Effect of Using Plastic and Rubber Wastes as Fine Aggregate on Some Properties of Cement Mortar

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ABSTRACT

This research describes the production of lightweight cement mortar using four types of fine aggregates including chopped rubber tires, chopped plastic wastes, a mixture from the previous types by 1:1, and a mixture composed from substitution of 10% from the previous type by natural sand. The use of these wastes has role in getting rid of their huge quantities which constitute a fundamental environmental problem because of the difficulty of its degradation.

Four, cement to aggregate ratios have been used. They are 1:0.5, 1:0.7, 1:1, and 1:1.2 for each aggregate type mentioned above, with changing w/c ratio and superplasticizer content to have a constant flow of about 23%. Also, the effect of curing samples by different methods, including continuous submerge in water, autoclave curing for 3 hours, and carbonation curing by 50% and 100% CO_2 at 75°C for 90 minutes, was studied.

The results indicated that it is possible to produce lightweight cement mortar, using any type of aggregates mentioned above, with compressive strength satisfying the requirements of clay brick class C of Iraqi Standard, that used in partitions, for a mix proportion of 1:1, except when using chopped rubber tires that need using mix proportion of 1:0.5 to satisfy the strength requirements, where the use of this aggregate type needs higher w/c ratio and superplasticizer content to get the required flow, which leads to lower strength in comparison with the other types. As for chopped plastic aggregate, although it needs lower water and superplasticizer content to get the required flow and strength, care should be taken to balance between the amount of water and superplasticizer added to avoid the possibility of segregation in it. So it was found that using the mixture of chopped plastic and rubber aggregate give the best properties.

Results also indicated that using all aggregate types with cement: aggregate mix proportion 1:1 satisfy the flexural strength requirements of American Standards for cellulosic fiber insulating boards, and were with thermal conductivity value slower than that for brick and concrete having density lower than 2000 kg/m^3. The results indicated

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that partial replacement of 10% mixed waste aggregates by normal sand cause increase in strength but in the same time increase density and thermal conductivity for the produced mortar.

Results also indicated that curing by autoclave or curing with 50% or 100% CO_2 cause increase in the 7 days strength compared with those cured by water but they show almost the same strength at 28 days age.

Keywords: cement mortar, compressive strength, flexural strength, plastic, rubber tires.

INTRODUCTION:

Large attention is being aimed to the environment and safe guarding of natural resources and recycling of waste materials. Actually many industries are producing a significant amount of scrap wastes. The growing quantity of rubber tires and plastic wastes had been a main concern in the last decades because they represent a huge non-biodegradable rejection with risk of vast quantities causing raising menace to the environment [1, 2, 3&4].

To reduce the problem of accumulated waste dumping, it is imperative that despoil materials should be used in an environmentally safe manner either as economic and beneficial purposes or as raw materials for other products. A variety of rubber and plastic wastes have been suggested as additives for cementitious materials, to enhance some of their properties and for economical purpose.

This research aims to use the chopped rubber tires and plastic wastes as fine aggregate to produce lightweight cement mortar.

Experimental Work

Material Used, Cement

Ordinary Portland cement, with trade mark of (Mass), that produced by (Bazian Company/ Iraq) was used. The cement chemical and physical properties are shown in Tables (1) and (2) which indicate that it satisfies the requirements of Iraqi Standard IQS 5/1984[5].

Table (1) Chemical composition and main compounds of the cement *

Oxides composition	Content%	Limits of Iraqi specification No.5/1984
CaO	61.12	---
SiO_2	20.18	---
Al_2O_3	5.00	---
Fe_2O_3	3.30	---
MgO	3.80	<5.00
SO_3	2.34	<2.80
L.O.I.	3.16	<4.00
Insoluble residue	0.14	<1.5
Lime Saturation Factor, L.S.F.	0.96	0.66-1.02
Main compounds (Bogue's equations)		
C_3S	50.40	---
C_2S	19.91	---
C_3A	7.67	---

C_4AF	10.03	---

* Test carried out by Central Organization for Standardization and Quality Control/ Baghdad

Fine Aggregate

Four types of fine aggregates were used in the research:

1. Chopped Rubber Tires

The scrap rubber used in this study was obtained from a local waste in Iraq, which are chopped to smaller sizes mechanically. The grading of rubber tires aggregate satisfies the requirements of Iraqi Standard IQS 45/1984 (Zone 2)[6], as shown in Table (3). Its specific gravity is 0.78.

