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Preparation of insulating concrete and testing its thermal conductivity and porosity and mechanical resistance and modelling the porous medium of it

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Abstract:*Thermal insulation plays a very important role in the field of energy conservation in buildings and in saving the cost of heating and air - conditioning equipment and the fuel necessary for that.*
In the first phase of this research ,three models for concrete insolation were prepared which included in their composition cement and aluminium powder and differ from each other by adding sodium hydroxide, sodium chloride and calcium carbonate to the cement with aluminium powder, which reacts with lime located in the cement and releases hydrogen gas that leaves the dough to be replaced by air to get porous structure. In this phase, the thermal conductivity test is carried out using a thermocouple measurement device, density and porosity measurement using a sensitive balance with immersion of samples in water, and measurement of sound absorption coefficient using receiver and transmitter of vibration waves and finally conducting mechanical resistance test using pressure test application device to obtain samples of insulating concrete with low thermal conductivity $(0.1 - 0.2)\frac{W}{m.K}$ *and low pores 22.1% and with bulk densities ranging from* $(587.1 - 1185.35)\ \frac{Kg}{m^3}$ *and absorption of sound coefficient ranges from (0.269- 0.14)* cm^{-1}*,and mechanical resistance ranging from (0.9-5.89) Mpa. In the second phase: a model was provided for the study of porous media based on the fractal theory to create a relationship that identifies the effective thermal conductivity (ETC) coefficient of two samples manufactured from the same insulating material, for two different humidity degrees:* S_w *(0.291-0.313) -the obtained the ETC for the first sample was* $0.1246(\frac{W}{m.K})$*, and for the second sample: 0.1309* $(\frac{W}{m.K})$ *- and to determine the characteristic dimensions (L, C) of the modeling, the dimension of porous and the iteration number (n).*

Keyword*: AAC(Aerated Autoclaved Concrete),FC (Foamed Concrete**),The insulating materials, the cellular concrete, Sierpinski carpet, the porosity, the bulk density, fractal dimension.*

Introduction

No longer energy conservation requirements in buildings can be an omission than in light of the unlimited rise in the prices of energy sources and the burden that this brings to low - income people, in the context of the rationalization of public consumption and wastage.

the beginning was with The Swedes, to make blended cement with lime, water and sand (Sometimes plaster is added as an accelerator to harden the concrete)The Mix expands and swells by the addition of Aluminium powder where the interaction leads to the generation of Hydrogen gas which gives the bubbly gaseous structure within the concrete and this structure plays a major role in giving the concrete its insolating properties.

The issue of energy conservation in buildings has become one of the most important topics at present in order to reduce the burden on those with limited income by reducing the consumption of fuel. This is done by applying appropriate thermal insulation. Thermal insulation is defined as the use of materials that help reduce heat leakage and transfer from inside of the building to outside in winter and vice versa in summer, through walls, roofs, floors and ventilation openings.

Egyptian built pyramids using calcified gypsum, and the Romans used in the construction of amphitheatres lime resulting from stones after mixing it with sand and water to link building stones, but for underwater installations Romans resorted to mixing lime with volcanic ash or baked clay powder.

In 1828,JosephAspdinmixed lime with limestone, then the mix was dried and then grinded, baked and then refined to be the first to create Portland cement

In 1845, Isaac Johnson determined the proportions of raw materials used in construction as well as the temperature of roasting to reach the Poznan cement.

In 1929 it was the discovery of AAC (Autoclaved Aerated Concrete) by the Swedish architect and inventor Dr. Johan Axel Eriksson in cooperation with Henrik Kreüger, to produce a building material popularly used and to be spread around the world.

Later the production of AAC was slowed in Europe, while the industry is growing and flourishing in Central Asia, China, India and the Middle East, due to the increasing population density and relatively high building density.

Lightweight concrete that is saturated with gas are classified (AC) Aerated Concrete to:

- (AAC): Aerated Autoclaved Concrete
- (NAAC**)**:Non Aerated Autoclaved Concrete Also called **(FC)** Foamed concrete. Fig (1) shows the classification of gas saturated or cellular concrete**[1]**.

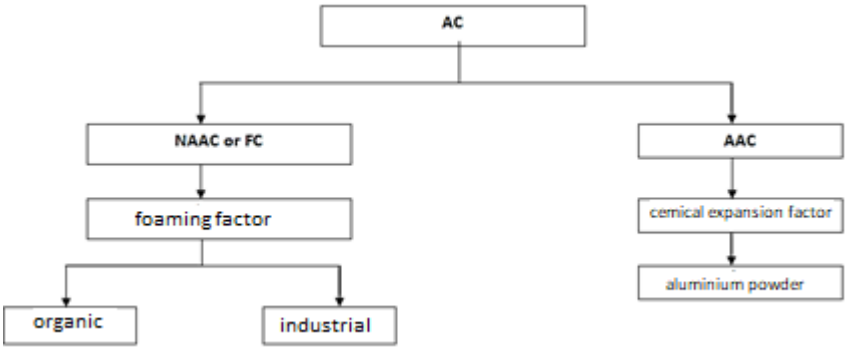

Fig.1:Methods of preparation of cellular concrete

The first checks by the interaction of aluminium powder with cement, lime and fine sand. The second by injection of foam generated in advance or entrance of foam generating agent to the cement.

The foam concrete differs from the concrete of the saturated gas processed with autoclave in factor generating voids (air pockets), because air pockets in the foam concrete form by the foam agent and this is a physical process.**[2]**

Materials and Methods

Section 1:

A. Portland cement conforming to the specification ASTMC150
B. Limestone (CaO)
C. Aluminium powder from aluminium waste.
D. Sodium Hydroxide NaOH.

E. Sodium Chloride.

F. Determination of effective thermal conductivity apparatus ETC (Effective Thermal Conductivity) located in Physics Lab - Faculty of Mechanical Engineering - University of Aleppo and using the effective thermal conductivity determination device ETC according to the standard ASTM-C177 by preparing a hot bath within a closed space and completely isolated in the form of Cuboid with square cross section its dimensions are(14.5 X 14.5) cm. It contains an electric heater to raise the internal surface temperature of the sample, which is fed through a feeder that can be set on (2,4,6,8) volt. Temperatures are taken from the time t = 0 until the temperature reading becomes stable using upper and lower sensors to measure the upper and lower surface temperatures of the sample with two displays and the measurement process continues for a period of time ranging from (45-60)min.

