content on Compressive Strength

That effect is shown in Table16 and figure 9. The compressive strength of LWAC using uncoated CSB changes according to the cement content, whereas compressive strength values of 59, 78 Kg/cm^2 have been indicated for 400 and 450 Kg/m^3 cement contents as presented in mixes H and I respectively. Increasing cement content from 350 to 450 Kg/m^3 increased compressive strength from 82 to 92 Kg/cm^2 for LWAC using EP as coarse LWA presented in mixes P and Q respectively, and from 125 to 156 Kg/cm^2 for LWAC using EPG as fine LWA as presented in mixes W and X respectively.

Table 16. Effect of Cement Content on Compressive Strength

Mix Id	Cement content (Kg/m^3)	Compressive Strength (Kg/cm2)	Compressive Strength of the mix relative to mix (C) %
C	350	51.5	100
H	400	59	114.563
I	450	78	151.456
P	350	82	159.223
Q	450	92	178.641
W	350	125	242.718
X	450	156	302.913

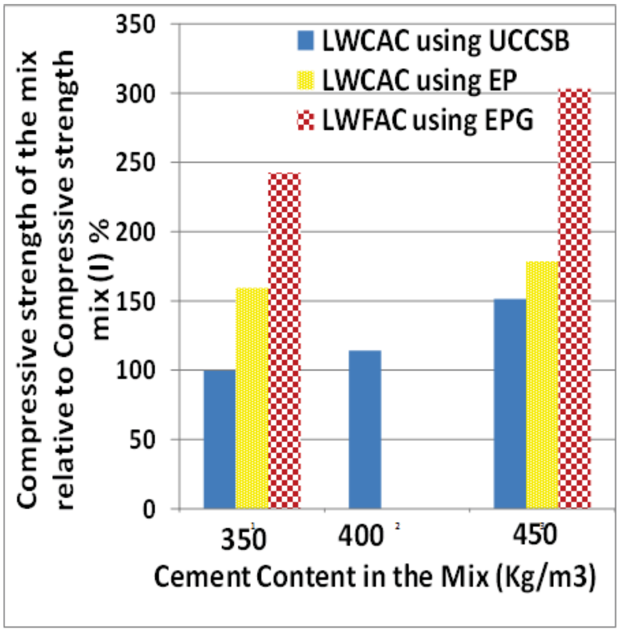

Fig.9 Effect of Cement Content on Compressive Strength

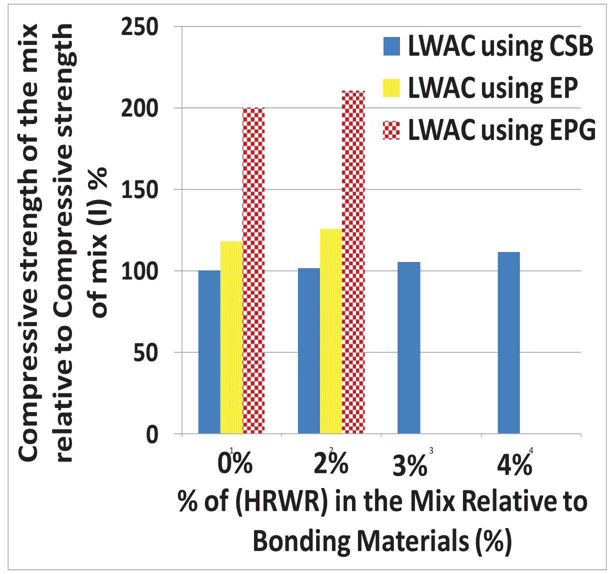

Fig 10 Effect of HRWR on Compressive Strength

3.2.3 Effect of HRWR on Compressive Strength

That effect is shown in Table 17 and figure 10. HRWR used in LWAC mixes strangely has negligible effect on its compressive strength of as LWA tends to float on the surface of the mix increasing the internal voids in the body of concrete mix. The compressive strength of LWAC using uncoated CSB changes according to the dose of er, whereas 79, 82, and 87 Kg/cm^{2}compressive strength values have been indicated for 2, 3 and 4% HRWR doses of cement by weight as presented in mixes J, K, and L respectively 2% HRWR of cement by weight increased compressive strength from 92 to 98 Kg/cm^2 for LWAC using EP as coarse LWA presented in mixes Q and R respectively, and from 156 to 164 Kg/cm^2 for LWAC using EPG as fine LWA presented in mixes X and Y respectively.

