JJMIE

Volume 4, Number 4, September 2010
ISSN 1995-6665
Pages 443 - 450

Jordan Journal of Mechanical and Industrial Engineering www.jjmie.hu.edu.jo

Experimental Investigations of the Effect of Some Insulating Materials on the Compressive Strength, Water Absorption and Thermal Conductivity of Building Bricks.

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Abstract

An experimental investigation was carried out to study the possibility of decreasing the consumed energy in buildings in Jordan by decreasing the thermal conductivity of building bricks. Insulation materials with different weight percentages are mixed with the traditional materials of the building bricks used in Jordan. The used materials were polystyrene, polycarbonate, polyethylene of (2.5, 5, 10 & 15wt %), wood dust and natural cork of (1, 2, 3, & 4 wt %), glass wool and rock wool layer of (24, 36, 48 and 60 gm). The water absorption, compressive strength and thermal conductivity, of the prepared bricks were determined and the obtained results are discussed and compared. The results showed that addition of the insulating materials resulted in reduction of water absorption in the entire materials examined (a minimum of -4.14% for glass wool addition) except natural cork and wood dust (a maximum of +207.62% of natural cork addition).The results also indicated a decrease in the compressive strength as much as (90.71 %) for both glass wool and natural cork additions. A pronounced decrease in thermal conductivity was also noticed of about 70 % of its value for the case of glass wool and natural cork additions, at addition rate of 4% weight.

Keywords: Thermal Conductivity, Building Materials, Insulating Materials, Water Content, Compressive Strength.

Nomenclature

Alphabetic Symbols

A	:Area	m^2
C_s	:Specific heat	J/kg.K
dT	:Temperature difference	°C
HFM	:Heat flow meter output	mV
k1-k6	:Calibration constants	----
Ls	:Sample thickness	m
q_x	:Heat rate	W
R	:Thermal resistance	m^2.k/W
R_{tot}	:Thermal resistance	k/W
T_C	:Cold plate temperature	°C
T_H	:Hot plate temperature	°C
Ť	:Mean temperature	°C
t_s	:Sampling interval	s
U	:Overall heat transfer coefficient	W/K.m^2

Greek Symbols

ρ	:Density	(kg/m^3)
λ	:Thermal conductivity	J/kg.K
Δ	:Difference	

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1. **Introduction**

Jordan is a Middle Eastern developing and non-oil producing country. In the long future the country will continue to be dependent on imported oil, since 94% of the total energy requirements are imported and only 6% are covered from local sources. The locally produced crude oil and natural gas covers only 3.7% of the overall consumed energy. In the last three years an unexpected large increase of oil prices occurred and badly influenced the Jordan economy, which raised the cost of consumed energy to 23 % of the Gross National Product of the country as reported in MEMR annual report [1]. Yahia, et al. [2] showed that in the years (2003-2007) the total energy consumption in the domestic (household) sector reached (21-23) % from the total energy consumption, from which the energy consumption due to heating, ventilation and air-conditioning in buildings represents the important part of total energy consumption in Jordan. Also Yahia, et al. [2] showed that one of the main problems facing hotels in Jordan is the high consumption of energy caused by heating, ventilation, and air conditioning systems (HVAC) and lighting, as well as other equipments in different departments; this is mainly due to the lack of insulation techniques in most hotels, so Jordan's government and people are compelled to take all measures for more efficient energy consumption. An important measure for energy saving is to lower building energy requirements to a minimum. Papadopoulos and Giama [3] reported that the energy consumption in the building sector constitutes a major part (40%) of the annual EU final energy use (European Commission, 2001). The most significant part of this amount of energy is consumed in space heating while the cooling demands, are still relatively small. Various measures that may be applied to lower building energy consumption are natural and controlled ventilation, solar shading, various types of glazing, orientation, shape of buildings, and thermal mass. Jaber [4] reported that more efficient energy consumption can be achieved by improving the buildings energy behavior by reducing the energy consumed by heating, ventilation and air-conditioning. In Jordan energy improvements can be also achieved by minimizing the energy consumption by using thermal insulating materials with low conductivity values (less than 0.04 W/m.K) and with a proper thickness. Papadopoulos [5] showed that an increase of thermal insulation thickness from 5 cm in 1975 to the current valid minimum of 20 cm resulted in drop of the average specific annual consumption from 300 kWh/m^2 to 50 kWh/m^2.