G. Analytical sensitive balance type Denver Instrument Form AA-200 Sensitivity 0.1mg.

H. Electric drying oven 250°C Heating Making Company (Janat).

I. Device to determine the mechanical resistance: the mechanical resistance of the samples was tested in the properties of materials laboratory at the Faculty of Mechanical Engineering, University of Aleppo using CHU-YEN apparatus brand of geared type. The maximum load of the device is 200KN and the speed of maximum progress is 500 mm / min. Anaxial pressure load has been applied to the samples in accordance with the specification ASTM E 1012 This is achieved by a moving overhead base that presses the sample from the top where the fixed bottom base is fixed, and the speed of progress has been adjusted to be 2mm / min. The data is read on a computer screen connected to the device, through which (the computer) the blueprints for the forces applied are obtained then they are converted to tables on the EXCEL software. These tables show the highest sheer strength at which the breakdown of the tested sample occurs, with strain and stress measurement for each sample. The device settings can be adjusted so that the cross section area of the sample is entered onto it the pressure force is applied. the sample is labelled to distinguish it from the rest of the samples, with controlling the unit used to measure stress (MPa -N / cm 2 -…etc.)

J. Sound wave energy measuring device (transmitter - receiver) that operates according to ISO10534-1: Sound insulation was tested in Physics Laboratory, Faculty of Mechanical Engineering,University of Aleppo. This is done by measuring the energy between the transmitter and the acoustic receiver by sending a sound wave at a certain frequency (3000kHz) then the sample is placed in front of the receiver and energy after penetration of the sample is measured, and that is conducted in the presence of Cathode-Ray Oscilloscope double band with electrical vibration generator (1-10kHz) equipped with a carbon amplifier to send acoustic waves, a microphone to receive sound waves and a metal base with a bridge to slide the amplifier and microphone. By knowing the energy of the wave before and after sample placement it is possible to calculate the sound absorption factor as we explained in advance to obtain the following results:

K. Virtual Porosity: These characteristics have been determined in accordance with the American standard ASTM-C20-00 By identifying the following values:

- Dry weight of sample **D**: The sample is weighed with a sensitive balance and is dry.
- Suspending Weight **S**: The sample is placed in the water and is boiled for two hours, then cooled to room temperature. After boiling, the sample should remain immersed in water thoroughly for a period of 12 Hr, then copper wire connects one of the arms of the sensitive balance then the wire is immersed in water and is formed in the shape of a loop and the balance is set to zero. Then the sample saturated with water is placed on the wire loop provided that they are completely submerged and then the weight **S**is determined [7].
- Saturated weight **W**: After determining the suspended weight we wipe the sample with a cotton cloth wet with water to remove the water droplets on the surface and then determine the weight **W**.

- the size **V** : Equal to the subtract of the weight of the suspension weight from saturated weight, V = W-S.

(Knowing that 1g Equal 1cm ^{3}At room temperature)

Laboratory work

The first sample:

Subject	Percentage(%)
Portland cement	84
Calcium carbonate	15
Aluminium	1

Solid components were weighed so that the total weight of the sample was 150 gr Afterthat the solid ingredients were blended well. Add water gradually until grout (cement paste) is formed with continuous manual mixing, and as a result the following reaction, gas is released according to the equation **[3]**:

$$2Al+3Ca(OH)_2+6H_2O \rightarrow 3CaO.Al_2O_3.6H_2O+3H_2$$

The sample was casted into a mold with dimensions (14.5 x 14.5) cmand with height no more than (1.5) cm, Then vibrating casting was conducted to ensure continuity of the reaction and to get two planar bases with the addition of a little sodium hydroxide solution (NaOH) of a concentration 1N to the surface of the upper sample gradually . The samples were left to dry with the addition of water after initial dryness and solidification in intermittent intervals until the final form of the sample was obtained after approximately 7 days, then it is placed in an oven at a temperature not exceeding 105 ℃ for about 6 hours .

The second sample:

Subject	Percentage(%)
Portland cement	99
Aluminium	1

The solid components of the sample were weighed so that the total weight of the sample was 150 gr according to the above ratios.weighting, blending and casting operations were completed in a similar manner to the first sample.

The Third Sample:

Subject	Percentage(%)
Portland cement	89
Sodium chloride (NaCl)	10
Aluminium	1

The solid components of the sample were weighed so that the total weight of the sample was 150 gr according to the above ratios, weighting, mixing and casting processes were performed in a similar manner to the first sample.

Results and discussion

4.1.Thermalconductivity: The thermal conductivity was tested in the physics laboratory at the Faculty of Mechanical Engineering, University of Aleppo, using the ASTM-C177 effective thermal conductivity detection device by preparing an indoor heated bath with an electric heater to raise the internal surface

temperature of the sample, Feeding The measurement process continues for a period of time ranging from min (45-60).

In order to calculate the difference between $\theta_1 \text{and} \theta_2$, which represent the upper and lower temperatures,The thermal conductivity from the apparatus is determined by calculating the difference between $\theta_1 and\ \theta_2$which represent the temperature of the upper and lower sensors. From Fourier's law:

$$Q = k.A.\frac{\Delta\theta}{L} \qquad (1)$$

Where

Q: thermal flow is estimated by [W]

θ: is the difference between the temperature of the surface of the two samples is estimated by [$K°$]

k: Thermal conductivity coefficient estimated by [$\frac{\text{W}}{\text{m}.K°}$]

A: sample surface area is estimated by [m^2]

L: The thickness of the sample is estimated by [m]

Thermal flow is calculated using the relationship:

$$Q = V \times I \qquad (2)$$

V: The feeding voltage is estimated by [V] (voltage) and is applied at 8V

I: The current strength is estimated at [A] (ampere) and applied at 1.1A

$$8.8 = \frac{k(14.6)^2 \times 10^{-4} \times (24)}{1 \times 10^{-2}} \Rightarrow k = 0.167\frac{W}{m.K}$$

