Project Name:

THE EFFECT OF ROCK WOOL AND CURING ON SOME PROPERTIES OF FERROCEMENT MORTAR

Annual Project Submitted to the Department of Building and Construction Engineering of the University of Technology in Partial Fulfilment to the Requirements for a Degree of B.Sc. in Building & Construction Engineering

BY

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Abstract

In the present work, the properties of ferrocement mixtures using rock wool fibers are studied. Rock wool used as a volumetric partial replacement of fine aggregate to estimate its effect on different properties of ferrocement mixtures. The process includes using four percentages of rock wool fibers (0, 2, 4 and 6 %) with lengths (5, 10) mm. In other hand, two types of curing (water and CO_2) were used for mixtures. Compressive strength, flexural strength ,density, absorption and thermal conductivity ,for different ages (7, 14 and 28 days) have been tested.

Introduction

American concrete institution (ACI 549R)[1] defined ferrocement as a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated, in a hydraulic cement mortar matrix. An application of ferrocement in construction is vast due to the low self-weight, lack of skilled workers, no need of framework etc. It is highly versatile form of reinforced concrete, it's a type of thin reinforced concrete construction, in which large amount of small diameter wire meshes uniformly distributed throughout the cross section. Constituent materials for ferrocement are cement**,** fine Aggregate, water, admixture ,skeletal steel reinforcing mesh, and coating. Strength of ferrocement depends on two factors quality of sand/cement mortar mix and quantity of reinforcing materials used.

The most important features of ferrocement are: It's Basic raw materials are available in most countries, ease of construction, low weight and long lifetime, low construction material cost, better resistance against earthquake, it can be punctured by collision with pointed objects, it is difficult to fasten to ferrocement with bolts, screws, welding and nail, and large number of labors required. [2]

Rock wool is a general name for fiber materials that are formed by spinning or drawing molten minerals. Rock wool is a furnace product of molten rock at a temperature of about 1600 °C, through which a stream of air or steam is blown. More advanced production techniques are based on spinning molten rock in high-speed spinning heads somewhat like the process used to produce cotton candy. The final product is a mass of fine, intertwined fibres with a typical diameter of 2 to 6 micrometers. Mineral wool may contain a binder, often a terpolymer, and an oil to reduce dusting

.Applications of mineral wool include thermal insulation (as both structural insulation and pipe insulation, though it is not as fire-resistant as high-temperature insulation wool), filtration, soundproofing, and hydroponic growth medium [3].

Gambhir [4] recommended mix proportions for reference mortar of ferrocement are: sand/cement ratio of 1 : 1.5 to 2.5.So that ,the ratio of(1:2) was chosen to meet the economical and physical requirement.

Ban and Ramli [5] studied the effect of using suitable mix proportion to achieve structural grade mortar with specific strength requirement and adequate level of workability for proper placement into construction formwork. High performance mortar mix with compressive strength exceeding 55 MPa and slump level within 50-90 mm which is suitable for heavy duty ferrocement construction work was successfully developed. Moreover, data on mix proportion for several other grades of mortar mixes ranging from grade 35 to grade 55 were also derived. It was found that optimum cement: Sand ratio of structural mortar is 1:2.25. With the use of this cement: Sand ratio in the production of structural grade mortar mix in fabrication of ferrocement structural elements, consumption of cement binder will be economized hence resulting in potential savings in term of material and production cost of mortar mix in the construction industry. Besides, it was also observed that strengths of mortar mixes do not vary linearly with cement content of the mix.

Lin et al [6] investigated using various rock wool waste contents (10, 20, 30 and 40% by weight of cement) as a partial replacement for Portland cement in mortars. The results demonstrated that the pozzolanic strength activity index for rock wool waste specimens is 103% after 91 days. The inclusion of rock wool waste in cement-based composites decreases its dry shrinkage and initial surface absorption, and increases its compressive strength. These improved properties are the result of the dense structure achieved by the filling effect and pozzolanic reactions of the rock wool waste. The addition of 30% and 10% rock wool wastes to cement is the optimal amount based on the results of compressive strength and initial surface absorption for a w/cm of 0.35 and 0.55, respectively.

Ming-Gin Lee [7] conducted a study to assess the acceleration of strength development by CO_2 curing . Two mortar specimens are made with Type I Portland cement and oil-well cement . After the CO_2 curing duration and demolding , the mortar samples were assessed through the mass gain , the compressive strength, the pressure drop , the temperature rise in the curing chamber , and the microstructure characteristics . The performance of the CO_2 cured mortars was found through the measurement of pressure drop , temperature rise, strength development , mass gain and carbonation.

The objective of the research

The aim of the project is to study the effect of using CO_2 and water curing on different percentages and lengths of rock wool fiber on some properties of ferrocement mortar such as compressive strength , flexural strength , density, absorption, and thermal conductivity.