Al-Sanea [6] found that the inclusion of a 5-cm thick molded polystyrene layer reduced the roof heat transfer load to one-third of its value in an identical roof section without insulation. Hernandez-Olivares et al. [7] studied mechanical and thermal properties of a composite material that is made of cork and gypsum; they found that cork-gypsum composite is characterized by both low thermal conductivity and low density. On the other hand, the mechanical properties of cork–gypsum composite are poor, and such a composite material was suggested for use in building applications as partitions.

Mohsen and Akash [8] showed that large energy savings about (76.8%) can be achieved when polystyrene is used for both wall and roof insulations. Those results were concluded in the light of the fact that only 5.7% of dwelling in Jordan`s urban areas have been provided with wall insulation and none of the roofs. They also reported that concrete blocks forms 63 % of construction materials in Jordan. Jubran et al. [9] investigated the use of Jordan Valley clay with addition of straw, chicken feather, human hair, cement and polystyrene as insulating materials. The percentage of insulating materials in the brick ranged from 2 to 20 %. They also found that the combined additives consisting of 10 % rock wool, 5% human hair and 5% cement gave the best thermal and mechanical properties. Jaber and Hammad [10] showed that adding thermal insulation system proved to be effective nearly 82% of the estimated required heating energy was saved by using thermal insulation of 0.057 m and about 7.2 m^2 of Trombe wall system where added and the payback period was less than 2 year. Awni Al-Otoom et al [11] presented a new technology based on crystallization of the salt solution of sodium acetate, which can be produced via the reaction of acetic acid and sodium carbonate. It is believed that the crystals of this salt grow relatively fast and, hence, minimize the pore volumes inside the concrete and increase the service life of the concrete. An optimum concentration of the solution was reported as 20 wt %. Bulent et al. [12] showed that using waste polyethylene and rubber pieces, which exist in environment and can be obtained with almost no cost remarkably, lower thermal conductivity of ordinary concrete. It is found that the insulation performance is improved for polyethylene bottle pieces between 10.27% and 18.16%, depending on the geometries of added pieces. The reuse of these materials in concretes seems to be good choice for contributing to cleaner environment and lower insulation cost.

The major construction materials of walls in Jordan are stone, reinforced concrete; cement blocks, mud and others. The cement blocks are the most widely used construction materials in Jordan, which forms about 63%; therefore decreasing their thermal conductivity will comprehend wide type of buildings and lead to significant savings in the consumed energy by heating and air-conditioning.

The main objective of this work is to investigate the effect of the addition of some insulation materials with different weight percentages on the water absorption, compressive strength and the thermal conductivity of the bricks used in building houses in Jordan. The objective of this arrangement besides lowering the thermal conductivity is to encourage the bricks factories locally and regionally to use some improved insulation materials in building bricks.

2. Theoretical Considerations

The inside door temperature of building is affected by the three modes of heat transfer: convection, conduction and radiation. The major portion of heat is transmitted into the building by conduction mode through the walls in addition to heat losses by air leakage. The thermal conductivity for steady state condition of a single wall can be calculated from the following Fourier`s law [13]:

$$q_x = -\lambda A \frac{dT}{dx} \quad (1)$$

Where, q_x is the heat rate in (W), A is the area of the wall normal to the direction of heat transfer in (m^2), $dx= x_2-x_1= L$ represents the wall thickness in (m), $dT= (T_{s,o}-T_{s,i})$ is the temperatures of the inside and outside surfaces of the wall in (K) and λ is the thermal conductivity of the wall material (W/m.K).

The composite walls involve several layers of different materials with different thermal conductivities. In the composite systems it is often convenient to work with Newton's law of cooling using the following equation:

$$q_x = UA\Delta T \quad (2)$$

Where U is the overall heat transfer coefficient (W/K.m^2) and defined as $U = \frac{1}{R_{tot} A}$, where R_{tot} is the total thermal resistance (k/W) and represents the sum of all parallel and series thermal resistances and ΔT is the overall temperature difference. In this research work the thermal conductivity of bricks containing different weight percentages of insulating materials are experimentally determined and compared with thermal conductivity of the bricks which do not contain any insulating materials.

3. Materials, Equipment and Experimental Procedures

3.1. Materials

The materials used throughout this work are the typical ones used in manufacturing the ordinary bricks used in building houses in Jordan. These are cement, soft sand cobble stones and white soft sand. Other insulating materials were used and added in different weight percentages to the bricks. These are: polystyrene, polycarbonate, polyethylene, natural cork, wood dust, glass wool and rock wool.