Error in measuring thermal conductivity:

$$\frac{\Delta k}{k} = \frac{\Delta V}{V} + \frac{\Delta I}{I} + \frac{\Delta X}{X} + \frac{\Delta\theta_1}{\theta_1} + \frac{\Delta\theta_2}{\theta_2}$$

$$\Delta V = 0.025 Volt$$

$$, \Delta I = 0.025\ A, \Delta X = 0.5\ \text{mm}, \Delta\theta_1 = 0.5\ ℃ \Delta\theta_2 = 0.5\ ℃$$

$$k = (0.167 \pm 0.0164)\frac{W}{m.K}$$

Thus the thermal conductivity determined for the second and third samples with calculating the committed error in the same way according to the following table (1), which shows the dimensions of the sample, the temperature groups and the heat transfer coefficient of the prepared samples:

Table(1):Thermal transfer coefficient of samples prepared

sample	$\boldsymbol{A \times 10^{-4}(\text{m}^2)}$	$\boldsymbol{L \times 10^{-2}(\text{m})}$	$\boldsymbol{\Delta\theta}$	$\boldsymbol{k \pm \Delta k}$ $(\boldsymbol{\frac{W}{m.K}})$
1	$(14.8)^2$	1	24	0.167 ± 0.0164
2	$(13.4)^2$	1.25	37.3	0.163 ± 0.0131
3	$(14.5)^2$	1.1	31.7	0.145 ± 0.01241

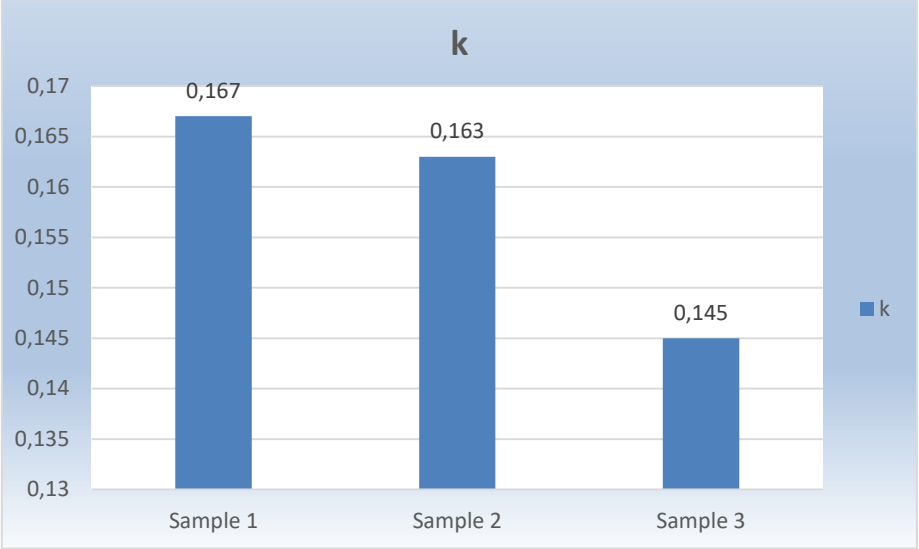

Fig.2:Thermal transfer coefficient of the three samples

4.2.Apparentporosity-thebulk density: After conducting the measurements on the next three prepared samples**:**

Porosity ϕ% :ϕ = {(W.D) / V} x100
Percentage of absorbed water **A**: A = {(W.D) / D} x100
Bulk Density B: B (g / cm3) = D / V

$$V_1 = 18.37 - 5.46 = 12.91$$

$$\phi_1 = \frac{18.37 - 16}{12.91} \times 100 = 18.3\%$$

$$A_1 = \frac{18.37 - 16}{16} \times 100 = 14.8\%$$

The results are summarized according to Table (2):

Table(2): The measured weights of the three samples

sample	Dry weight D (g)	Suspended Weight S (g)	Saturated weight W (g)
1	15.325	5.26	18.1875
2	14.41	6.785	31.315
3	21.125	6.205	31.89

Table(3):Porosity results and percentage of average absorbed water

sample	Porosity P%	Volume V(cm^3)	Bulk density B ($\frac{Kg}{m^3}$)	Apparent Specific weight T	Percentage of water absorbed A
1	22.1	12.927	1185.35	1.5335	18.85
2	68.9	24.53	587.1	1.9465	117.575

3	41.8	25.685	823.7	1.412	50.9

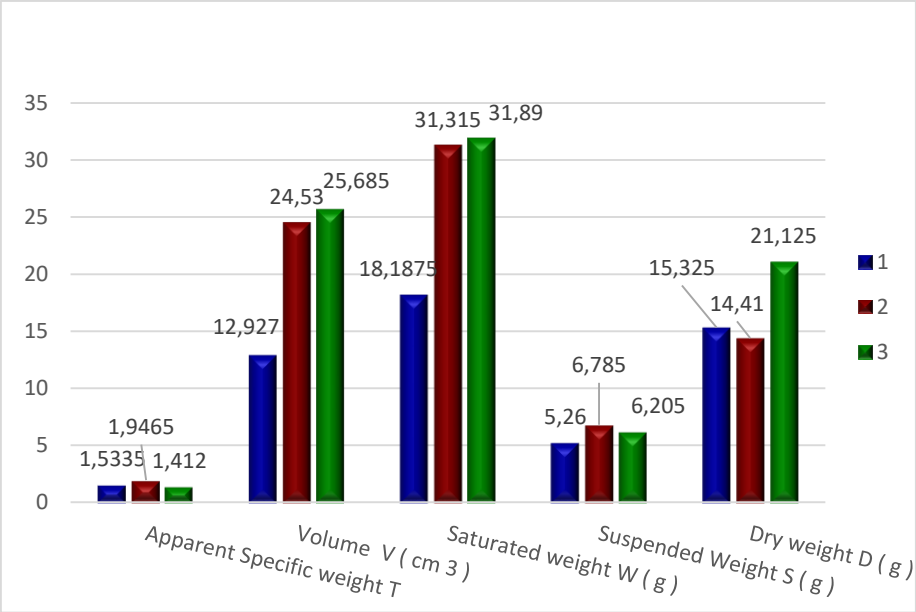

Fig3:apparent porosity and the proportion of absorbed water

First of all from Fig (2), which shows the change of the thermal conductivity of the samples, the greatest value of the thermal conductivity was for sample (1) which record $0.167\left(\frac{W}{m.K}\right)$. This means that it has the least insolation (in comparison with the other two samples) and this sample is composed of mixture of aluminium, cement and calcium carbonate without any other additives, and the porosity have reached 22.1 % At the same time , it recorded the lowest value of water absorption 18.85 % . This means obtaining a heat and moisture insulating material at the same time as described in Fig (3).

