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Preparation of Coating Layer for Thermal and Sound Insulation for Residential Buildings

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Abstract: The use of thermal and acoustic insulation consider the most important and effective methods for a comfort environment in residential buildings which it's reduce the effect of heat in summer and coldness in winter, also, reduce the noise from using air-conditioning system and the surrounding noise, all that will results in cost and energy saving. In this study, simple and available raw materials is used in order to have coating layer which is easy to prepare and apply on exterior walls of buildings that can give the required properties and specifications, these materials are (polystyrene, polyester resin, mullite nad TiO_2 nanoparticles), the concrete and cement mortar is used as substrate. Coating process for samples surfaces carried out by cold spray technique using air-brush and air-gun sprayer, the coating layer prepared from raw materials (polystyrene and polyester), mullite was added with different ratios (1, 3 nad 5%) also, another layers prepared with the same ratios with the addition of 2% and TiO_2 nanoparticle, the samples coated with different layers then all set to make the required tests and study their properties to find out its feasibility in different environments. A measurements was made to find out the effect of the used materials and the additions by studying Scanning Electron Microscope (SEM), thermal conductivity by (Hot Disk device) to find out the best coating layer and their ratio, UV resistance test to measure the degradation rate, then numerical analysis using ANSYS 11 to analyze thermal insulation and image processing used to analyze sound insulation. The results show improvement in UV radiation resistance the results shows that the best resistance was up to 66.6% for day one and raised up to 90% for day seven of test. A comparison made between the numerical results and experimental results, generally the coating layers improves concrete and cement mortar resistance to external thermal effect, the best result was measured for the sample with 5% of mullite powder and (2%) of TiO_2 nanoparticles in spite of the results of thermal conductivity, sound analysis using image processing technique show that the coated sample with 5% of mullite powder and (2%) of TiO_2 nanoparticles gives the best sound insulation compared to uncoated cement sample.

Key words: Coating layer, thermal insulation, sound insulation, mullite, polystyrene, UV test

INTRODUCTION

Constructions and buildings represent huge consumers of energy in all countries, especially in severe weather where a major part of energy spends in the air-conditioning of these constructions and buildings. A reduction in air-conditioning load can be made by thermal insulation, beside the suitable design and selection of building covering and its components, the usage of thermal insulation in building walls and roofs which is considered a major source in decreasing the air-conditioning system size requirements as well as reducing the annual energy cost (Al-Homoud, 2004).

Thermal insulation is usually used to keep buildings temperature comfort at different seasons where the building will be cooler in summer and warmer in winter which is achieved by decreasing heat flow between buildings walls (exterior surfaces) and the surrounding, also, thermal insulation is considered large energy and money saver because it reduces heat lost from buildings in addition energy efficiency achieved in a very good way (Matthew, 2010; Al-Homoud, 2005).

Recently insulating coatings considered most common solution to apply thermal insulation for exterior surfaces, these coatings have the ability for suppressing heat flow between buildings and the surrounding nad maintain comfortable temperatures inside the buildings, the performance of coatings depends on the properties of raw materials that made from, selection criteria beside the climate condition. In addition to achieve the best

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performance, these insulating materials must be applied to the closest point of heat flow entry. In another meaning, the coating applied from inside winter heating is dominated and from outside cooler summer is dominated (Bynum, 2001).

Concrete is the most popular building material used in Iraq where in recent decade the concrete was used to build building walls beside roofs due to its high compressive strength and other excellent properties, the thermal conductivity of concrete is relatively accepted but the main issue that the specific heat capacity of concrete considered high which make the building walls storage heat in it. In order to decrease the effect of specific heat capacity by applying a thermal insulation layer on the outer surface of the walls (Illston and Domone, 2001).

Ibrahim *et al*. (2014) have studied the energy behavior of the building's multilayer external wall structures have used insulating coating consisting of silica aerogel which known as (super)-insulation materials. Results have shown that for continued and non-heating cases, the usage of insulating materials at the middle of the walls and on external surface improves the performance from maximum time-lag and minimum decrement value point of view. In most of cases, the aerogel insulation coatings have improved the performance of walls than other insulation materials (Ibrahim *et al*., 2014).

Buratti *et al*. (2014) have investigated the thermal and sound properties of innovative insulation systems which used as coatings for building by mixing granular silica aerogel with plaster with different ratio. The used coating was transparent and had a very low thermal conductivity with different percentage of aerogel. The results have rising the thermal and acoustic insulation due to the low thermal conductivity for the coating layer and the pores that produced when applied on the existing walls (Buratti *et al*., 2014).