Table (2): Physical properties of cement *

Physical Properties	Test results	Limits of Iraqi specification No.5/1984
Specific surface area (Blaine Method), m^2/kg	330	≥230
Setting time (Vicat Apparatus), Initial setting, hr:min Final setting, hr:min	 2:10 4:30	 ≥00:45 ≤10:00
Compressive strength, MPa 3 days 7 days	 19.63 28.93	 ≥15.00 ≥23.00
Soundness (Autoclave Method), %	0.09	≤0.8

* Test carried out by Central Organization for Standardization and Quality Control/ Baghdad

Chopped Plastic Wastes

The plastic waste was obtained throughout this research generally produced from plastic boxes and pipes. The grading of chopped plastic waste conforms for the requirement of Iraqi Standard IQS 45/1984 (zone 1)[6] with specific gravity of 1.40,Table (3) shows its grading.

Mixture Of Chopped Rubber Tire With Plastic Wastes

This type contain a mixture of rubber tire and plastic waste in proportion of 1:1.Its grading, shown in Table (3), conform to the requirements of Iraqi Standard IQS 45/1984 (zone 1)[6].

Mixture of Rubber Tire And Plastic Wastes With Natural Sand

This type of fine aggregate produce from a mixture of chopped rubber tires: plastic waste: natural sand with a ratio of 0.45: 0.45: 0.10.Its grading, shown in Table (3), conform to the requirements of Iraqi Standard IQS 45/1984 (zone 1).

Natural sand from (Al-Ukhaider/ Karbala) was used. The grading of used natural sand is shown in Table (3). All of its properties were within the requirements of the Iraqi Standard IQS 45/1984[6] Zone 2 with specific gravity of 2.60.

Chemical Admixture

Glenium 54, of carboxylic ether polymer based, was used in this research as a HRWRA. It is manufactured by Fosroc Company. It conforms to ASTM C 494 Type F [7] requirements.

Water

Potable (tap) water, from Baghdad water-supply network system, was utilized for mixing and curing.

Mixture Proportions

Four mix proportions of 1:0.5, 1:0.7, 1:1, and 1:1.2cement: fine aggregate ratio was chosen to be casted for each type of fine aggregate used in this research. The w/c ratio and superplasticizer content adjusted to have a flow of about 23%, as shown in Table (4).

Table (3) Grading of different fine aggregate types

Sieve size mm	% passing for fine aggregate type				
	Natural sand	Chopped rubber tires	Chopped plastic	Mixture of chopped rubber and chopped plastic	Mixture of chopped rubber and chopped plastic and natural sand
4.75	100	100	90	95	95.5
2.36	87	100	61	80.5	81.2
1.18	69	81	32	56.5	57.8
0.6	58	40	17	28.5	31.5
0.3	20	20	6	13	13.7
0.15	0.5	4	0	2	1.9
Fineness modulus	2.88	2.55	3.94	3.25	3.18

Mixing and Casting

Mixing of cement mortar was carried out according to ASTM C305-99 [8]. The superplasticizer was dissolved in the prepared mixing water in the required quantity for each mix. After mixing, the molds were filled in two layers, each of them mechanically vibrated. Then after, the samples were covered with polyethylene sheet for about 24 hours.

Curing of Specimens

After de-molding, four methods of curing were used:

1. Conventional Curing: Specimens were submerged in water until testing age.
2. Autoclave curing: The specimens were autoclaved at 210°C and under 1.5 MPa pressure for 3 hours according to ASTM C 151 –05[9]. After that, the samples were kept inside polyethylene bags in laboratory until testing age.

3. Carbonation curing: Two percent of carbon dioxide (CO_2) concentration (50% and 100%) was used to cure the specimens that placed in chamber at 75^{o}C for 90min. After that, the samples were kept inside polyethylene bags in laboratory until testing age.

Results and Discussion

Fresh Properties

The results indicated in Table (4) show that it is possible to have a homogeneous mortar mix with the required flow of about 23%, using all types of the studied fine aggregate, with all the four mortar mix proportions (1:0.5, 1:0.7, 1:1 and 1:1.2). This was done by changing the w/c ratio and superplasticizer content.

The results indicated that the use of chopped rubber tire as fine aggregate increase the w/c ratio and superplasticizer demand in comparison with the other types of aggregate to obtain the required flow of 23%. This might be due to its high fineness that means increasing the surface area which need more paste to cover all the aggregate particles and reduce friction between them.