It should be noted that this sample was prepared from aluminium and cement with the addition of calcium carbonate, which helped to give a more solid form of the sample, the addition of alkali solution on the surface during the vibration casting helped to continue the interaction and the release of gas and obtaining suitable porosity which achieved good insulation.

Sample (2) prepared from cement and aluminium powder achieved average thermal conductivity$0.163(\frac{W}{m.K})$ with high porosity of 68.9% and large absorption of moisture 115.575 %.

With respect to the sample (3) The average values were recorded relative to the other two samples (1,2) The average Porosity has reached 41.8 % with relatively low thermal conductivity $0.145(\frac{W}{m.K})$

But they recorded a relatively high value of absorbed water 50.9 % This means lower performance in terms of moisture insulation with noticing that this sample was prepared from the cement with aluminium powder and sodium chloride, which leads to the occurrence of an additional interaction. Then the sample is washed with water to remove sodium chloride. Returning to Fig (3) we note that the density is correlated to the thermal conductivity where the higher the density the lower the thermal conductivity.

4.3.Soundinsulation: The following table shows the results of the sound absorption coefficient:

Table(4):Results of sound absorption coefficient

Sample number	Section space A (cm^2)	Sample thickness (cm)	Frequency (kHz)	Total wave energy (v)	Absorbed Wave Energy (v)	$(\frac{E}{E_0})$	$\ln\frac{E}{E_0}$	Sound absorption coefficient (cm^{-1})
1	0.6 × 0.6	0.9	3000	1.4	1.2	0.857	-0.154	0.171
2	0.6 × 0.6	1.25	3000	1.4	1	0.71	-0.336	0.269
3	0.6 × 0.6	1.1	3000	1.4	1.2	0.857	-0.154	0.14

$$E = E_0 . e^{-\alpha X} \qquad (3)$$

X:The thickness of the sample
α:Sound absorption coefficient
E:The energy of the wave absorbed
E_0: Total trans-wave energy

Returning to the table (4) we note that the highest value of the sound absorption factor is for the second sample to be 0.269. This is explained by the higher porosity of this sample, in which air occupies most of the volume, while the absorption of sound coefficient of the remaining two samples is reduced, therefore it is possible to use sample (2) as a good sound insulator in construction work.

4.4.Mechanicalresistance:
The law of stress (Mechanical resistance):

$$\sigma = \frac{F}{A} \qquad (4)$$

σ: represents stress (mechanical resistance) [N/m^2]
F: represents the applied mechanical force [N]
A: represents the area of the section to which the force applies [m^2]

Table (5):Results of mechanical resistance of the three samples

Sample number	Medium mechanical resistance (Mpa)
1	5.8925
2	0.7876
3	0.9094

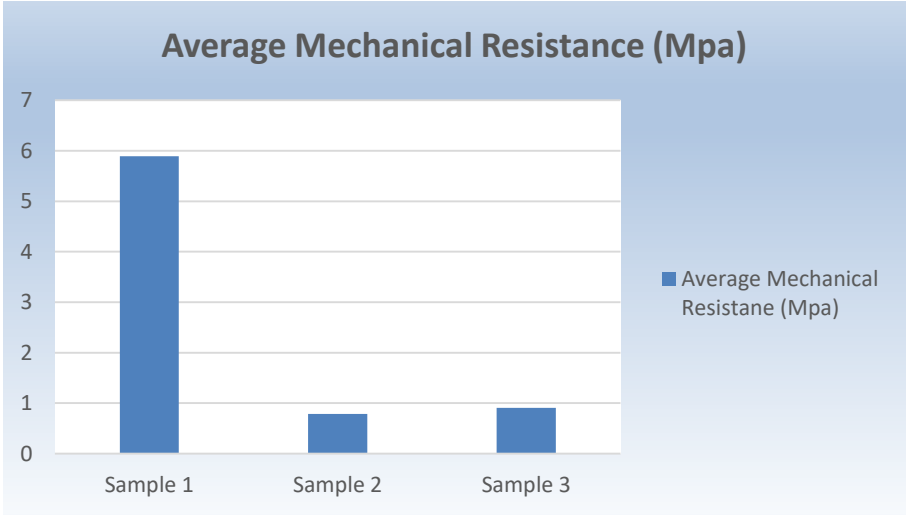

Fig.4:mechanical resistance

It is noted from Fig (4) that the first sample has the high mechanical resistance where it is manufactured from the addition of calcium carbonate to the mixture of aluminum powder and cement with a little solution of sodium hydroxide during the casting and this improves mechanical resistance.

4.5.Section 2: Modeling the porosity of the insulating material

The fractal theory is used to describe existing tools and elements of an anarchic nature that are irregular in shape and dimensions and thus difficult to determine according to Euclidean geometry**[4]**. One of the forms of this fractional theory is the Sierpenski Carpet, which is based on the division of the porous medium into unitary square cells characterized with side length L that are centered by an inner square its side length is C. This division can be repeated number of times within each single square cell until the desired objective is achieved which is achieving the characteristics of this porous medium for the highest degree of accuracy.

Where the white areas refer to the pores, while the dark areas represent the mother solid mater and the simplest case (Fig(5)) of this representation is assuming that L = 3 and C = 1 [5].