MATERIALS AND METHODS

The raw materials used in this thesis are presented in Table 1.

Samples preparation

Preparing cement mortar: Numbers of cement mortar mixture is made for every test according to an experimental design all the cement mortars have a water-to-cement ratio (w/c) of 0.5 and a sand-to-cement ratio of 1:3 (one part of the Ordinary Portland Cement (OPC) and 3 parts of sand) according to ASTM specifications (C109) (Anonymous, 2014). After that the samples are cured in water for 28 days.

Table 1: The raw materials used

Raw materials	Formulation	Purity (%)	Origin of manufacturing
Cement	-	-	Iraqi cement factory (Tasluja)
Sand	-	-	Iraqi markets (Al-Ekhaider Region)
Mullite	$3Al_2O_3.2SiO_2$	99.9	Henan Xinmi Changxing Refractory Material Co., Ltd. (China)
Titanium dioxide	TiO_2	99.9	Anatase/Guangzhou Jiechuang Trading Co., Ltd. (China)
Polystyrene	$(C_8H8)n$	99	Iraqi markets
Polyester resin	$(C_{10}H_8O_4)n$	99	Iraqi markets
Chloroform	Ch_3Cl	99.6	SDFCL-S D Fine-Chem Limited (India)
Dimethylformamide (DMF)	C_3H_7NO	99.9	Honeywell Burdick and Jackson® Company (Germany)

Table 2: Coating layers proportions and mixing

Sample No.	Chloroform (wt.%)	DMF (wt.%)	Polystyrene (wt.%)	Polyester (wt.%)	Mullite (wt.%)	Tintnium dioxide (wt.%)
S	-	-	-	-	-	-
S0	40	40	20	7	-	-
S1	40	40	20	7	1	-
S2	40	40	20	7	3	-
S3	40	40	20	7	5	-
S4	40	40	20	7	1	2
S5	40	40	20	7	3	2
S6	40	40	20	7	5	2

Fig. 1: Uncoated cement mortar samples

Fig. 2: Coated cement mortar samples

Preparing coating layer: The coating layer is prepared from similar ratio of chloroform and DMF (1:1) by taking 40% of each solvents and mixed them together using magnetic stirrer for 15-20 min, then 20% of polystyrene particles is added into the solvents nad mixed until we got transparent solution after that (7%) of the solution is replaced with polyester resin and mixed well. when we get a well mixed solution, a different ratio is added of (Mullite) and (Titania) as listed in Table 2. For each ratio of mullite added to the solution a similar amount was replaced from the same solution before the addition of mullite powder. Figure 1 and 2 show the uncoated and coated cement mortar samples.

Table 3: Spray process parameters

Operating gas	Gas temperature	Gas pressure	Feed rate	Spray distance
Air	30°C	9 bar	350 mL/min	35-55 cm

Airbrush spray gun coating process: The airbrush technique consists of:

- Spray gun which is used to spray the coating solution
- Spray container which contains the coating solution
- Air compressor which is used to compress air into the device

Suspension container valve which is used to control the suspension flow and a nozzle with small slot is used to spray the suspension using the compressed air. The nozzle is directed onto the specimen surface. The spraying of coating on samples surfaces is done vertically. The spray process parameters are listed in Table 3.

RESULTS AND DISCUSSION

Scanning Electron Microscope (SEM): Figure 3 shows the SEM micrograph of the reference cement mortar (S) at the age of 28 days and demonstrates a porous structure that is full of large size pores that explains the reduction of mechanical properties. Figure 4 shows the SEM micrograph of S6 sample, the large size pores where reduced and the surface become more homogenous than (S) Surface. Also, small pores were noticed which effects the sound insulation as will be illustrated in sound test section.

The selection of those samples for comparison was based on the reference sample and the best result from thermal test sample. Figure 4 illustrates the difference in morphology of S and S6, also the distribution of mullite and TiO_2 nanoparticles.

UV test: In this study, we discuss the results of samples from Ultra Violet test (UV) nad study the effect of UV on the polymer used in coating layer and the rate of degradation. The results show the difference in weight continued with time, the sample coated with only polymer mix lost weight more than other samples due to effect of UV on chains of polymer structures where the addition of mullite and TiO_2 nanoparticles affected the weight lose in different amount and reduce the effect of UV. Figure 5 and 6 comparison was made between the coated samples (S1-S3) nad coated samples (S4-S6), the difference in weight decreased with the presence of TiO_2 nanoparticles which means that degradation rate reduces (Yang *et al*., 2014).