Table 17. Effect of HRWR on Compressive Strength

Mix Id	%of HRWR	Compressive Strength (Kg/cm^2)	Compressive Strength of the mix relative to mix (I) %
I	0	78	100
J	2	79	101.282
K	3	82	105.128
L	4	87	111.538
Q	0	92	117.949
R	2	98	125.641
X	0	156	200
Y	2	164	210.256

3.2.3 Effect of Silica Fume on Compressive Strength

That effect is shown in Table18 and figure 11, using silica fume in the mix could increase the compressive strength, the compressive strength of LWAC using uncoated CSB changes according to the dose of silica fume in the mix, whereas 95, 117, and 123 Kg/cm^2 compressive strength values have been indicated for 10, 20, and 30% silica fume of cement by weight as presented in mixes M, N, and T respectively. 20% silica fume by weight increased the compressive strength from 98 to 122 Kg/cm^2 for LWAC using EP as coarse LWA presented in mixes R and S respectively and from 164 to 194 Kg/cm^2 for LWAC using EPG as fine LWA presented in mixes Y and Z respectively.

Table 18. Effect of Silica Fume on Compressive Strength

Mix ID	% of Silica Fume	Compressive Strength (Kg/cm^2)	Compressive Strength of the mix relative to mix (L) %
L	0	87	100
M	10	95	109.195
N	20	117	134.483
T	30	123	141.379
R	0	98	112.644
S	20	122	140.229
Y	0	164	188.505
Z	20	194	222.988

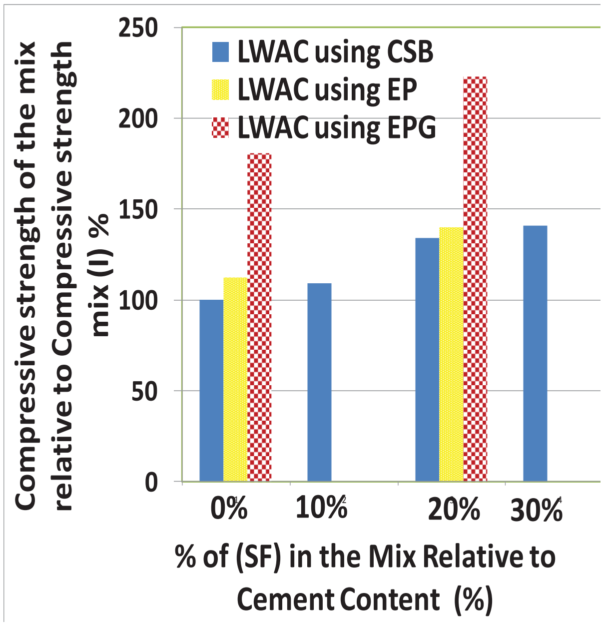

Fig 12 Effect of Silica Fume on Compressive Strength

4. Conclusion

The followings have been concluded:

- Using expanded polystyrene as lightweight aggregate is better than crushed and brick because it's impervious material and the produced concrete possesses less water cement ratio, less unit weight, and higher compressive strength.
- All lightweight concrete types reduce the unit weight of the concrete considerably,where as lightweight fine aggregate proves to be better than lightweight coarse aggregate regarding concrete strength.
- Using crushed sand bricks in lightweight aggregate concrete isn't recommended as it highly reduces the concrete strength.
- Silica fume in lightweight concrete mixes improves the compressive strength oflightweight aggregate concrete.
- Using a high range water reducer in lightweight aggregate mixes causes high fluidity in combination with mechanical compaction may lead to aggregate segregation, whereas the lightweight aggregate particles tend to rise to the surface hence causing a non homogenous matrix which fails prematurely under compression.
- It is recommended to use lightweight fine aggregate concrete rather than lightweight coarse aggregate concrete when producing lightweight aggregate concrete.
- It is recommended to use crushed sand brick without surface coating in lightweight aggregate concrete for non-structural applications.
- It is recommended to use lightweight fine aggregate concretes using expanded polystyrene as partial replacement of sand in structural applications such as building construction, due to its low density and reasonable compressive strength.
- It is recommended not to use mechanical vibrators to compact lightweight aggregate concrete especially in case of using high range water reducer and super-plasticizer to prevent float of lightweight aggregate on the surface.
- It is recommended to use high range water reducer and super-plasticizer only in case of using silica fume to avoid increase in water requirements especially in case of using uncoated crushed sand brick.

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