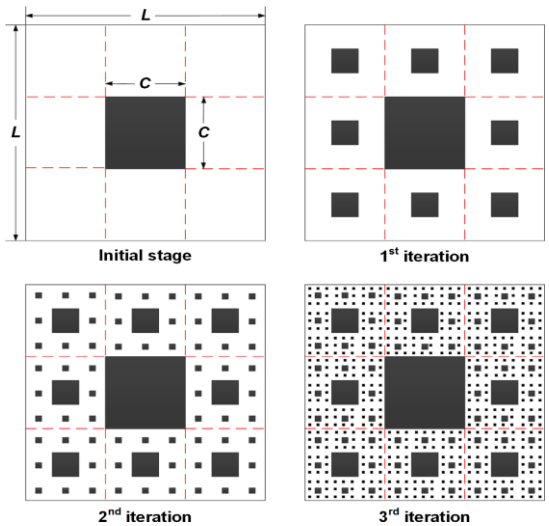

Fig .5: illustrates the study of the porous medium according to the fractal model (Sierpinski carpet) [5]

The fractional dimension is calculated according to **[5]**depending on the following relationship:

$$D_f = \frac{\ln\ (L^2 - C^2)}{\ln L} \qquad (4)$$

As porosity represents the ratio between the area occupied by dark areas and the total area of the carpet, and also according to Feng, porosity is determined by the relationship:

$$\phi = \left(\frac{L^2 - C^2}{L^2}\right)^{n+1} \qquad (5)$$

A number of thermal resistors represented by the matrix (solid) and air bubbles (two-phase medium, dry state) were obtained by repeated representation of iteration (n). This is shown in Fig (6) as follows:

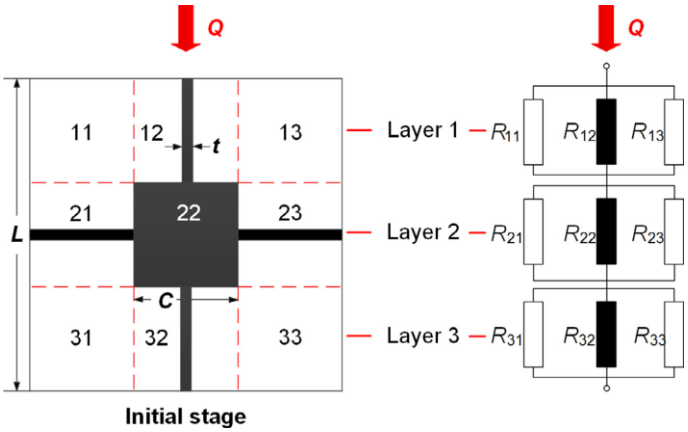

Fig .6: represents the thermal resistors in the case of a two-phase medium

The dark zones in the real medium are interconnected, which means an additional effect on the thermal conductivity through the thermal resistors represented by internal thermal conductivity conductors (thickness t).

In[4]presented the relationship that governs fractal geometry:

$$M(L) \sim L^{D_f} \qquad (6)$$

Where M (L) can represent the length of a line, surface area, cube size, or block object.
In case L = 13, C = 5 (Fig(7)) the modeling becomes asfollows [6]:

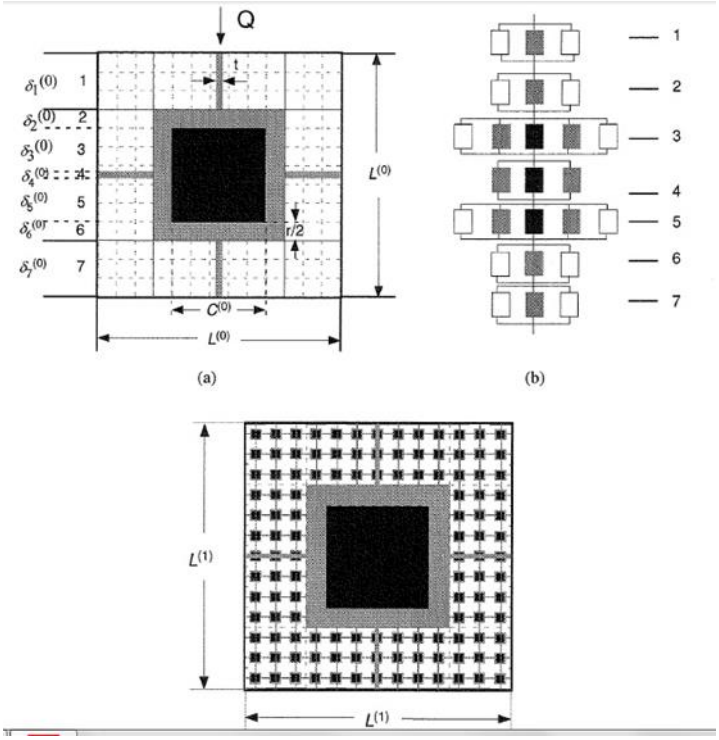

Fig .7: Sierpinskicarpet according to [6]

The contact resistance between molecules consists of two parts:

- The wet phase surrounding solid particles with r / 2 thickness
- Wet phase represented by thick barriers t

The wet phase includes: S_{wsp} where wsp represents the wet phase surrounding the molecules, while S_{wb} is the content of the barriers where wb indicates the depth of the wet phase in the barrier.
w refers to the wet phase; p refers to the pore phase.

$$S_w{}^{(0)} = S_{wsp}{}^{(0)} + S_{wb}{}^{(0)} \qquad (7)$$

$$S_{wsp}{}^{(0)} = \frac{V_{wsp}}{V_p} = \frac{\left(r^{(0)} + C^{(0)}\right)^2 - C^{(0)2}}{L^{(0)2} - C^{(0)2}} = \frac{L^{(0)2}}{L^{(0)2} - C^{(0)2}}\left[\left(r^{(0)+} + \frac{C^{(0)}}{L^{(0)}}\right)^2 - \left(\frac{C^{(0)}}{L^{(0)}}\right)^2\right]$$

$$S_{wb}{}^{(0)} = \frac{V_{wb}}{V_p} = \frac{4t^{(0)}\left(\frac{L^{(0)} - C^{(0)} - r^{(0)}}{2}\right)}{L^{(0)2} - C^{(0)2}} = \frac{L^{(0)2}}{L^{(0)2} - C^{(0)2}} \cdot 2t^{(0)+} \cdot \left(1 - \frac{C^{(0)}}{L^{(0)}} - r^{(0)+}\right)$$