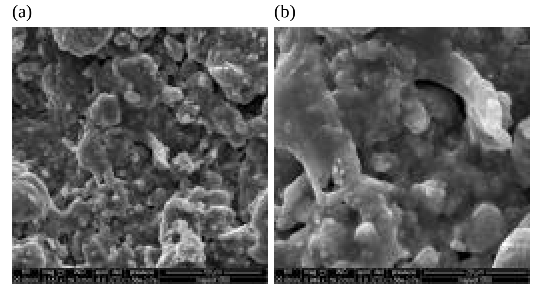

Fig. 3: The SEM test for Samples (S): a) The 50 μm picture size of Sample (S) and b) The 20 μm picture size of Sample (S)

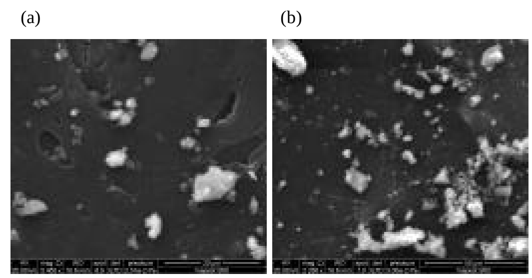

Fig. 4: The SEM test for Samples (S6): a) The 50 μm picture size of Sample (S6) and b) The 20 μm picture size of Sample (S6)

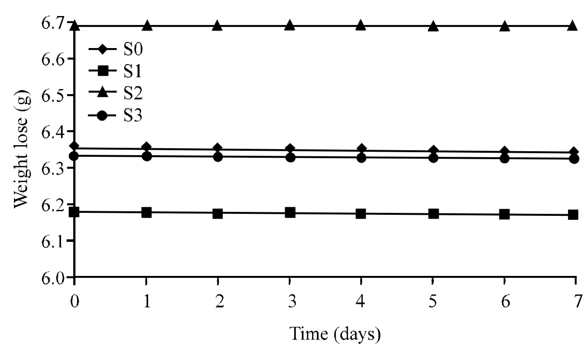

Fig. 5: Weight difference in S1-S3 samples

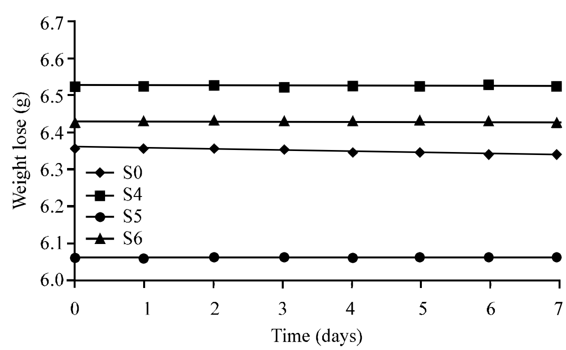

Fig. 6: Weight difference in S4-S6 samples

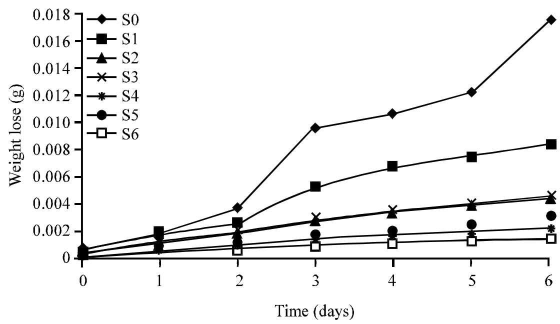

Fig. 7: Weight loses for all coated samples

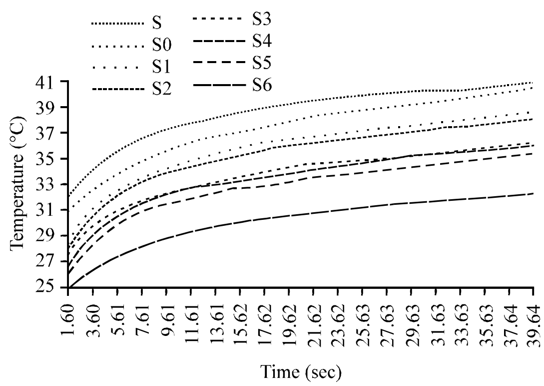

Fig. 8: Temperature variation of all cement mortar samples

Figure 7 shows the weight lose (ΔW) with time (days) for coated samples where the results for 7 days (24 h).