The insulation materials were chosen because of their ease of handling, low water absorption values, low cost and low thermal conductivity [14, 15]

3.2. Equipment

The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit shown in Figure. 1 was used to measure the thermal conductivity of the different manufactured specimens. The apparatus consists mainly of an insulated fiberglass hinged enclosure. The base section of the closure contains the heat flow meter and the cold plate assembly and mounted on four springs. The plate is cooled with water to maintain it at constant temperature. The enclosure lid houses the electrically heated hot plate, which is electronically controlled for setting the required temperature. A computerized system is used to determine and display the measured values of thermal conductivity.

The faces of the enclosure are insulated to ensure adiabatic boundary condition and to ensure that all faces of the specimen are not in direct contact with the hot and the cold plates. This thermal conductivity measuring method is a heat flow meter method which complies with the International Standard for steady-state measurement, ISO8301, [16].

The compressive strength of the different specimens was determined using the universal testing machine.

3.3. Experimental Procedures

The experimental procedure started with preparation of the dry concrete bricks following the same procedure used in preparation of the bricks used in buildings in Jordan, which is in accordance with the International Standards. The bricks were of the dimensions 300x300x30 mm. In this research work thirty three specimens were prepared for water absorption, compressive strength and the thermal conductivity tests. The insulating materials were added in different weight percentages during the preparation of the specimens. Summary of the data regarding the tested bricks is shown in Table 1. Each sample has been left to dry for 60 days at ambient temperature of 25 °C. All insulating materials were added in the form of small solid pieces except the rock and glass wool, in which insulation layer is inserted in the middle of the block, this arrangement is done due to difficulties of obtaining these materials in solid pieces.

Table 1. Specimens' Specifications.

Insulation Material (IM)	Specimen code	Cement, coarse, sand and water(w/c) content	(IM) Content in specimen	IM Density	Thermal Conductivity	Specimen Mass	Specimen Number
		(%)	(%)] or (gm)	(ρ)(kg/m^3)	(λ) (W/m.K)	(gm)	
Standard	S	1:3.33:1.66:0.81	0	----	----	2168	1
Polystyrene 330	PS1,2,3,4	1:3.33:1.66:0.81	2.5,5,10 & 15%	1050	0.08-0.1	2110,2081, 1985, 1919	4
Polycarbonate	PC1,2,3,4	1:3.33:1.66:0.81	2.5,5,10 & 15%	1200-1220	0.19-0.22	2134,2110, 2036, 1985	4
Polyethylene 218	P1,2,3,4	1:3.33:1.66:0.81	2.5,5,10 & 15%	910-925	0.305-0.37	2080.1970 1980,1879	4
Polyethylene 952	PE1,2,3,4	1:3.33:1.66:0.81	2.5,5,10 & 15%	945-964	0.42-0.51	2124,2088 1977,1900	4
Wood dust	WS1,2,3,4	1:3.33:1.66:0.81	1,2,3, & 4%	550-650	0.13-0.16	2125,2087 1991, 1835	4
Natural Cork	NC1,2,3,4	1:3.33:1.66:0.81	1,2,3 & 4%	100-150	0.04 - 0.05	2005,1890, 1752,1595	4
Glass wool	GW1,2,3,4	1:3.33:1.66:0.81	24,36,48 & 60 gm	10-75	0.03 – 0.04	2150,2113, 2098,2040	4
Rock wool	RW1,2,3,4	1:3.33:1.66:0.81	24,36,48 & 60 gm	23-200	0.042–0.052	2170,2141, 2127,2100	4