Experimental Work and Materials

Experimental Work

The mortar of ferrocement was produced using rock wool. Prisms and cubes with dimensions (160*40*40),(50*50*50) mm respectively and cylindrical mold with (45) mm in diameter and (10) mm in height have been casted .The numbers of samples casted was 278 samples for all shapes and ages. Two types of mixtures were casted with/without adding rock wool with different percentages of volumetric replacement of sand using CO_2 and water curing.

The Materials Used

1. Ordinary Portland Cement

Ordinary Portland cement (OPC) manufactured in Iraq was used for mortar mixture throughout the present work. This cement complied with the Iraqi specification IQS, No.5[8]. Also, the compounds of cement calculated according to Bogue equations, ASTM C 150[9] are listed in Table (1).

2. Sand

Natural sand (passes on sieve size No. 2.36 mm) was used as fine aggregate in all mixtures. Presence of particle size larger than 2.36 mm may cause mortar to be porous. Some properties of sand were illustrated in Table (2) and the grading was according to IQS, No.45[10] zones III and IV.

3. Rock Wool

Rock wool was used in this research as a replacement of fine aggregate in all mixes (except for reference mix). It has a yellow color and is characterized by low density. Rock wool used in this research has a cylindrical shape, with a range of the diameter from7μm to 20μm, as shown in Fig. (1).The manufacturing process includes melting of volcanic rock (Basalt) in a furnace at very high temperatures, typically 1300°C to 1500°C.After the furnace droplets of the vitreous melt are spun into fibers, droplets fall onto rapidly rotating flywheels through tiny holes in rapidly rotating spinners. This shapes it into fibers. The mineral wool is sawn to the required size and shape. The replacement was (2, 4, and 6) % as a volumetric partial replacement percentages of fine aggregate. The required quantity of rock wool was cut with lengths (5and 10) mm and it weight by sensitive scales. Tables (1) and (2) show some physical properties and chemical analysis of rock wool respectively.

Table (1) Main compounds of OPC

Main compounds	% By weight of cement	**Limits of IQS, No.5**
C3S	50.59	-
C2S	17.57	-
C3A	10.82	**>5.00**
C4AF	9.13	-

Table (2) Properties of fine aggregate

Properties	Test results	**IQS (No.45) limits**
Sulphate content SO_3 (%)	0.47	**≤ 0.5**
Specific gravity	2.8	-----
Absorption (%)	1.3	-----

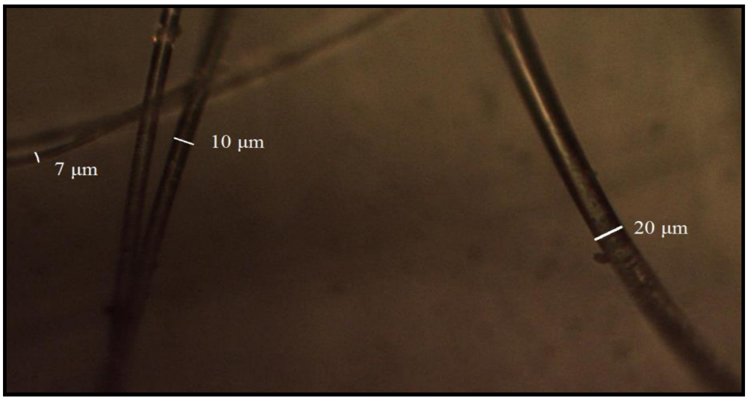

Figure (1) Diameter of rock wool

Table (3) Some physical properties of rock wool

Property	Test result
Color	Yellow
Absorption, %	< 1
Density ,kg/m³	40
Melting point ° C	> 1200
Thermal conductivity W/mK	0.04

Table (4) Chemical analysis of rock wool

Oxide composition	**% by weight**
SiO_2	50
CaO	18
MgO	8
Fe_2O_3	5
Al_2O_3	12.6
K_2O	1.2
Na_2O	3.1
TIO_2	3

Mixing, Casting, compaction and curing of cement mortar samples

First stage, Trial mixtures with varying percentages of water were made to get the normal consistency according to ASTM C230 [11]. The water cement ratio is shown in Table (5).

Second stage is mixing mortar cement mixtures of ferrocement. The ratio 1:2 was chosen to meet good economical and physical properties. Mortar specimens were prepared from mixing OPC, well-graded dry sand, rock wool and water.

Table (5) Water /Cement ratio of mortar for different rock wool percentages

rock wool percentage (%)	Water / Cement ratio		
	Reference	Length of rock wool fiber	
		5mm	10mm
0	0.35	---	---
2	---	0.37	0.35
4	---	0.375	0.395
6	---	0.385	0.4

The following mixing procedure was carried out compliance to ASTM C 305[12].

1-Add all mixing water in the bowl of the mixer.

2-Add the cement to the water and start mixing for 30 sec.

3- Add sand and rock wool at slow speed for 30 sec.

4- Stop the mixer and change for medium speed and mix for 30 sec.

5- Stop the mixer for 90 sec. During first 15 sec. scrape down into the batch any mortar and for reminder time, close the mixer enclosure or cover the bowl with the lid.

6- Finish by mixing at medium speed for 60 sec.