Thermal conductivity properties: Thermal conductivity test was performed on prepared samples in order to determine the effect of the coating layer on the cement mortar by hot disk equipment (Anonymous, 1997). Figure 8 shows the temperatures variation with time for all coated cement samples including the reference sample (uncoated cement sample) which show all coated samples have temperatures difference better than uncoated cement sample, while the best of all is S6 where the effect of mullite and TiO_2 nanoparticles reduce the temperature difference.

The comparison shows that the temperatures variation for samples (S4-S6) is lower than that of samples (S1-S3) which means the TiO_2 nanoparicles have good effect on coating layer and disturbs the heat flow of the coated samples. The TiO_2 nanoparticles improve the thermal conductivity and specific heat capacity of coating layer which leads to decrease the effect of specific heat capacity of cement mortar as well as concrete. Figure 9 shows the thermal conductivities of cement mortar (uncoated and coated) samples (S, S0-S6).

Figure 10-17 refers to the relation between the simulation variation in average temperature distribution

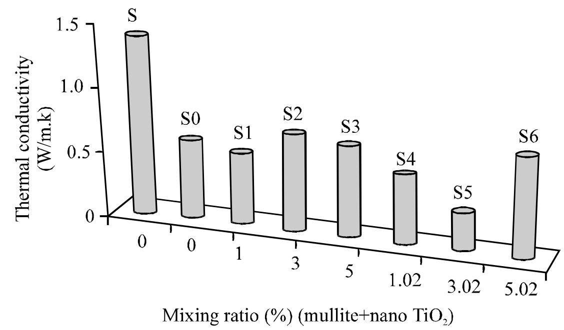

Fig. 9: Thermal conductivities for cement mortar samples (uncoated and coated samples)

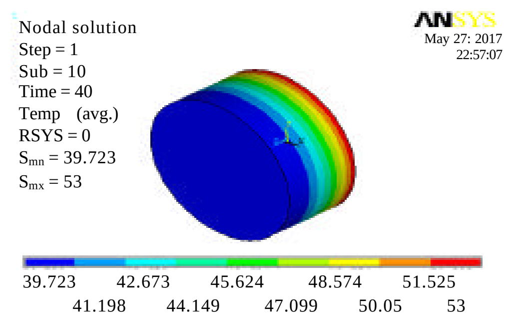

Fig. 10: Temperature distribution type (S), element text temperature distribution

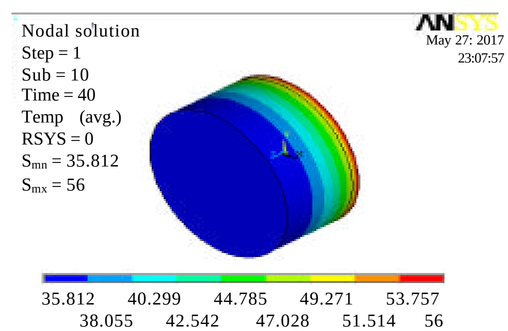

Fig. 11: Temperature distribution, element text temperature distribution type (S0)

and the distance from the heat source. Also, each figure shows the variant in temperature distribution (for all samples) throughout the element where many properties and boundary conditions are effect. As shown in this figures the temperature distribution at the center position is greater than the other locations due to the effect of the thermal capacity. Thereby, the heat flow from outer surface will divide into two parts (storage part and heat conduction part).

The coating layer will reduce the inclination of conduction curve through by the element. Thus, the temperature in the inner surface of the room is less than

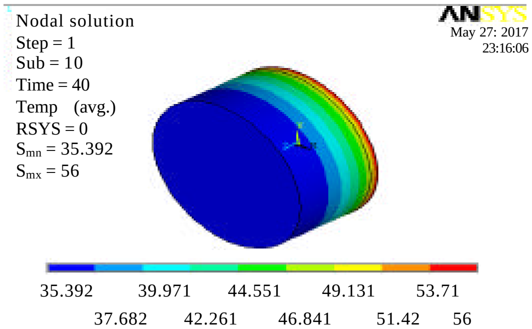

Fig. 12: Temperature distribution type (S1) (a) element text temperature distribution

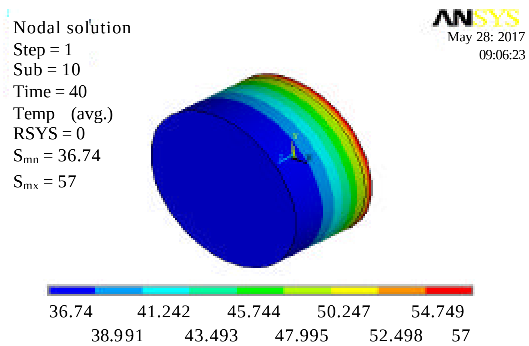

Fig. 13: Temperature distribution type (S2) (a) element text temperature distribution