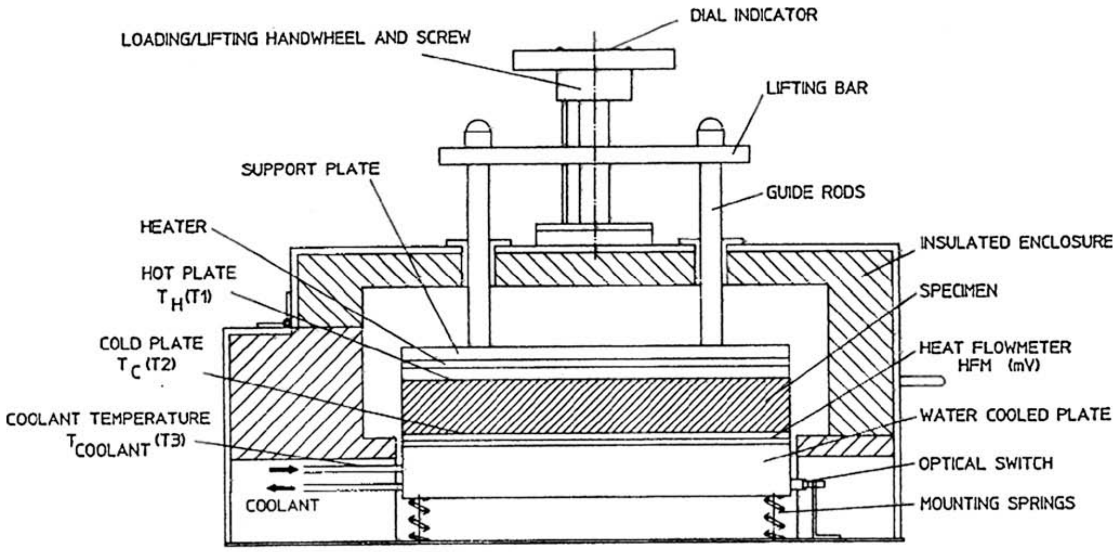


Figure 1. Cross-sectional diagram of the B480 heat flow meter apparatus (P.A. Hilton Ltd.).

3.3.1. . Water Absorption Test

This test was performed in accordance with ASTM D-570-81 standard. Tap water was used in this test. The specimen was placed in a container of water at room temperature. At the end of 24 h the sample was removed from water and the process was repeated until it reached the saturation (equilibrium) condition. During this period, the specimens' weight difference was recorded at different times. The uncertainty average was (±0.1gm). The percentage of water retention (WR %) was calculated using the following formula:

$$WR\% = \frac{weight\ of\ wet\ sample - weight\ of\ dry\ sample}{weight\ of\ dry\ sample}\ x\ 100\% \quad (4)$$

3.3.2. Determination of the Compressive Strength

The mechanical strength of each specimen was determined using the universal testing machine, where the specimen was compressed between the upper and lower platens of the machine until fracture of the specimen had occurred. The uncertainty average of the used machine was (± 0.1%).

3.3.3. Determination of Thermal Conductivity

For determination the thermal conductivity the specimen is positioned between the hot and the cold plates and adjusted until the test position lamp illuminates to denote that the correct pressure has been applied. The determination of the thermal conductivity of the specimen requires the measurement of the following four parameters:

- The hot plate temperature T_H ,with a suitable range from (0 to 70°C)
- The cold plate temperature T_C in °C
- The coolant fluid temperature $T_{coolant}$ with a suitable range from (0 to 40°C)
- The heat flow meter (HFM) output in (mV)

The values of T_H, T_C and the heat flow meter output are taken after the steady state condition has been reached. This state is reached when the difference in five consecutive readings at sampling interval give values of thermal resistance to within (1%) without changing monotonically in one direction. The sampling interval is stated in, ISO8301, as $t_s=\rho.C_s.\ L_s.\ R$ or 300 s, whichever is the greatest, where ρ is the density in (kg/m^3), C_s specific heat in (J/kg.K), Ls the thickness in (m) and R is thermal resistance in (m^2.k/W) of the specimen. At each sample interval, the measured values of (T_H, T_C and output of the heat flow meter) are passed to the computer through a serial communications board which is an integrated part of the instrument, for data logging purposes. The thermal conductivity is then automatically determined by a computer program using the following equation:

$$\lambda = \frac{ls\left[\left(k_1 + (k_2 * \check{T})\right) + \left(\left(k_3 + (k_4 * \check{T})\right) * HFM\right) + \left(\left(k_5 + (k_6 * \check{T})\right) * HFM2\right)\right]}{dT} \quad (3)$$

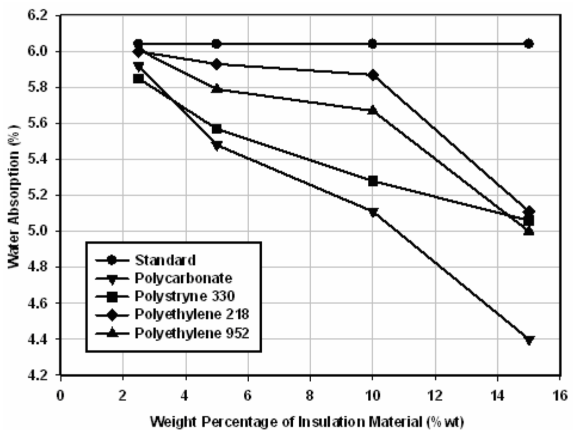
Where k_1 to k_6 are calibration constants supplied with the instrument, HFM is the heat flow meter reading, L_s is the specimen thickness in m, $\check{T}= (T_H+T_C)/2$ is the average temperature and $dT=(T_H - T_C)$ is the temperature difference. The humidity of the room was controlled and maintained lower than 50%, and the thickness (Ls) of each slab specimen was measured by the device. It is worth pointing out that in all the experiments the standard error of measurement on average was less than 5% of the measured value.