Where $r^{(0)+} = \frac{r^{(0)}}{L^{(0)}}$ and the non-dimensional thickness of the barrier

Where $t^{(0)+} = \frac{t^{(0)}}{L^{(0)}}$ and represents thenon-dimensional thickness of the wet phase

In order to repeat (n) times we write:

$$S_{wsp}{}^{(n)} = \frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2} - C^{(n)2}}\right)^{n+1} - 1\right]\left[\left(\frac{r^{(n)}}{L^{(n)}} + \frac{C^{(n)}}{L^{(n)}}\right)^2 - \left(\frac{C^{(n)}}{L^{(n)}}\right)^2\right] \quad (8)$$

$$S_{wb}{}^{(n)} = \frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2} - C^{(n)2}}\right)^{n+1} - 1\right]\left[2t^{(n)+} \cdot \left(1 - \frac{C^{(n)}}{L^{(n)}} - r^{(n)+}\right)\right] \quad (9)$$

In this simulation, for t = 0, we get an excellent connection between the molecules

$$\frac{1}{R_1^{(0)}} = \frac{1}{R_{11(g)}^{(0)}} + \frac{1}{R_{1t}^{(0)}} + \frac{1}{R_{11(g)}^{(0)}} = \frac{2}{R_{11(g)}^{(0)}} + \frac{1}{R_{1t(w)}^{(0)}}$$

$$\frac{1}{R_1^{(0)}} = 2\frac{\frac{L^{(0)}-t^{(0)}}{2}.k_g}{\frac{L^{(0)}-C^{(0)}-r^{(0)}}{2}} + \frac{t^{(0)}.k_w}{\frac{L^{(0)}-C^{(0)}-r^{(0)}}{2}}$$

$$\frac{1}{R_2^{(0)}} = \frac{2k_g\frac{L^{(0)}-C^{(0)}-r^{(0)}}{2}}{\frac{r}{2}} + \frac{k_w(C^{(0)}+r^{(0)})}{\frac{r}{2}}$$

$$\frac{1}{R_3^{(0)}} = \frac{2k_g\frac{L^{(0)}-C^{(0)}-r^{(0)}}{2}}{\frac{C^{(0)}-t^{(0)}}{2}} + \frac{2k_w\frac{r^{(0)}}{2}}{\frac{C^{(0)}-t^{(0)}}{2}} + \frac{k_s.C^{(0)}}{\frac{C^{(0)}-t^{(0)}}{2}}$$

$$\frac{1}{R_4^{(0)}} = \frac{2k_w\frac{L^{(0)}-C^{(0)}-r^{(0)}}{2}}{t^{(0)}} + \frac{2k_w\frac{r^{(0)}}{2}}{t^{(0)}} + \frac{k_s.C^{(0)}}{t^{(0)}}$$

$R_5^{(0)} = R_3^{(0)}$ و $R_6^{(0)} = R_2^{(0)}$ و $R_7^{(0)} = R_1^{(0)}$

$$R_{sc}^{(0)} = R_1^{(0)} + R_2^{(0)} + \cdots + R_7^{(0)}$$

$$R_{sc}^{(0)} = \frac{1}{k_g}\left\{\frac{1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}}{\left[(1-t^{+})+\beta_{wg}{}^{(0)}.t^{+}\right]} + \frac{r^{(0)+}}{\left(1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{wg}{}^{(0)}\left(\frac{C^{(0)}}{L^{(0)}}+r^{(0)+}\right)} + \frac{\frac{C^{(0)}}{L^{(0)}}-t^{(0)+}}{\left(1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{wg}{}^{(0)}r^{(0)+}+\beta_{sg}.\frac{C^{(0)}}{L^{(0)}}} + \frac{t^{(0)+}}{\left[\beta_{wg}{}^{(0)}\left(1-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{sg}.\frac{C^{(0)}}{L^{(0)}}\right]}\right\} \quad (10)$$

$$k_{e,sc}^{+(0)} = \frac{k_{e,sc}^{(0)}}{k_g} = \frac{L^{(0)}}{R^{(0)}.A^{(0)}.k_g} \quad (11)$$

$$A^{(0)} = L^{(0)} \times 1$$

$$k_{e,sc}^{+(0)} = \left\{\frac{1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}}{\left[(1-t^{(0)+})+\beta_{wg}{}^{(0)}.t^{(0)+}\right]} + \frac{r^{(0)+}}{\left(1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{wg}{}^{(0)}\left(\frac{C^{(0)}}{L^{(0)}}+r^{(0)+}\right)} + \frac{\frac{C^{(0)}}{L^{(0)}}-t^{(0)+}}{\left(1-r^{(0)+}-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{wg}{}^{(0)}r^{(0)+}+\beta_{sg}{}^{(0)}.\frac{C^{(0)}}{L^{(0)}}} + \frac{t^{(0)+}}{\left[\beta_{wg}{}^{(0)}\left(1-\frac{C^{(0)}}{L^{(0)}}\right)+\beta_{sg}{}^{(0)}.\frac{C^{(0)}}{L^{(0)}}\right]}\right\}^{-1} \quad (12)$$

$$k_{e,sc}^{+(1)} = \frac{k_{e,sc}^{(1)}}{k_g} \quad (13)$$

$$\beta_{wg}{}^{(1)} = \frac{\beta_{wg}{}^{(0)}}{k_{e,sc}^{+(0)}}$$

$$\beta_{sg}{}^{(1)} = \frac{\beta_{sg}{}^{(0)}}{k_{e,sc}^{+(0)}}$$

to repeat n times we write:

$$k_{e,sc}^{+(n)} = k_{e,sc}^{+(n-1)} \left\{ \frac{1 - r^{(n)+} - \frac{C^{(n)}}{L^{(n)}}}{\left[(1 - t^{(n)+}) + \beta_{wg}{}^{(n)}.t^{(n)+}\right]} + \frac{r^{(n)+}}{\left(1 - r^{(n)+} - \frac{C^{(n)}}{L^{(n)}}\right) + \beta_{wg}{}^{(n)}\left(\frac{C^{(n)}}{L^{(n)}} + r^{(n)+}\right)} + \frac{\frac{C^{(n)}}{L^{(n)}} - t^{(n)+}}{\left(1 - r^{(n)+} - \frac{C^{(n)}}{L^{(n)}}\right) + \beta_{wg}{}^{(n)} r^{(n)+} + \beta_{sg}{}^{(n)}.\frac{C^{(n)}}{L^{(n)}}} + \frac{t^{(n)+}}{\left[\beta_{wg}{}^{(n)}\left(1 - \frac{C^{(n)}}{L^{(n)}}\right) + \beta_{sg}{}^{(n)}\frac{C^{(n)}}{L^{(n)}}\right]} \right\}^{-1} \qquad (14)$$

$$\beta_{wg}{}^{(n)} = \frac{\beta_{wg}{}^{(0)}}{k_{e,sc}^{+(n-1)}}$$

$$\beta_{sg}{}^{(n)} = \frac{\beta_{sg}{}^{(0)}}{k_{e,sc}^{+(n-1)}}$$

The test is carried out on two new isolates (the same as the first sample at the beginning of the research in section 1). They include one chemical structure, cement, aluminum boron and calcium carbonate.

The samples were moistened by manual spraying and immersion to obtain two different hydrations for the two samples and measured the weights of samples before wetting m_m and after wetting m_d, to calculate water weight m_d and then calculated the degree of saturation as follows:

$$S_w = \frac{V_w}{V_p} = \left(\frac{\rho}{\rho_w}\right)\left(\frac{c}{\phi}\right) \qquad (15)$$

Since c is the moisture content and is calculated from the equation:

$$c = \frac{m_w}{m_d} \qquad (16)$$

Where the mass of water is calculated from the relationship:

$$m_w = m_m - m_d \qquad (17)$$

Where ρ is the bulk density of samples and is calculated according to ASTM-C177 and ρ_w is the water density $\rho_w = 998\ kg/m^3$ for the temperature of 22℃, the porosity is also calculated according to ASTM-C177.

Table (6): Stages of calculation of the degree of saturation

	m_m g	m_d g	m_w g	C (m_w/m_d)	ρ Kg/m³	ρ_w Kg/m³	ρ/ρ_w	S_w	ϕ
Sample1	248	181.083	66.92	0.370	552.600	998.000	0.554	0.7028	0.291
Sample2	'194	138.85	55.15	0.397	554.000	998.000	0.555	0.705	0.313

The fractal dimension D_f was calculated according to reference [**7**] by studying the volume and weight distribution of the particles in the samples to determine the fracture dimension, where the dry cement particles are sifted within different diameters. The fractional dimension is calculated using the following relationship:

$$D_f = -\frac{\ln\left[\frac{M(r>R_i)}{M_T} * \left(\frac{R_{max}}{R_i}\right)^3\right]}{\ln(\frac{R_i}{R_{max}})} \qquad (18)$$

$M(r > R_i)$: represents the percentage of cumulative weight in each sieve (g)

R_i: is the mean diameter of the volumetric distribution class (the mean of the larger sieve and the smaller sieve)

R_{max}: indicates the maximum diameter between all sieves.

Considering that:

$$R_{min} = \frac{C}{\left(\frac{L-C}{2L}\right)^n} \quad , R_{max} = C$$

By combining equations, we get:

$$\frac{R_{max}}{R_{min}} = \frac{1}{\left(\frac{L-C}{2L}\right)^n} (19)$$

Solving equation (19) with equations (4) and (5) using MATLAB, obtained L,C,n as follow:

Table (7): Experimental L, C, n values for the Sierpenski carpet

	ϕ	D_f	R_{max}/R_{min}	L	C	n	S_w
Sample 1	0.7028	2.34	32	0.7902	0.2192	3.4	0.291
Sample 2	0.705	2.38	32	0.8118	0.2241	3.41	0.313

Table (8): The degree of moisture saturation and the experimental thermal conductivity of each sample

Sample	$A \times 10^{-4}(m^2)$	$L \times 10^{-2}(m)$	$\Delta\theta$	$k_{pra}(\frac{W}{m.K})$
1'	$(14.8)^2$	0.9	29	0.12465
2'	$(14)^2$	0.7	24	0.1361

The thermal conductivity was tested in the physics laboratory at the Faculty of Mechanical Engineering, University of Aleppo, using the ASTM-C177 effective thermal conductivity detection deviceas mentioned above.

In order to correlate the theoretical values to the experimental, we adopt the experimental constant $\frac{S_{wsp}}{S_w} = cn$, by substituting the empirical constant as follow:

$$r^{(n)+} = \sqrt{\frac{cn.S_W}{\frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2}-C^{(n)2}}\right)^{n+1}-1\right]} + \frac{C^{(n)2}}{L^{(n)2}} - \frac{C^{(n)}}{L^{(n)}}}$$

$$= \sqrt{\frac{cn.S_W}{\frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2}-C^{(n)2}}\right)^{n+1}-1\right]} + \frac{C^{(n)2}}{L^{(n)2}} - \frac{C^{(n)}}{L^{(n)}}} \qquad (20)$$

$$t^{(n)+} = \frac{4cnS_w}{2\frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2}-C^{(n)2}}\right)^{n+1}-1\right]\cdot\left(1-\frac{C^{(n)}}{L^{(n)}}-r^{(n)+}\right)}$$

$$= \frac{4cnS_w}{2\frac{L^{(n)2}}{C^{(n)2}}\left[\left(\frac{L^{(n)2}}{L^{(n)2}-C^{(n)2}}\right)^{n+1}-1\right]\cdot\left(1-\frac{C^{(n)}}{L^{(n)}}-r^{(n)+}\right)} \qquad (21)$$