Three steel molds were used to cast mixtures. The first mold was with dimensions (50×50×50) mm to test compressive strength, bulk density and absorption test. The quantities of materials used for mixing is as in Table (6). The second mold was with dimensions (160×40×40) mm to test the flexural strength. The quantities of materials used for mixing is as in Table (7).The third mold was cylinder with (45) mm in diameter and (10 mm) in height for thermal conductivity.

Table (6) Quantities of materials used in mixtures (6 cubes).

Replacement by rock wool (%)	Sand (gm)	Rock wool (gm)	Cement (gm)
0	1706	0.00	648
2	1672	0.7	648
4	1638	1.4	648
6	1604	2.2	648

Table (7) Quantities of materials used in the mixing mortar (6 prisms).

Replacement by rock wool (%)	Sand (gm)	Rock wool (gm)	Cement (gm)
0	2324	0	883
2	2278	1.0	883
4	2231	2.0	883
6	2185	3.0	883

3.3.2 Casting, compaction and curing

After cleaning of steel molds, the internal faces were thoroughly oiled to avoid adhesion with the mortar after hardening .Mortar casting was carried out in two layers and each layer was compacted by using vibrating to remove the large air voids. Finally the excess mortar was removed from the top of the specimens so that to smoothen their upper surface. The molds were covered with nylon bags to prevent loss of moisture from the surface and to avoid plastic shrinkage cracking. After 24 hours, the molds were demolded. Reference mixture specimens (without rook wool) were kept in water curing tank until testing. Half of specimens (with rock wool) were cured with water and the other one cured with CO_2. All other mixtures with different percentages of replacement cured with CO_2 in carbonation chamber machine, as shown in Fig. (2). In this curing method, the samples were put in the oven for 30 minutes under 50°C. After that, the samples put in the carbonation chamber and closed it firmly. The chamber will be discharged of air then the machine starts to pump CO_2 to the chamber with a concentration of 100% CO_2 and for two hour. Then the samples were kept in plastic bags till testing date.

Fig. (2) Carbonation chamber machine

Testing Hardened Mortar

1. ***Compressive Strength Test***

Compressive strength test is carried out according to ASTM C109 [13]. Cubes of (50×50×50 mm) were tested for each mix and determination the average compressive strength. The specimens were tested at ages of 7, 14 and 28 days. The specimens are placed in the loading machine and loaded until failure as in Fig. (3). Compressive strength is then calculated as follows:

$$f\,m = P/A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

$f\,m$= compressive strength in psi or [MPa],

P= total maximum load in [N], and

A= area of loaded surface [mm^2].

2. **Flexural Strength Test**

This test was performed for prism with dimensions (40*40*160) mm at ages 7, 14 and 28 days according to ASTM C348[14]. The specimens are placed in the loading machine and loaded until failure as in Fig. (4).The average of three prisms are taken, flexural strength is then calculated as follows:

$$S_f = 0.0028\,P \qquad (2)$$

Where:

S_f = flexural strength, [Mpa], and
P = total maximum load, [N].

Fig.(3) Compressive Strength Test

Fig.(4) Flexural Strength Test

3. **Density Test**

This test was performed according to BS EN 1015-10[15]. Three cubes were tested with dimensions (50*50*50) mm at ages 7, 14 and 28 days using formula:

***ρ = m* / V…………………………………. (*3*)**

Where:

ρ = The density(kg/m³);

m = The mass of the specimen [kg];

V = The volume of the specimen [m³].

4. Thermal Conductivity

This test was performed according to ASTM C518 [16]. Two cylinder with (45) mm in diameter and (10) mm in height for thermal conductivity (λ) and thermal conductance(*C)* were tested at age 28 days. The heat flow meter apparatus establishes steady state One-dimensional heat flux was done through a test specimen between two parallel plates at constant but different temperatures, as in Fig. (5). Fourier's law of heat conduction is used to calculate thermal conductivity and thermal conductance.

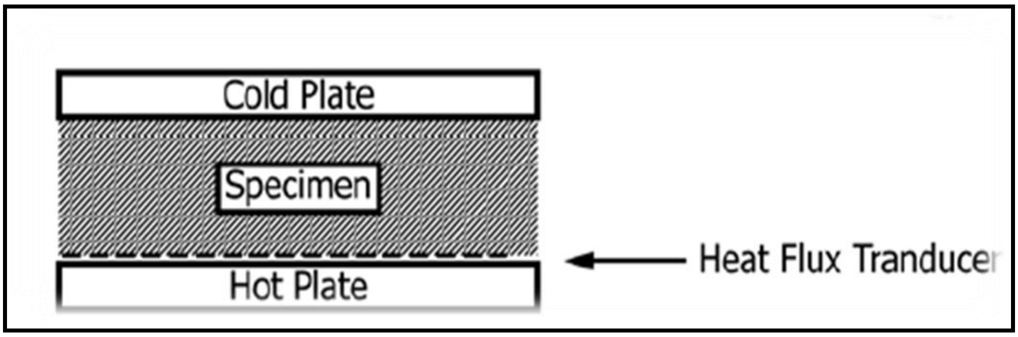

Fig. (5) Apparatus with One Heat Flux Transducer and One Specimen

5. Absorption

Three cubes with dimensions (50*50*50) mm were used to measure the absorption. The cube is dried in an oven at a temperature of 100-110°C for 24 hrs. . After removing the specimen from the oven, it is allowed to cool, weighted and designated as (A). After final drying, the specimen is immersed in tap water no less than 48 hrs. . The specimen is surface dried by removing surface moisture with a towel, and weighted and designated as (B). These cubes were tested at ages 7, 14 and 28 days using formula:

Absorption, % = [(B- A)/ A] × 100

Where:

A= mass of oven-dried specimen in air, [g]

B= mass of surface-dry specimen in air after immersion, [g]

Results and Discussion

General

The final results from the experimental work will be analyzed to show the effect using rock wool and different curing methods on ferrocement mortar.

Results

1. Bulk density

The density values of ferrocement composite at various ages using different lengths and percentages of rock wool fibers using water curing are showed in Fig. (6).

Generally, it can be seen from the results in Fig. (6) that the density of the specimens cured in water with different lengths and percentages of rock wool fiber increases with the progress of the age; this is due to the fact of the continuous hydration process. Also, the results showed that reference specimens have density value more than other specimens for all ages except for specimens with (6)% replacement and (10) mm in length.

The results indicate that for using (5mm) of fiber length, using different rock wool percentages of (2, 4 and 6)% compared with using only the natural sand as a fine aggregate in reference mixture (0% rock wool), the density is increasing until (4)% rock wool and begins to drop gradually by increasing this percentage for all ages. When using (10) mm fiber, the density is increasing until (6) %.

Generally, the percentages of increment (improvement) in density values of mixtures with (10) mm are more than for (5) mm for all percentages of replacement and ages.

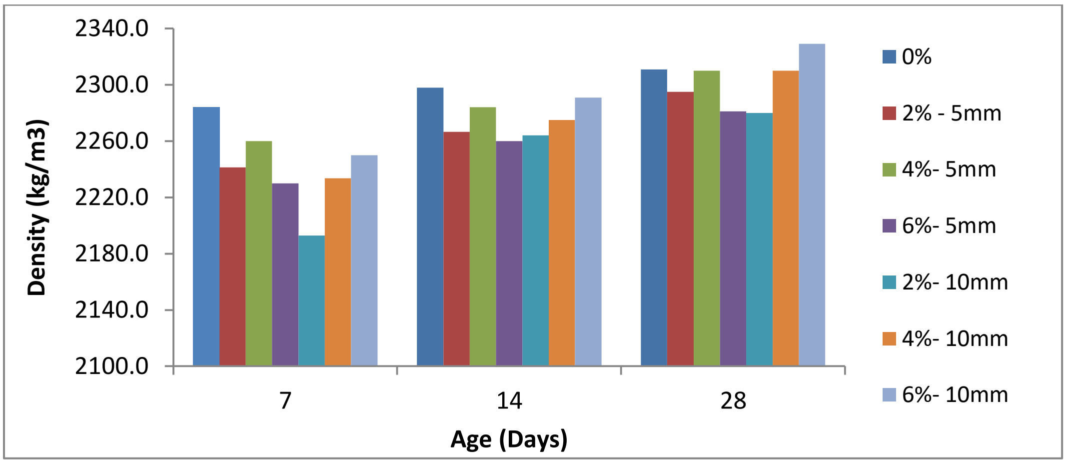

Fig. (6) The effect of rock wool on density of ferrocement mortar with water curing.

When using CO_2 curing, there were improvements in the results compared with using water curing as showed in Fig. (7).

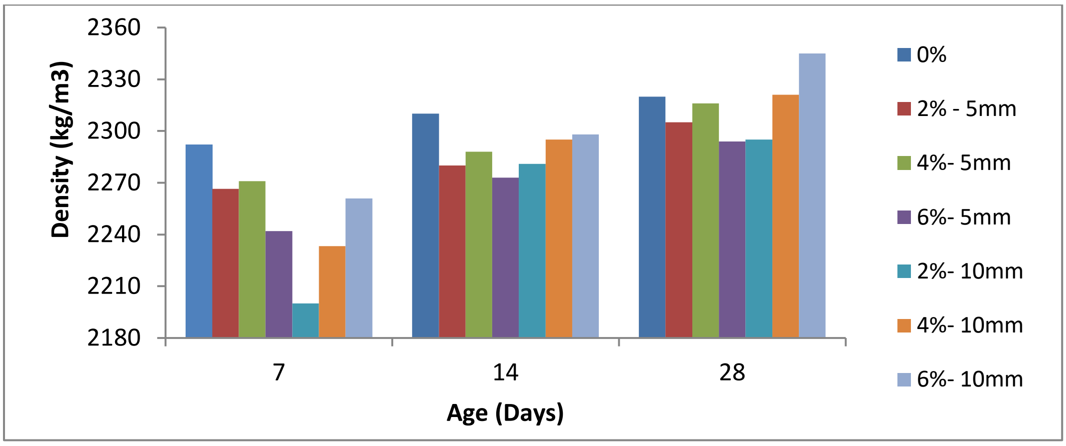

Fig. (7) The effect of rock wool on density of ferrocement mortar with CO_2 curing.