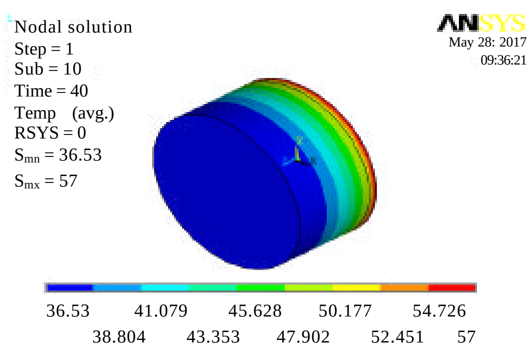

Fig. 14: Temperature distribution type (S3) (a) element text temperature distribution

that without coating. The results are compound from the effects of two properties (thermal capacity and thermal conduction coefficient). Each coating layer (with different ratio of mullite and TiO_2 nanoparticles) has different effect on the heat flow and temperature inclination.

Figure 18-25 show the comparison between the theoretical and experimental temperature distribution for all cement mortar samples (uncoated and coated). Where the theoretical distribution (a) show the variation of temperature in numerical analysis, the time of each numerical and experimental test is 40 sec.

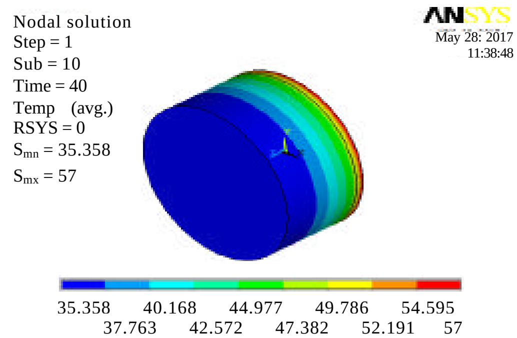

Fig. 15: Temperature distribution type (S4) (a) element text temperature distribution

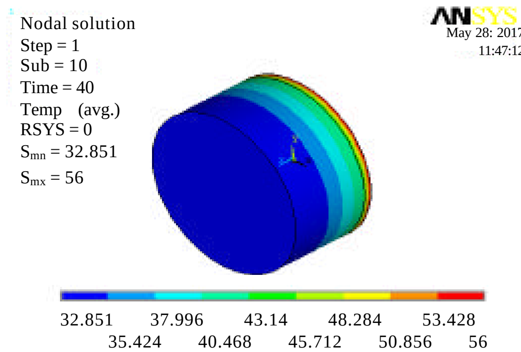

Fig. 16: Temperature distribution type (S5) (a) element text temperature distribution

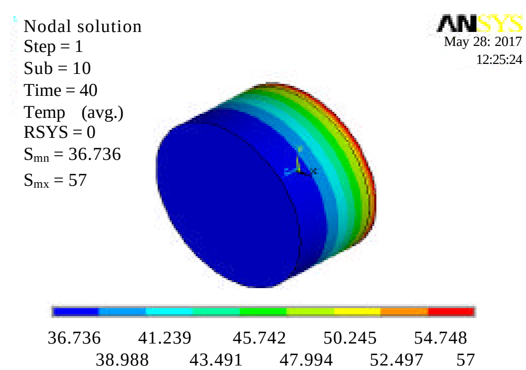

Fig. 17: Temperature distribution type (S6) (a) element text temperature distribution

Sound insulation test: Figure 26 and 27 show the graph of sound wave for Samples (S) and (S6) which illustrate the difference in the sound wave passed through the surface of the samples, the sound passed through, Sample (S6) reduced due to the presence of the coating layer which considered as sound barrier.

For noise-induced structure vibration, also energy stored in solids in shear and compression all types of