4. Results and Discussion

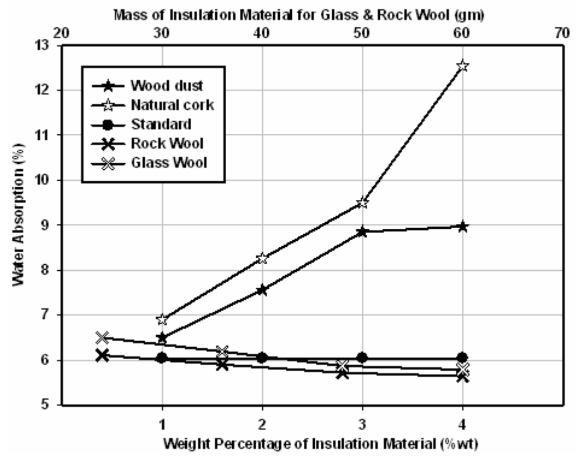
4.1. Effect of the Insulating Material Addition on Water Absorption

Effect of insulation material on water absorption is shown in Figures (2a and 2b). Also the figures include the standard specimen, which does not include insulation materials.

It can be seen from Figure (2a) that increasing the weight percentage of the insulating materials results in reduction of the water absorption for the following insulating materials: polycarbonate, polystyrene 330, polyethylene 952 and polyethylene 218, arranged in



(a)



(b)

Figure 2, (a)Weight percentage of insulation material viz. water absorption percentage, (b) Weight percentage of insulation material viz. water absorption percentage.

sequence starting with the minimum water absorption percent , (polycarbonate).

However, this was not the case for the other insulating materials namely natural cork and wood dust, where the water retention percentage i.e. absorption percentage was found to increase with the increase of their weight percentage as indicated by Figure (2b). This can be explained in terms of porosity in the main structure of these materials, as the number of bores is much higher than the case of the previously four mentioned insulating materials in Figure (2a). This increase is also due to the increase in the material mass diffusivity (due to the addition of insulation) and to the ability of insulation material to absorb water.

Furthermore it can also be seen from Figure (2b) that in the case of glass wool and rock wool there is little or no difference in the water absorption percentage of the reference standard specimen, being maximum in the case of rock wool (6.62%).

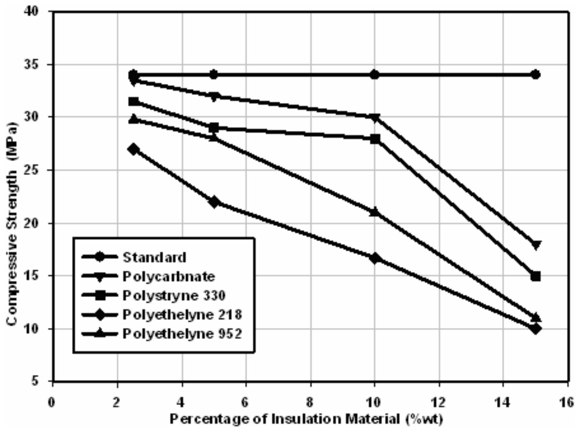
The different values of water absorption percent for the different insulating materials are explicitly shown in Table (2).

It can be seen from this table the maximum absorption percent is in case of natural cork addition being (+207.62%) followed by wood dust (+148.51%) whereas the minimum absorption percent is in the case of glass wool addition (-4.14%) followed by rock wool addition (-6.62%).