2. Compressive strength

The results in Fig.(8) indicate that compressive strength of reference specimens, which used only the natural sand as a fine aggregate and water curing are generally less than that of other specimens used the same curing for all ages.

Reference specimens results were less than specimens with (5) mm rock wool. This may be because of, at 2 % replacement, fiber work as a bridge for cracks which consequently increases compressive strength of ferrocement mortar especially for first ages. It is observed that the compressive strength of specimens with (5) mm rock wool suffer from a decrement with the increase of the rock wool percentages. This decrement may be because of conglomerate phenomena inside specimens which lead to weakness spots. For mixtures with (10) mm fiber replacement, compressive strength increased as percentages of replacement increasing until (6) %. This action may be referring to increment in the interfacial bond between the matrix and fiber which gave integrity to specimens. At (6) %, balling of fiber will make an opposite effect on compressive strength.

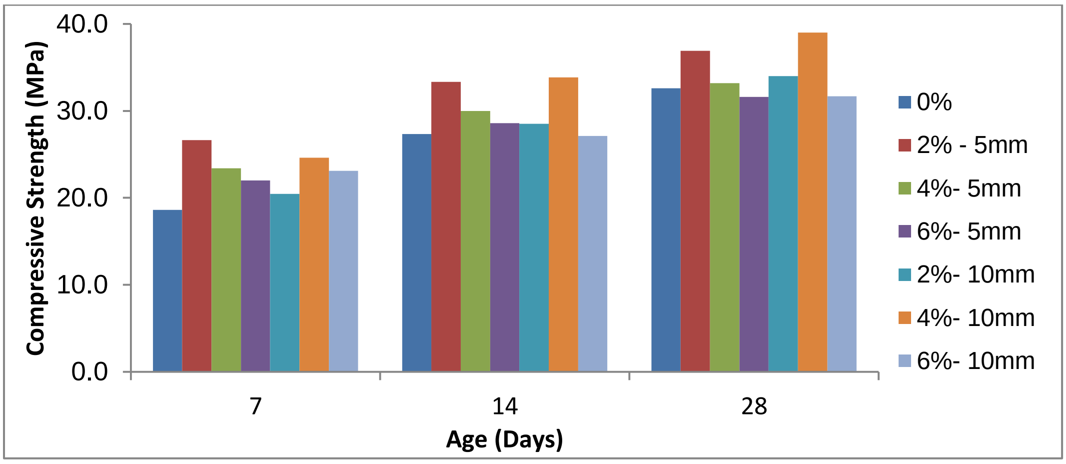

Fig. (8) The effect of rock wool on compressive strength of ferrocement mortar with water curing.

A progress was noticed in compressive strength when used CO_2 curing compared with water curing due to accelerated action of CO_2 curing, as shown in Fig.(9).

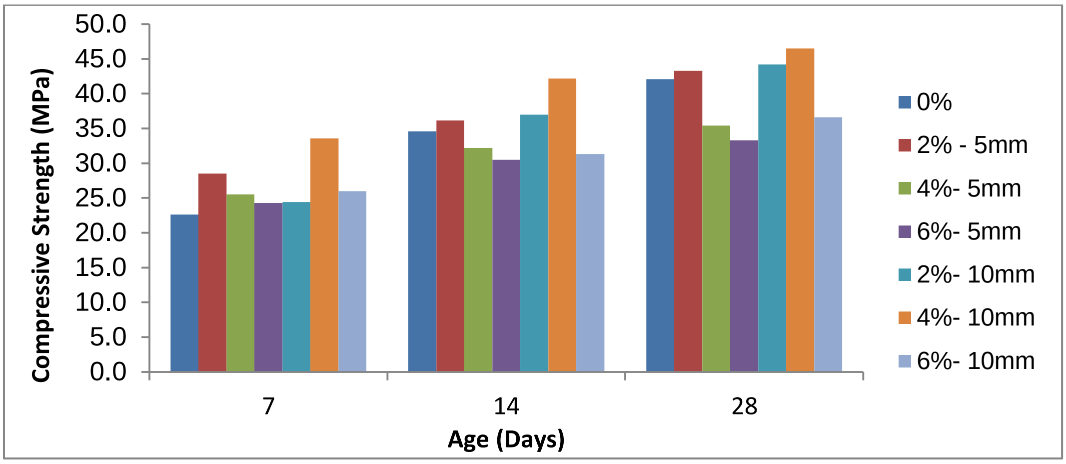

Fig. (9) The effect of rock wool on compressive strength of ferrocement mortar with CO_2 curing.