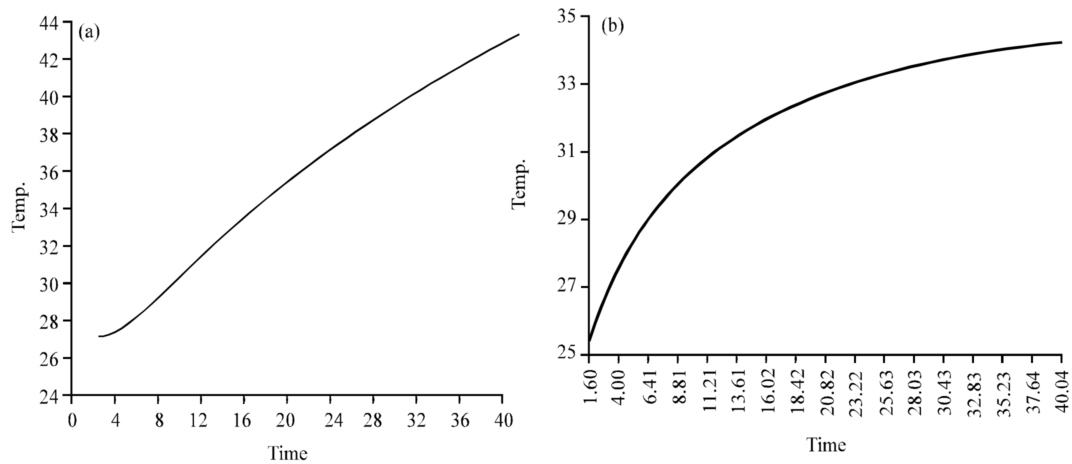

Fig. 18: S-temperature variation with time: a) Element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

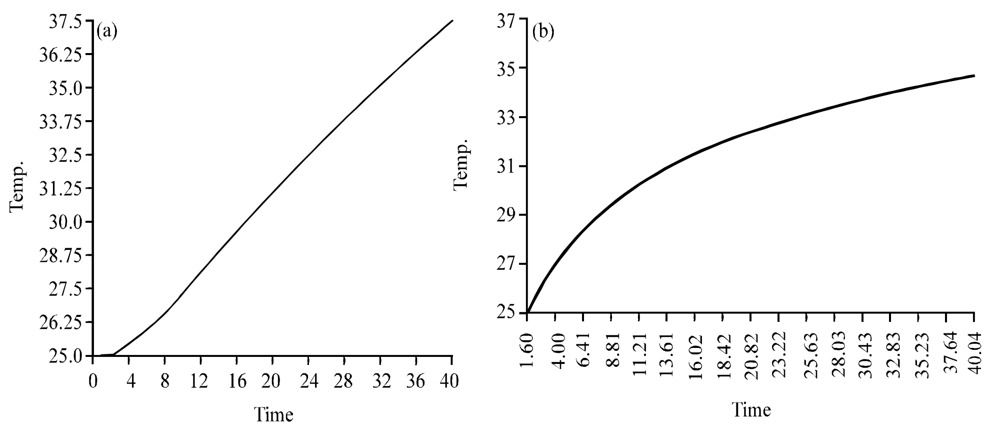

Fig. 19: a) S0-temperature variation with time element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

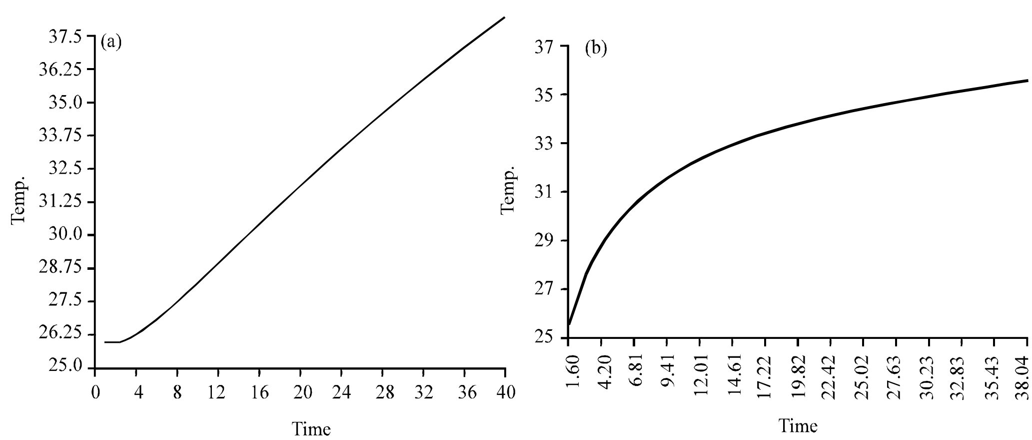

Fig. 20: S1-temperature variation with time: a) Element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