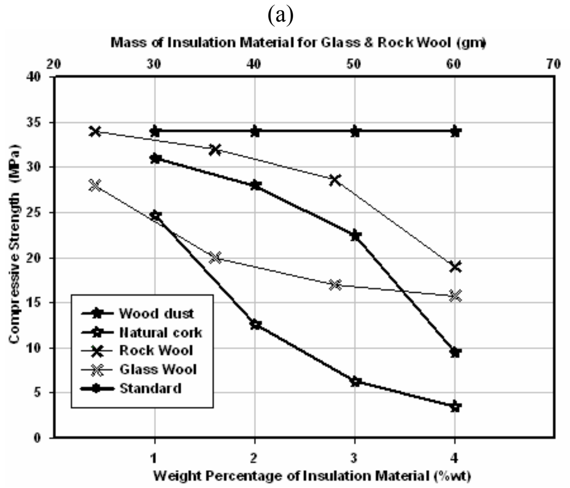
This is confirmed by the weight of the blocks shown in Table (1); where the higher the porosity percent the higher will be the number of pores resulting in less weight

4.2. Effect of the Insulating Materials on Compressive Strength

The effect of the weight addition of insulating materials on the compressive strength of the building bricks is shown in Figures (3a & 3b) for polycarbonate , polystyrene 330 , polyethylene 952 and polyethylene 218 , also included is the standard specimen (without addition of insulating material) for comparison purposes.



(a)



(b)

Figure 3. (a)Weight percentage of insulation material against its compressive strength, Weight percentage of insulation material against its compressive strength.

It can be seen from Figure (3a) that for all the above mentioned insulating materials the compressive strength decreases as the weight percentage of the insulating material increases. The highest decrease is in the case of polyethylene 218 addition and the minimum decrease is in the case of polycarbonate addition. Furthermore it can be seen from this figure that the decrease in compressive strength occurs gradually by the increase of the weight percentage (up to 10%) in the case polycarbonate and polystyrene 330 additions and up to 5% in the case of polyethylene 952 addition.

The same trend was observed in the case of rock wool, wood dust, glass wool and natural cork, as indicated by the curves of Figure (3b). The minimum decrease in compressive strength is in the case of rock wool followed by wood dust then glass wool. The maximum reduction in compressive strength is in the case of natural cork, being 90.71 %, Table (2). The effect of mass of insulation materials and the compressive strength is shown in Figures (4a &4b). It can be observed in these figures that the denser is the specimen, the higher is the compressive strength. This result is also concluded by Khedari et al. [17]

The values of the effect of addition of different insulating material on their compressive strength are explicitly shown in Table 2.

Table 2. Comparison among the effect of different insulating materials at their maximum addition rate on weight, water absorption compressive strength and thermal conductivity.

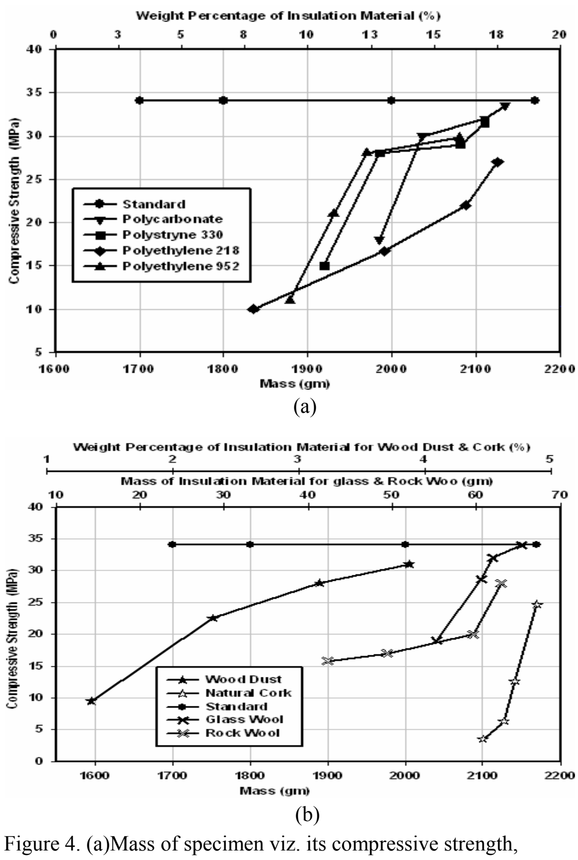
Insulation Material (IM)	Specimens Code	Content of (IM)	Compressive strength	Absorption	Thermal Conductivity	Weight
		(%)or(gm)	(%)	(%)	(%)	(%)
Standard	S	0	100.00	100	100	100
Polystyrene 330	PS4	15	44.10	83.77	53.58	88.50
Polycarbonate	PC4	15	52.30	72.84	61.12	91.56
Polyethylene 218	P04	15	29.40	84.60	56.88	86.67
Polyethylene 952	PE4	15	32.35	82.78	55.43	87.63
Wood dust	WS4	4	27.94	148.51	52.48	84.64
Natural Cork	NC4	4	10.29	207.62	33.91	73.57
Glass wool	GW4	60(gm)	46.47	95.86	33.71	94.10
Rock wool	RW4	60(gm)	55.88	93.38	69.46	96.86

4.3. *Effect of the Insulating Material Addition on Thermal Conductivity*

The effect of the weight addition of insulating material on thermal conductivity of the building bricks is shown in Figures (5a and 5b).