3. Flexural strength

Figure (10) show results of flexural strength testing of ferrocement mixtures at 7, 14 and 28 days with different lengths, percentages of volumetric rock wool replacement using water curing.

Specimens with (10) mm, perform considerably better than the corresponding reference and (5) mm specimens except specimens containing (4) % replacement percentages. This improvement in flexural strength may be as a result of interfacial bond between the matrix and fiber.

At percentage (4) % for both specimens with (5) and (10) mm, there are increment in the results compared with other specimens because of cracks arresting. For specimens with (5) mm the flexural strength decrease at (2) % because the little bonding force and balling at (6) %.

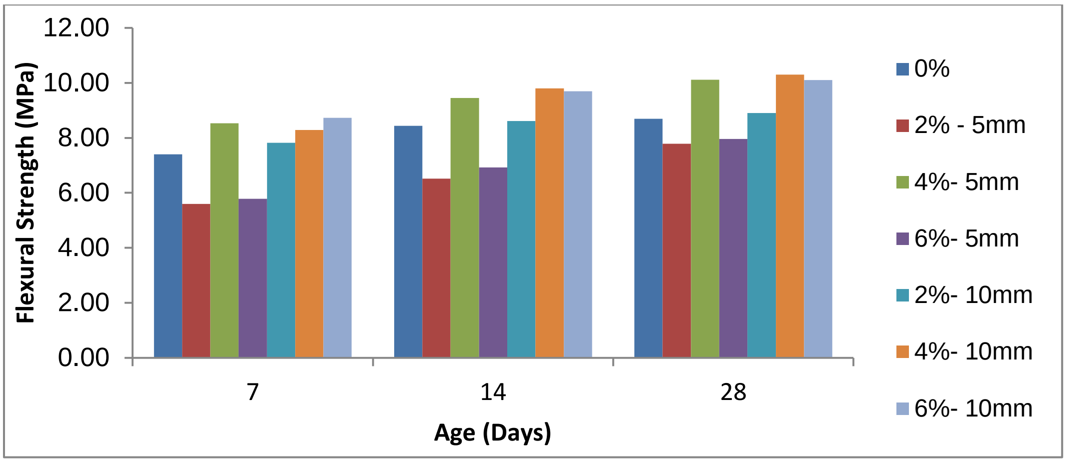

Fig. (10) The effect of rock wool on flexural strength of ferrocement mortar using water curing.

In other hand, using CO2 curing shown an impressive development in flexural strength compared with using water curing for all ages and rock wool replacement percentages, as in Fig. (11).

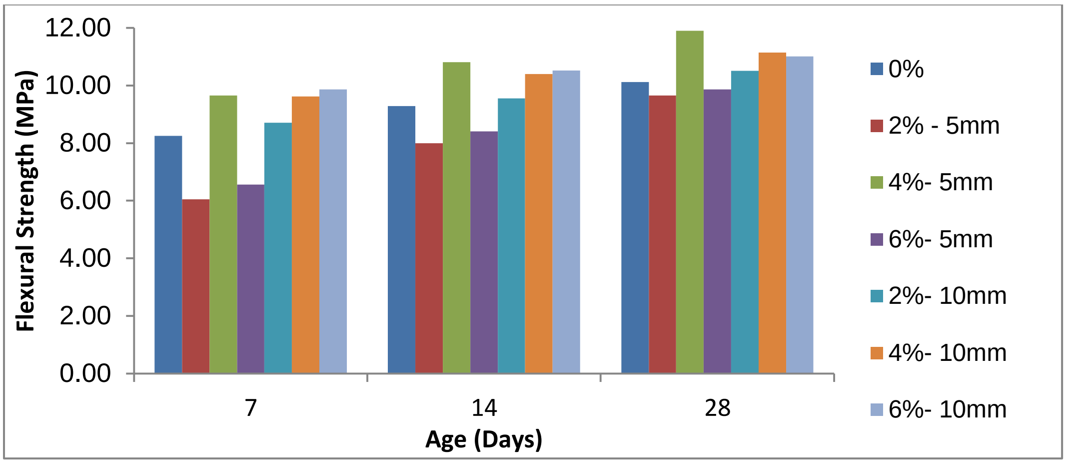

Fig. (11) The effect of rock wool on flexural strength of ferrocement mortar using CO_2 curing.

4. Thermal Conductivity

From Figures (12) and (13), it can be noticed that the thermal conductivity (**λ**) and thermal conductance(***C***) increase with the increment of length and percentage of replacement of rock wool fiber using water curing. In the same time, these values for specimens with (10) mm were slightly more than that of specimens with (5) mm. The other thing, the value of thermal conductivity of specimens with (6) % replacement, was greater than others. This behavior may goes back to the small voids inside specimens, the arresting act of fiber to cracks and the high percentage of rock wool which is an igneous rock.