Table (4) Properties for cement mortar (cured in water)with different aggregate types

Group No.	Mix No	Fine aggregate type	Cement/aggregate ratio	Dosage of S.P by cement wt. (%)	w/c ratio	Flow %	28 days dry density kg/m^3	28 days compressive strength, MPa
Group 1	M1	Chopped rubber tires	1:0.5	1	0.33	23.3	1603	10.78
	M2		1:0.7	1.8	0.34	23.2	1515	8.55
	M3		1:1	2.4	0.36	23	1337	7.37
	M4		1:1.2	3	0.38	22.7	1312	4.22
Group 2	M5	Choppedplastic wastes	1:0.5	0.3	0.31	23.4	1833	17.62
	M6		1:0.7	0.5	0.33	23.1	1747	15.64
	M7		1:1	0.8	0.34	23	1689	13.73
	M8		1:1.2	1	0.36	22.8	1510	9.13
Group 3	M9	50%Plastic+ 50% Rubber wastes	1:0.5	0.6	0.33	23.2	1743	14.44
	M10		1:0.7	1	0.34	23.1	1636	12.93
	M11		1:1	1.3	0.35	23	1543	10.37
	M12		1:1.2	1.6	0.38	22.6	1449	5.68
Group 4	M13	45%Plastic+ 45%Rubber+ 10%Sand	1:0.5	0.5	0.33	23.2	1761	16.32
	M14		1:0.7	0.8	0.34	23.1	1675	14.55
	M15		1:1	1.1	0.35	23	1582	12.78
	M16		1:1.2	1.6	0.36	22.9	1487	7.32

Mortar group2 used chopped plastic waste as fine aggregate, this type of aggregate is very sensitive to the w/c ratio and superplasticizer content added to the mix to obtain the required homogeneity and flow of about 23% without segregation but the mix still need to use superplasticizer with lower amount with it to be mix homogeneously.

Group 3 has been chosen by mixing the two previous types of wastes and use it as well graded aggregate in producing cement mortar. This mortar group, although show higher superplasticizer and w/c ratio requirement in comparison with group 2 due to the increase in fine particles of rubber tires, the mix didn't show any tendency to segregation.

Group 4 shows the results of substitution 10% of the combine aggregate of group 3 by natural sand. The results indicate the superplasticizer content requirement show little decrease to obtain the required flow compared to the third group mortar, without any tendency to segregation. This might be due to the reduction of fine particles in the mixture.

Hardened Properties

Table (4) indicates the dry density and compressive strength at 28 days age for different studied mortar secured continuously in water. While Table (5) indicate all the studied hardened properties of cement mortars with mix proportions of 1: 1 (cement: LWA), subjected to different selected types of curing.

Dry Density

Table (4) indicate that the 28 days age dry density of cement mortars, cured continuously in water, are (1312-1603) kg/m^{3}when using chopped rubber tires aggregate and (1510-1833) kg/m^3 for those using chopped plastic aggregate. These densities were (1449-1743) kg/m^3 when using a mixture of chopped tires and plastic aggregate. While the density were (1487-1761) kg/m^3 for group (4) that use a mixture of chopped tires and plastic with natural sand as aggregate, depending on mix proportion of the mortar.

The results indicated in Table (5) showed that the dry density of all 1:1 mortar types are(1335.2-1690.1) kg/m^3 for different aggregate types mixtures and curing type at 28 days age, which are suitable to be considered as lightweight materials.

According to Table (5), the 28 days age dry density of (Mix3) with rubber tires aggregate shows lower dry density than those using other types of aggregate (Mix 7,Mix 11and Mix 15). The decrease in dry density was (20.87%, 13.35% and 15.49%) respectively. This is attributed to the lower specific gravity of fine rubber tires aggregate compared with plastic and natural sand. Results also indicates that using CO_2 in curing cause a higher density in comparison with the other types of curing.

Compressive Strength

The average compressive strength of three 50 mm cube samples recorded for each test in Tables (4 and 5) and Fig (1). The results shown in Table (4) indicate that the 28 days compressive strength of cement mortar using chopped rubber tires strength is lower than that satisfying the 9MPa requirements for class C[10] of clay brick (used for partitions) unless using a mix proportion (cement: aggregate ratio) of 1:0.5. This might be because of the fine particles of aggregate that need higher amount of paste to cover. Also it might be due to either a poor bond between the cement paste and rubber aggregates or to the lower strength of the rubber aggregates.