It can be seen from these figures that, for all the eight tested insulating materials, as the weight percentages increases the thermal conductivity decreases. However, the decreasing rate is more pronounced for the insulating materials in Figure (5b) namely the wood dust, rock wool, natural cork and glass wool. The addition of any these materials becomes effective after 1.5 weight percentage addition for (wood dust & cork) and 36 gm for (rock & glass wool), and reduces the thermal conductivity of the brick to less than half its value in the case of wood dust, natural cork and glass wool. The most effective insulating material among this group is glass wool and natural cork, where the thermal conductivity dropped to above 70 % of its value, at addition rate of 4% weight.

Compared to the other group presented in Figure (5a), which includes polycarbonate, polyethylene 218, polystyrene 330 and polyethylene 952, it can be seen that those presented in Figure (5a) are less effective in reducing the thermal conductivity, and their addition becomes effective after 5% weight addition and they did not reduce the thermal conductivity more than 37% in the case of polyethylene 952, which is the most effective insulating material in this group. Even at addition rate of 15% weight, none of the insulating materials of this group resulted in 50% reduction. It is worth noting that at addition rate more than 10% weight, their effectiveness in reducing the thermal conductivity becomes comparable as



(a)

(b)

Figure 4. (a)Mass of specimen viz. its compressive strength, (b)Mass of specimen viz. its compressive strength.

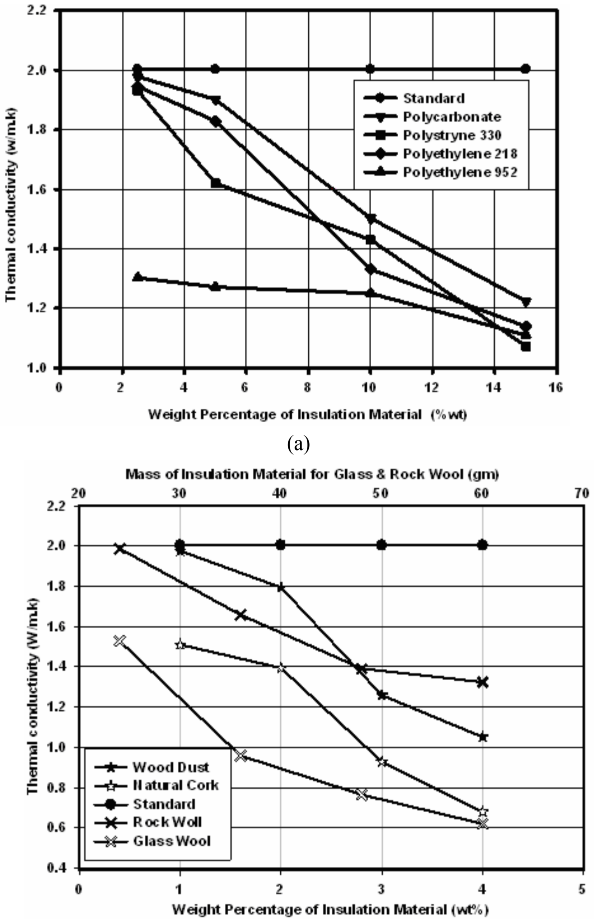


Figure 5. (a) Weight percentage of insulation material viz. thermal conductivity, (b) Weight percentage of insulation material viz. thermal conductivity .

implicated in Figure (5a). This is in general agreement with the findings reported in references 7 and 18. The effect of addition of any of the insulating materials on mass and thermal conductivity is shown in Figures (6a and 6b) from which it can be seen that for any of the added insulating materials as mass increases the thermal conductivity increases which is in general agreement with the findings reported in references [19 , 20].

4.4. Comparison among the Eight Different Added Insulating Materials

Figure (7) summarizes the effect of the addition of different added insulating materials on weight, water absorption, compressive strength and thermal conductivity, as compared to the standard specimen without addition of any of the added insulating materials.

5. Conclusions

The following points may be concluded from the results obtained in this research work:

- Addition of any of the insulating materials, except natural cork and wood dust, at any rate to the building bricks used in Jordan resulted in reduction of water absorption, decrease in the compressive strength and pronounced decrease in thermal conductivity.