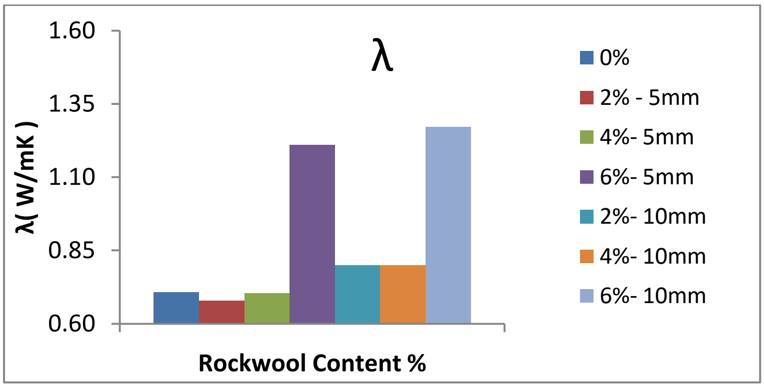

Fig. (12) The effect of rock wool on thermal conductivity of ferrocement mortar using water curing.

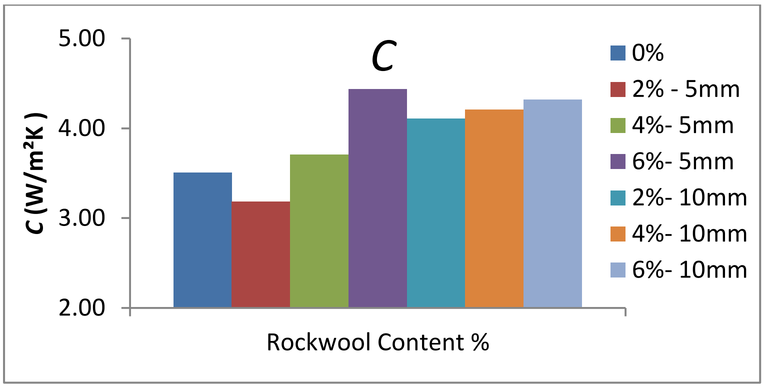

Fig. (13) The effect of rock wool on thermal conductance of ferrocement mortar using water curing.

Due to using CO_2 curing, the values of thermal conductivity and thermal conductance showed a development in the results by compared it with water curing for the same mixture, as noticed in Figs. (14) and (15) respectively.

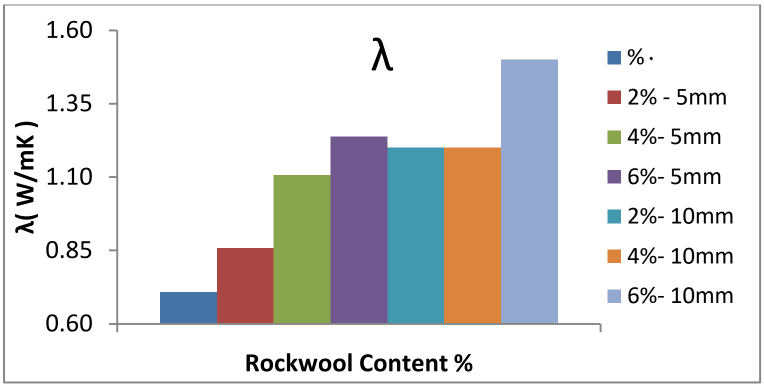

Fig. (14) The effect of rock wool on thermal conductivity of ferrocement mortar using CO_2 curing.

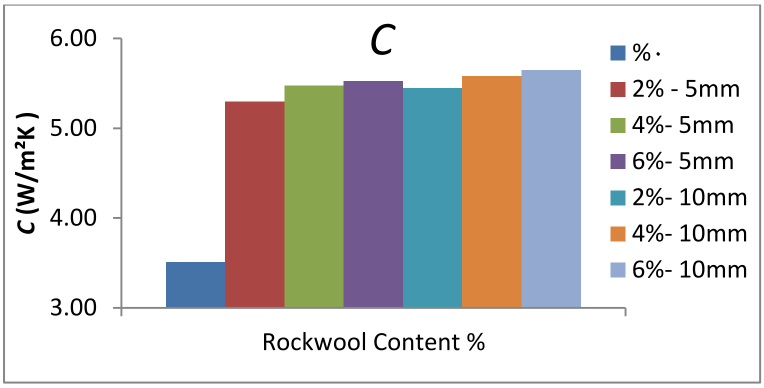

Fig. (15) The effect of rock wool on thermal conductance of ferrocement mortar using CO_2 curing.

5. Absorption

The results obtained from measuring water absorption of the ferrocement mortar specimens are shown in Fig. (16). All percentages of absorption of all specimens decrease with age because of continuity of cement hydration. Also, with water curing, it can be seen that the percentage of the absorption of reference specimens is less than other specimens with progress of the age.

The absorption percentage of (4) % for both specimens with (5) and (10) mm were the highest value among other specimens. For all mixtures, the absorption percentages increase with the increment of replacement until percentage (4) % and begin to decrease. The reason for increment of absorption may be because the increase of small, open and continuous crack from the surface of specimens.