Table (4) show that the use of chopped plastic as fine aggregate with all studied mix proportions produce mortar with strength enough to satisfy the requirements of class C brick and even class B that can be used in load bearing walls when using mix proportion of 1:1 or with higher cement content although that the density increase when using higher cement content.

Table (4) show that using a mixture of chopped rubber tires and plastic aggregate improved the mortar strength compared with that using chopped rubber aggregate by about 40%, which permit using this aggregate mixture in producing mortar with mix proportion of 1:1 that satisfy the strength requirements of class C of clay brick without any tendency to segregation. This comes from the improvement in the size distribution of the produced aggregate.

Table (4) show that the institution of 10% natural sand in the previous type of aggregate improve the mortar compressive strength using the 1:1 mixture of rubber and plastic aggregate by about 19%.This might be due to higher specific gravity of natural sand compared with the two types of waste aggregate.

Table (5) shows that curing samples with 50% and 100% CO_2 increased the 7 days age compressive strength by average of 9.3 and 18.5% respectively, but the strength equalized at 28 days age. Berger et al cited by Baojian et al[11] found that cement subjected to natural carbonation have higher rate of strength development than traditional moist introduced at the early stage of cement hydration. Results show that the rate of strength development decreased after 7 days age, may be because of self-desiccation of samples kept in the polyethylene bags after the CO_2 curing till the testing age.

Table (5) Average test results for specified mortar with (1:1) for all types of curing.

Mix No.	Curing type	28 days Dry density kg/m^3	Compressive strength (MPa)			Flexural strength (MPa)			Thermal conductivity at 28 days age (W/m.K)
			7 days	28 days	90 days	7 days	28 days	90 days	
M3	Water curing	1336.6	4.62	7.37	8.03	0.98	1.63	1.78	0.5083
	50% CO_2 curing	1337.4	5.16	7.33	7.98	1.44	1.60	1.74	--------
	100% CO_2 curing	1338	5.53	7.36	8.01	1.46	1.62	1.76	0.5261
	Autoclave curing	1335.2	5.11	7.32	7.96	1.42	1.59	1.73	---------
M7	Water curing	1689.3	10.56	13.73	14.83	1.95	2.78	2.96	0.5784
	50% CO_2 curing	1689.9	11.40	12.79	14.07	2.37	2.74	2.93	----------
	100% CO_2 curing	1690.1	12.30	13.59	14.54	2.39	2.76	2.94	0.5972
	Autoclave curing	1688.0	11.28	12.68	13.97	2.36	2.73	2.92	-----------
M11	Water curing	1542.6	7.80	10.37	11.19	1.56	2.17	2.39	0.5401
	50% CO_2 curing	1543.1	8.51	9.66	10.68	1.78	2.14	2.36	-------------
	100% CO_2 curing	1544.2	9.59	10.27	10.98	1.88	2.16	2.37	0.5639
	Autoclave curing	1541.8	8.46	9.54	10.67	1.76	2.13	2.35	---------
M15	Water curing	1581.6	9.76	12.78	13.80	1.93	2.34	2.55	0.5862
	50% CO_2	1581.6	10.60	11.87	13.18	2.19	2.31	2.51	-----------

	curing								
	100% CO_2 curing	1582.1	11.22	12.37	13.13	2.21	2.33	2.53	0.5967
	Autoclave curing	1580.0	11.37	12.39	13.64	2.17	2.30	2.49	-----------

Table (5) showed that curing samples by autoclave also increased the 7 days age compressive strength but it is equal to that of moist curing at 28 days. This might be also because of the self-desiccation of samples kept in the polyethylene bags after the autoclave curing till the testing age.

Flexural Strength:

The average flexural strength of three 40*40*160 mm prism samples recorded for each test in Table (5) and Figure (2) demonstrate that all mortar, with 1:1 mix proportion, and the four types of aggregate in this work show flexural strength that satisfy the requirements of ASTM C208-95 [12] for cellulosic fiber insulating board.

Table (5) show that mortar using chopped rubber tires as fine aggregate have the lowest flexural strength. This might be due to either a poor bond between the cement paste and rubber aggregates or to the lower strength of the rubber aggregates.

Mortars using chopped plastic as fine aggregate have higher flexural strength than that with chopped rubber aggregate by about 70% and reach 2.78 MPa at 28 days age of moist curing. This might be due to the rough surface of this type of aggregate compared to the rubber aggregate, which contribute in increasing the bond between the aggregate and cement paste. The use of an aggregate mixture between the two types improved the flexural strength of the first group mortar using rubber aggregate alone by about 33%. This might be due to the production of dense grading of the produced aggregate, in addition to providing rougher aggregate particles that increase bond between the aggregate and the paste.