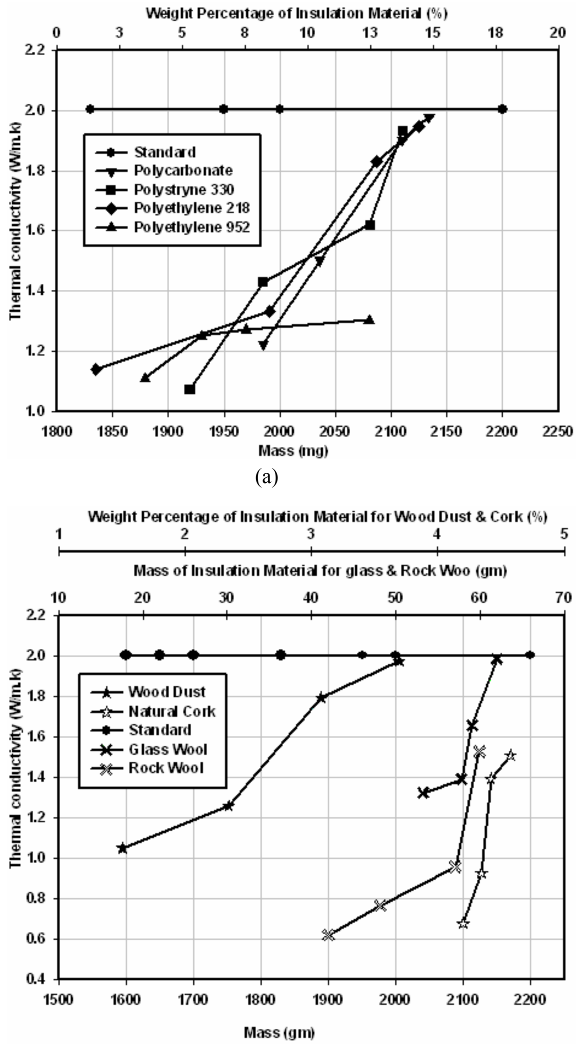


Figure 6. (a) Mass of specimen viz. its compressive strength, (b) Mass of specimen viz. its compressive strength.

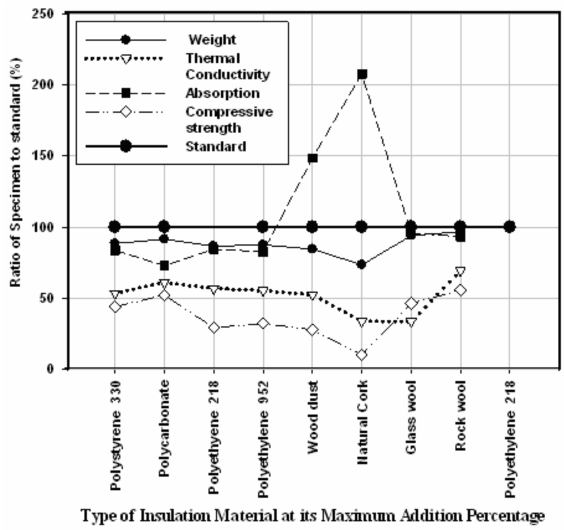


Figure 7. Comparsion among the effect of the different insulating materials at their maximum addition rate on weight, water absorption compressive strength and thermal conductivity.

- The most effective material among the tested insulating materials in reducing thermal conductivity is found to be glass wool and natural cork, followed by wood dust and polystyrene 330, then polyethylene 952 and polyethylene 218. The least effective insulating materials in reducing the thermal conductivity of the building bricks are polycarbonate and rock wool.
- Addition of any of the insulating material resulted in decrease of the compressive strength of the building bricks. The minimum reduction in mechanical strength is caused by addition of rock wool and polycarbonate. However these insulating materials are the least effective ones in the reducing the thermal conductivity of the building bricks.
- The maximum absorption percent is in case of natural cork addition being (+207.62%) and the minimum absorption percent is in the case of glass wool addition (-4.14%).
- The minimum decrease in compressive strength is in the case of rock wool and the maximum reduction in compressive strength is in the case of natural cork, being (90.71 %).
- The most effective insulating material is glass wool and natural cork, where the thermal conductivity dropped to above (70 %) of its value, at addition rate of 4% weight.
- Finally, it is concluded that the addition of glass wool is the most effective insulating material, with moderate decrease in the mechanical strength and water absorption.

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