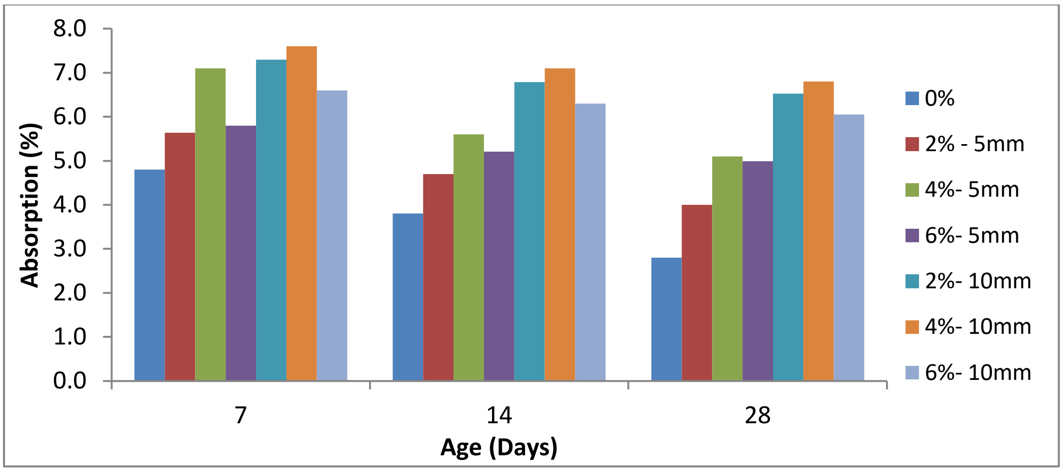

Fig. (16)The effect of rock wool on absorption of ferrocement mortar using water curing.

In same time, the properties of the ferrocement mortar showed a progress in the results when using CO_2 compared with using water curing, as shown in Fig. (17).

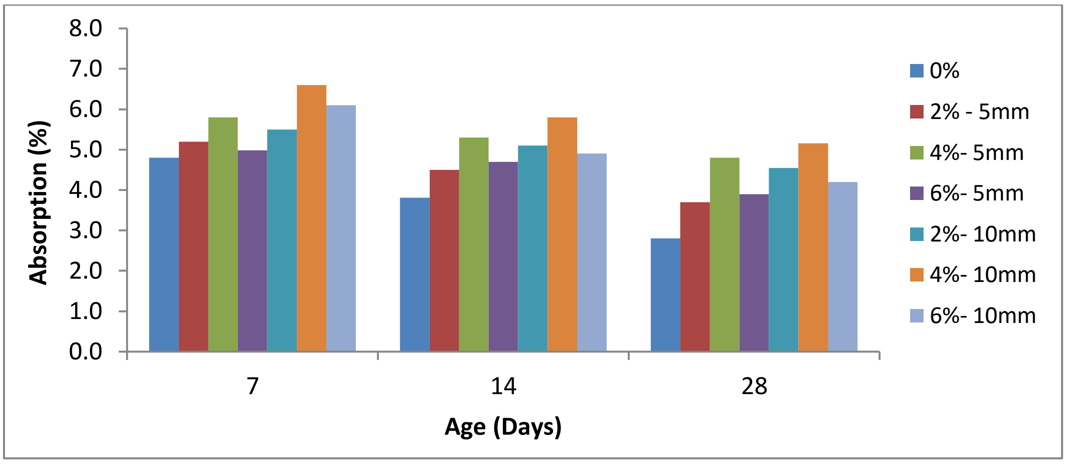

Fig. (17)The effect of rock wool on absorption of ferrocement mortar using CO_2 curing.

Conclusions

This study was performed to estimate the effect of using rock wool on different properties for composite of ferrocement mortar. Four percentages of rock wool fibers were used (0, 2, 4 and 6) %. Two lengths of fibers (5 and 10) mm were used. The investigated properties for using CO_2 and water curing were included: bulk density, compressive strength, flexural strength, thermal conductivity and absorption. Based on results presented in this study it can be concluded that:

1- Almost all mixtures of ferrocement composites have density lower than reference mixture at the same age.
2- Improvement of compressive strength for all ferrocement composites with rock wool compared with reference mixture.
3- Ferrocement composites, with (4) % replacement and fiber length (5) mm and all composites with fiber length (10) mm with all percentages (2, 4 and 6) %, have flexural strength better than reference mixture at the same age.
4- Except for ferrocement composite with (2 and 4) % replacement and (5) mm length, all results of thermal conductivity for different mixtures were more than reference mixture. In the same time, the thermal conductance for ferrocement composite with (2) % replacement and (5) mm fiber length are better than reference and other mixtures.
5- Adding rock wool fiber as a replacement of fine aggregate increased the absorption percentage for all mixtures at the same ages and reduced with the progress of age.
6- Using CO2 curing shown an impressive development in studied properties compared with using water curing for all ages and rock wool replacement percentages.

This study show the beneficial combined effect of using different percentages and lengths of residual rock wool fiber on different characteristics of sustainable composite ferrocement mortar.

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