The institution of 10% natural sand in the previous type of aggregate improve the mortar flexural strength of that using the 1:1 mixture of rubber and plastic aggregate by about 8%.

Table (5) showed that the effect of different types of curing on mortar flexural strength is the same as on flexural strength. Results indicate that curing samples with 50% and 100% CO_2 increased the 7 days age flexural strength by average of 16.4 and 19.2 respectively except when using chopped rubber tires that raise the effect of CO_2 to be 47 and 49% respectively. It is also found that the strength equalized at 28 days for different types of curing. This might be due to the densification of the bond zone between the paste and aggregate by the effect of carbonation. While the reason of the decrease rate of strength development after 7 days age may be because of self-desiccation of samples kept in the polyethylene bags after the CO_2 curing till the testing age.

Also it shows that curing samples by autoclave also increased the 7 days age flexural strength but it is equal to that of moist curing at 28 days age.

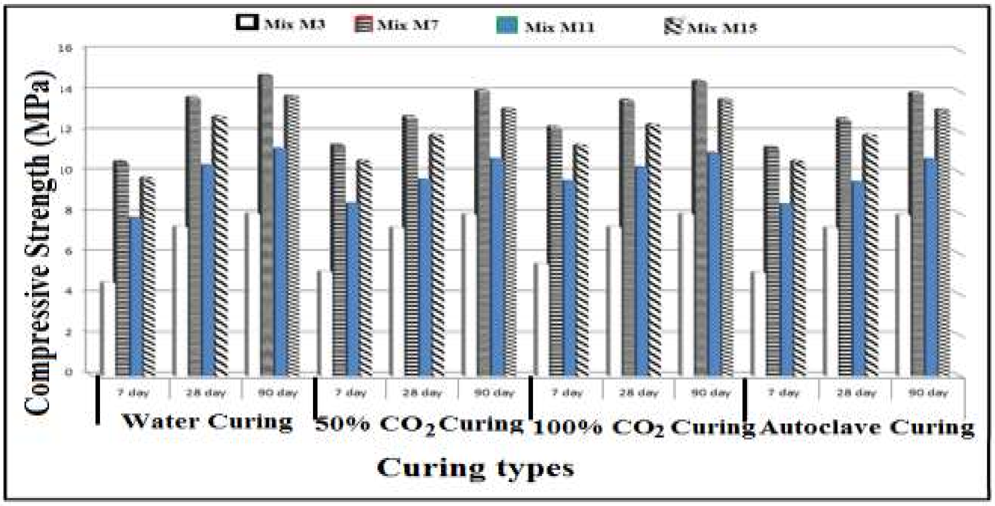

Figure (1): Effect of curing type on compressive strength of mortar using different types of aggregate

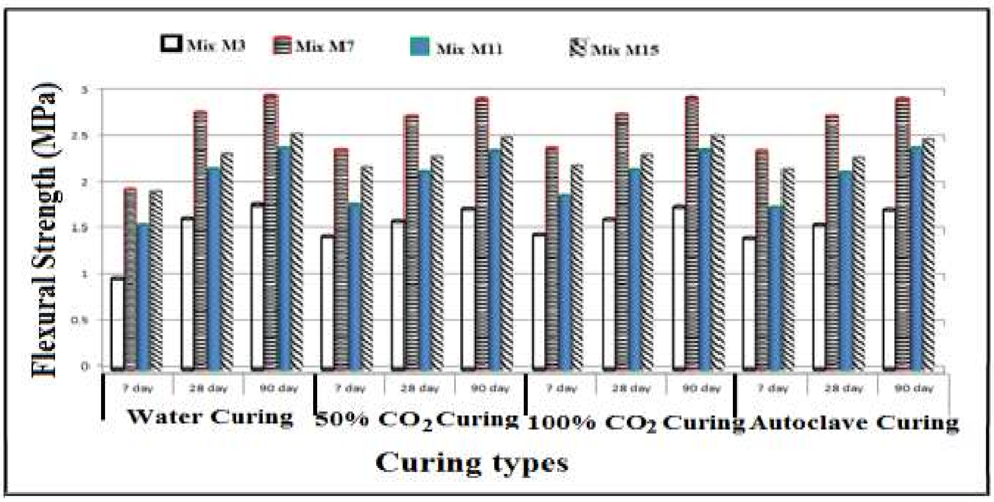

Figure (2): Effect of curing type on flexural strength of mortar using different types of aggregate