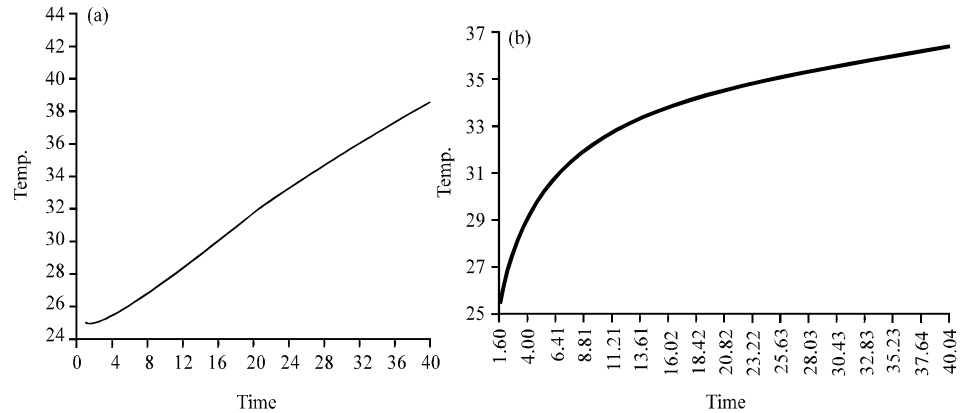

Fig. 21: a) S2-temperature variation with time element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

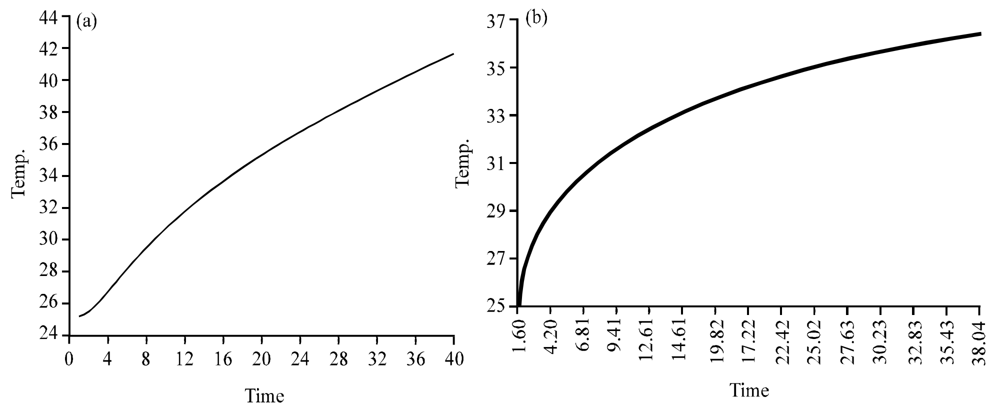

Fig. 22: a) S3-temperature variation with time element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

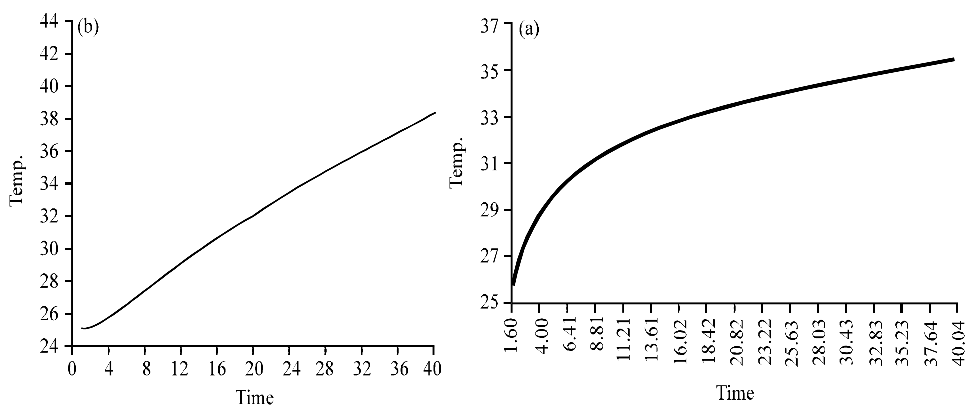

Fig. 23: a) S_4-temperature variation with time element text temperature distribution for one node (No.5840) and b) Temperature distribution from hot disk test (experimental values)

waves can be sustained in structure as compression (longitudinal waves or bending waves (fluxeral)), shear waves and torsional waves. Since, the fluid can only store energy as compression, they can only sustain as