By compensating the values of thermal conductivity in k_s, k_g and k_w at 22°C, we write:

$$\beta_{wg}{}^{(0)} = \frac{k_w}{k_g} = \frac{0.6}{0.024} = 25$$

$$\beta_{sg}{}^{(0)} = \frac{k_s}{k_g} = \frac{0.29}{0.024} = 12.08$$

As we mentioned above, we obtain $r^{(n)+}$ and $t^{(n)+}$ using experimental constant value ranging from 0 to 1 and by substituting the values of $\beta_{wg}{}^{(0)}$ and $\beta_{sg}{}^{(0)}$ in equation (24) for the repetition values n and by inserting a loop for $\beta_{wg}{}^{(n)}$ and $\beta_{sg}{}^{(n)}$ in the matlab program and taking into account that the calculated thermal conductivity of the program is non-dimensional and the thermal conductivity coefficient obtained from the device is dimensional, therefore the coefficient of the calculated thermal conductivity coefficient of $k_{e,sc}^{+(n)}$ from equation (24)) with $k_g = 0.024\,\frac{W}{m.K}$ leads us to the theoretical thermal conductivity $\boldsymbol{k_{theo}}$(theory) as indicated in the following table:

Table (9): The thermal and theoretical thermal conductivity of each sample

	k_{theo}(Theory) $(\frac{W}{m.K})$	K_{pra}(Exp.) $(\frac{W}{m.K})$	Difference %
Sample 1	0.1281	0.1246	2.66
Sample 2	0.1361	0.1309	3.78

Note from Table (3) that the difference between the theoretical and experimental values is due to the following reasons:

a) Measurement errors of the device when determining thermal conductivity coefficient:

$$P = V \times I = k.A.\frac{\Delta T}{L} = k.A.\frac{(\theta_1 - \theta_2)}{L}$$

$$\frac{\Delta k}{k} = \frac{\Delta V}{V} + \frac{\Delta I}{I} + \frac{\Delta X}{X} + \frac{\Delta \theta_1}{\theta_1} + \frac{\Delta \theta_2}{\theta_2}$$

$$\Delta V = 0.025\ \text{V}, \Delta I = 0.025\ \text{A},\ \Delta X = 1\ \text{mm}, \Delta \theta_1 = 0.5\ ℃$$

$$\Delta \theta_2 = 0.5\ ℃$$

$$\frac{\Delta k}{0.1246} = 0.0805 \Rightarrow \Delta k = 0.01003 \frac{\text{W}}{\text{m. K}}$$
$$\frac{\Delta k}{0.1309} = 0.0805 \Rightarrow \Delta k = 0.0105 \frac{\text{W}}{\text{m. K}}$$

Table (10): Measurement errors of the device when determining thermal conductivity coefficient

	$k_{pra}\ (\frac{W}{m.K})$	$\pm\Delta\ k_{pra}(\frac{W}{m.K})$
Sample 1	0.1246	$\pm$0.01003
Sample 2	0.1309	$\pm$0.0105

b) Balance errors when measuring density, porosity and humidity.
c) Errors related to the measurement of the fractal dimension in the performance of the process of sieving (neglect of cement suspended in each sieve).
d) Errors related to ambient conditions with the knowledge that the experiments were conducted at room temperature (22-25).

Conclusions and Recommendations

The characteristics of the porous medium C, L of two samples made from the same insulating material (hollow concrete) and within uniform working conditions which were determined by determining the fractal dimension Dffor porosity ϕ change (0.7028-0.705) and for the same repeat number (n = 4), and the samevariable humidity saturation SW(0.291-0.313). We note from Fig (8) that the experimental and theoretical thermal conductivity of the first sample is smaller than the second sample. This is due to the high amount of moisture saturation of the second sample which lead to increase the thermal conductivity.although the porosity of the second sample is higher, the temperature is high due to high humidity valuewhich transform the sample into a heat conducting material rather than to be an insulator.

If a particular material is to be applied as a thermal insulator, its porosity should be controlled as much as possible, in a way that most water molecules do not occupy most of its pores when exposed to external weather conditions (high humidity - continuous rainfall throughout the year).

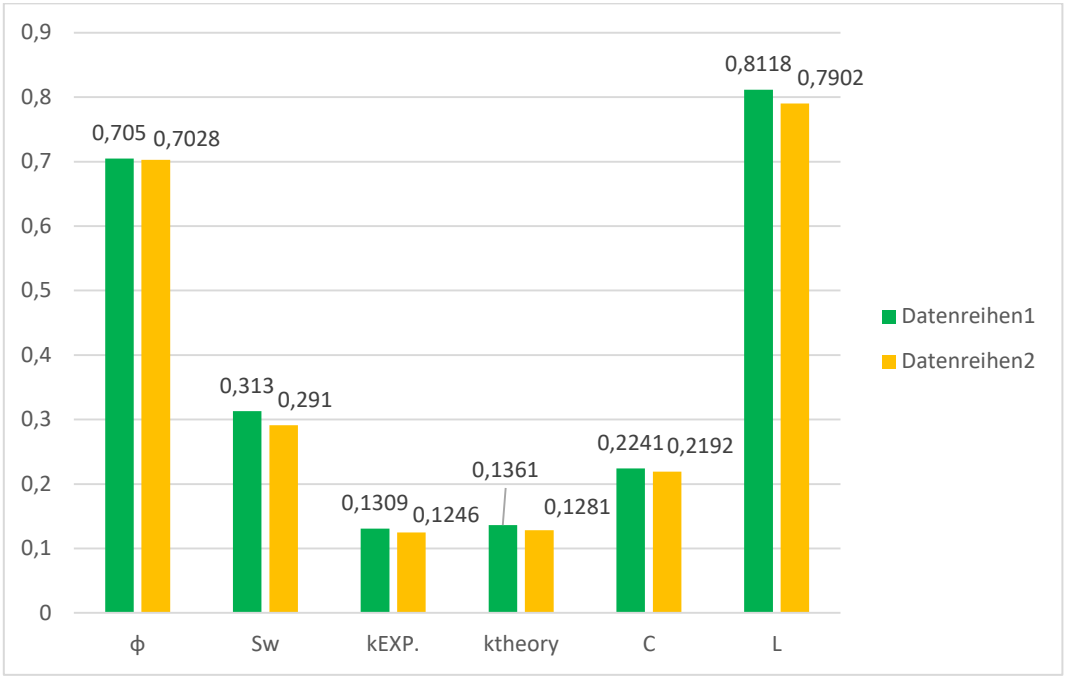

Fig .8: Chart showing the change of thermal conductivity coefficient with moisture saturation and porosity

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