Thermal Conductivity:

Table (5) show the thermal conductivity at 28 days age of the produced 1:1 mortar mixtures using the four types of the studied aggregates. Results show that all types of mortars have thermal conductivity of 0.5261-0.5862 W/m.K which is lower than that of brickwork (inner leaf 1700kg/m^3) and within that of concrete with density lower than 2000 kg/m^3, indicated in Table (6), which encourage using the chopped rubber and plastic wastes in manufacturing mortar building units used as partitions in construction works. The lowest thermal conductivity found when using chopped rubber tires as fine aggregate due to the lowest density produced from it.

It is found that curing samples with 100% CO_2 increased thermal conductivity of mortar by little amount of about 3.3% compared with those moist cured.

Table (6) typical thermal conductivity of some building materials [12]

Building material	Thermal conductivity, W/m.K
Cast concrete (normal weight 2300 kg/m^3)	1.63
Cast concrete (dense 2100 kg/m^3 typical floor)	1.40
Cast concrete (dense 2000 kg/m^3 typical floor)	1.13
Cast concrete (medium 1400 kg/m^3)	0.51
Cast concrete (lightweight 1200 kg/m^3)	0.38
Cast concrete (lightweight 600 kg/m^3)	0.19
Concrete slab (aerated 500kg/m^3)	0.16
Mortar	0.80
Brickwork (outer leaf 1700kg/m^3)	0.84
Brickwork (inner leaf 1700kg/m^3)	0.62

CONCLUSIONS:

Based on the experimental work results in this investigation, the following conclusions can be drawn:

1. It is possible to produce mortar using chopped rubber tires and plastic wastes as fine aggregate with a slump flow of (23%) either individually or mixed together or use 10% of natural sand with them. The produced four types of mortar satisfy the strength and thermal conductivity required to manufacture insulation boards for partitions in building.
2. Using chopped rubber tires as fine aggregate require more w/c ratio and superplasticizer content to attain the required flow of mortar. While using chopped plastic wastes need special attention to choose the required w/c ratio and superplasticizer content so as to prevent segregation.
3. Mortar prepared using chopped rubber tires as fine aggregate have lower density than mortar prepared using the other types of studied aggregates.
4. The 28 days compressive strength of cement mortar using chopped rubber tires strength is lower than that satisfying the 9MPa requirements for class C of clay brick (used for partitions) unless using a mix proportion (cement: aggregate ratio) of 1:0.5. The use of chopped plastic as fine aggregate with all studied mix proportions produce mortar with strength higher than that with chopped rubber, it is enough to satisfy the requirements of class C brick and even class B that can be used in load bearing walls when using mix proportion of 1:1 or with higher cement content. In case of using a mixture of chopped rubber and chopped plastic or substitution 10% of natural sand with this mixture, as fine aggregate, the mortar strength satisfies the strength requirement of class C clay brick.

5. All mortar mixes specimens (1:1) with the four types of aggregate in this work show flexural strength that satisfy the requirements of ASTM C208-95 for cellulosic fiber insulating board., with the lowest when using the chopped rubber tires.
6. All types of mortars have thermal conductivity at 28 days age of 0.5261-0.5862 W/m.K which is lower than that of Brickwork (inner leaf 1700kg/m^3) and within that of concrete with density lower than 2000 kg/m^3 which encourage using the chopped rubber and plastic wastes in manufacturing mortar building units used as partitions in construction works. The lowest thermal conductivity found when using chopped rubber tires as fine aggregate due to the lowest density produced from it.
7. Curing samples with 50% and 100% CO_2concentration increased the 7 days age compressive strength by average of 9.3 and 18.5% respectively, but the strength equalized at 28 days age with those permanently cured with water. The effect of different types of curing on mortar flexural strength is the same as on flexural strength. Results indicate that curing samples with 50% and 100% CO_2 increased the 7 days age flexural strength by average of 16.4 and 19.2 respectively except when using chopped rubber tires that raise the effect of CO_2 to be 47 and 49% respectively. It is also found that the strength equalized at 28 days for different types of curing.
8. Curing samples by autoclave for 3 hours produce approximate effect on mortar properties compared to CO_2 curing, where the autoclaved samples strength is higher at 7 days and equal at 28 days age compared to the permanent water cured samples.

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