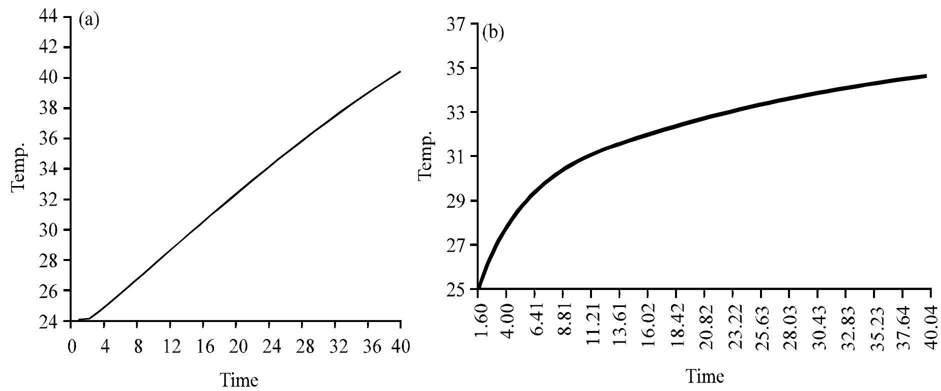

Fig. 24: a) S5-temperature variation with time element text temperature distribution for one node (No. 5840) and b) Temperature distribution from hot disk test (experimental values)

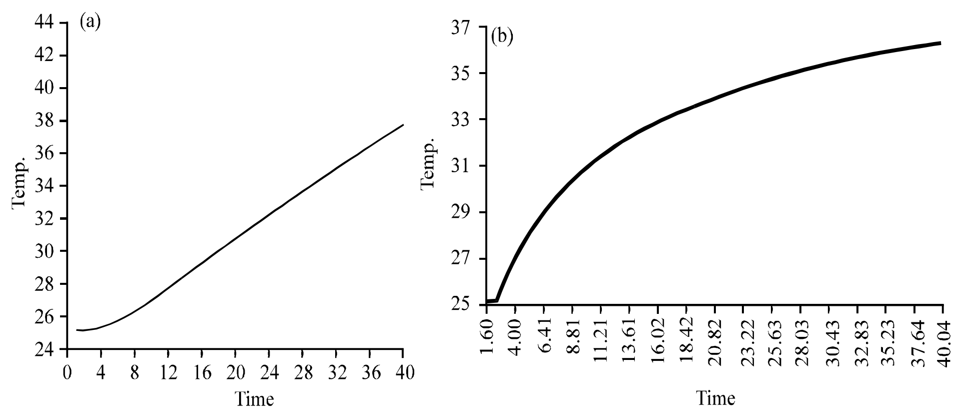

Fig. 25: a) S6-temperature variation with time element text temperature distribution for one node (No. 5840) and b) Temperature distribution from hot disk test (experimental values)

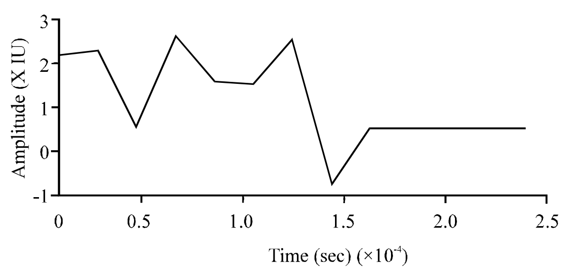

Fig. 26: The sound wave of Sample (S)

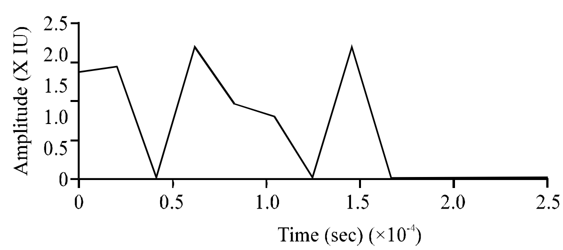

Fig. 27: The sound wave of Sample (S6)

compression waves. However, the bending waves are the only type of structure wave that act directly in sound radiation and transmission. In this situation, the bending wave particular velocities are perpendicular to the direction of wave propagation resulting in an effect exchange of energy between the structure and the fluid (Hopkins, 2007). In this case, the coating layer stored energy inside its dense and compressed structure and then scatter the sound wave by the pores found in cement structure as shown in SEM for Sample (S).

CONCLUSION

According to the results of the present research, the following can be concluded. TiO_2 nanoparticles has a significant effect on the degradation rate of polymers components where the UV resistance has been improved (66.6%) in day one while the improvement increased to (90%) in day 7 for Sample (S6). An improvement of 71% in thermal conductivity had been achieved by adding (3 wt.%) of mullite powder and (2 wt.% of mullite ratio) TiO_2

nanoparticles (S5) Sample while (26%) achieved by adding (5 wt.%) of mullite powder and (2 wt.% of mullite ratio) TiO_2 nanoparticles (S6) Sample. An improvement has been achieved in sound insulation by adding (5 wt.%) of mullite powder and (2 wt.% of mullite ratio) TiO_2 nanoparticles (S6) Sample.

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